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EXPERIMENTAL STUDY

Neuroprotective effects of hesperidin on cerebral vasospasm after subarachnoid hemorrhage in rats: an experimental study

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ABSTRACT

BACKGROUND: Subarachnoid hemorrhage (SAH) is a severe neurological emergency with high morbidity and mortality, primarily due to vasospasm and delayed ischemia. Hesperidin (HSP), a natural flavonoid, possesses strong antioxidant and vasoprotective properties. This experimental animal study examined HSP's neuroprotective role in oxidative stress and vascular remodeling after SAH, focusing on the extracellular regulated kinase 5–Kruppel-like factor 2–endothelial nitric oxide synthase (Erk5-KLF2-eNOS) pathway.

METHODS: The study was conducted from 2021 to 2022. Forty female Wistar albino rats were divided into five groups: control (G1, n=8), sham (G2, n=8), SAH + Vehicle (G3, n=8), SAH with low-dose HSP (G4, n=8), and SAH with high-dose HSP (G5, n=8). SAH was induced using a double injection of homologous blood into the cisterna magna. Biochemical markers (superoxide dismutase [SOD], catalase [CAT], glutathione peroxidase [GPx], nitric oxide [NOS]), basilar artery morphometry, and molecular expressions (Erk5, p-Erk5, KLF2, eNOS) were evaluated 48 hours post-SAH.

RESULTS: SAH significantly increased oxidative stress and reduced vascular lumen diameter in untreated rats (G3). Both HSP-treated groups (G4 and G5) showed improved antioxidant enzyme levels (SOD, CAT, GPx) and near-normal NOS levels. Morphometric analysis demonstrated significant preservation of basilar artery lumen diameter in treated groups, with no significant changes in wall thickness. Molecular analysis revealed upregulation of the Erk5-KLF2-eNOS pathway, suggesting a role in vasodilation and mitigation of oxidative stress.

CONCLUSION: HSP protects against SAH-induced vasospasm and oxidative damage by enhancing antioxidant capacity and modulating the Erk5-KLF2-eNOS pathway, suggesting its therapeutic potential.

Keywords: Hesperidin; subarachnoid hemorrhage; rat; vasospasm.

INTRODUCTION

The incidence of subarachnoid hemorrhage (SAH) in the United States of America (USA) is between 10 and 14 per 100,000 population per year, most commonly secondary to intracranial aneurysm rupture (6.9 to 9 per 100,000 in the USA).[1-3] It is also a disease with high morbidity and mortality rates and can occur due to head trauma, arteriovenous malformation, or bleeding diathesis without an underlying vascular pathology.[4] Despite the development of new endovascular treatment methods in recent years (such as flow converters and intrasaccular devices) compared to the traditional microsurgical method, and despite the increased treatment of non-bleeding aneurysms, there has been no significant change in the morbidity and mortality rates of SAH.[2,5]

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The mortality rate, which is 15% at the time of aneurysm rupture, increases up to threefold in the following one-month period.[2,6] The quality of life of survivors is reduced due to severe sequelae and neuropsychiatric disorders (such as depression and anxiety).[7-9] All these negative outcomes are thought to be mainly due to late cerebral ischemia (secondary cerebral ischemia; SCI) following aneurysmal SAH.[9] Despite the successful results obtained in many experimental studies on the treatment and prevention of vasospasm, which has been accepted as a precursor to the development of SCI for decades, there is still no clinical trial with acceptable results.[10,11] The period characterized by autophagy, apoptosis, inflammation, destruction of the blood-brain barrier, global cerebral edema, and oxidative stress mechanisms and related factors that begins after aneurysm rupture is called early brain injury (24-72 hours).[9,12] There is an urgent need for ongoing scientific research into new approaches for the prevention and treatment of early brain injury (EBI), which represents this period of pathophysiological destruction triggered by vasospasm.

Vasospasm, microthromboembolism, and neuronal damage, which are secondary complications of SAH, are closely related to oxidative stress. It has been previously shown in an experimental model of SAH that endothelial nitric oxide synthase (eNOS) uncoupling exacerbates oxidative stress and consequently secondary complications.[13,14] Recently, the results of activation of the extracellular regulated kinase 5 (Erk5) pathway, modulated by eNOS and its activator, the transcription factor Kruppel-like factor 2 (KLF2), in attenuating vasospasm have been notable.[15]

Hesperidin (HSP) is a bioactive flavonoid polymer abundantly present in citrus peels. HSP can directly cross the blood-brain barrier and alleviate hypoxia-induced blood-brain barrier dysfunction through its antioxidant action.[16] In addition, it has exhibited antioxidative properties against spinal cord injury, subarachnoid hemorrhage, and cancer.[17-19] Despite a previous study showing that HSP attenuates acute vasospasm after SAH, its mechanism of action is unclear.[18] Therefore, this study evaluates the vasoprotective role of hesperidin via the Erk5-KLF2-eNOS pathway and highlights its potential as a natural flavonoid polymer in cerebrovascular therapy.

MATERIALS AND METHODS

Animals

This experimental study was approved by the Ethics Committee of Zonguldak Bülent Ecevit University and was conducted in the Research and Animal Laboratory of the same university (02-28-2021/01). All procedures performed in studies involving animals were in accordance with the ethical standards of the institution or practice at which the studies were conducted. This article does not contain any studies with human participants performed by any of the authors.

The study was carried out between March 2021 and February 2022. Forty female Wistar albino rats weighing 350-400 g each were included in the study. All animals were housed at room temperature (22-25°C) under a diurnal (12:12-hour day/night) cycle with free access to food and water throughout the experiment.

Groups

Forty female Wistar albino rats (300-350 g) were divided into the following groups: Control group (G1, n=8, not subjected to any treatment or intervention); Sham + vehicle group (G2, n=8, subjected to sham experimental intervention and administered subarachnoid physiological saline); SAH + vehicle group (G3, n=8, subjected to SAH and administered subarachnoid physiological saline); SAH + low-dose HSP (G4, n=8, subjected to SAH and administered 100 mg/kg HSP, Sigma-Aldrich, USA); and SAH + high-dose HSP (G5, n=8, subjected to SAH and administered 300 mg/kg HSP, Sigma-Aldrich, USA). Subarachnoid hemorrhage was induced by a double injection of homologous blood into the cisterna magna as described by Pedard et al.[20] The second SAH model was performed 24 hours after the first.

Study Design (Induction of SAH by the Double-Injection Homologous Blood Method in Rats)

All rats were anesthetized with ketamine (4 mg/100 g) and xylazine (1.5 mg/100 g) intraperitoneally, and the hair was shaved from the suboccipital region to the neck. After the rats were placed in the prone position, their heads were tilted 30° forward and fixed. A midline skin incision was made between the occiput and atlas arch, and the muscles of the craniocervical region were dissected. The atlanto-occipital membrane was exposed. Hemostasis was achieved with electrocautery at all stages. A 26-gauge catheter filled with homologous arterial blood from the carotid artery of a rat of the same age and sex not included in the study was inserted through the vertical midline at a right angle to the atlanto-occipital membrane. To prevent an increase in intracranial pressure, 0.25 ml of cerebrospinal fluid was drawn into a syringe. Then, 0.25 mL of blood was injected into the cisterna magna in the first infusion. The second infusion was performed 24 hours after the first infusion, using the same surgical procedures. The second infusion was performed with the same amount of blood (0.25 mL) as in the first infusion. After both procedures, the rats were kept in an upside-down position (30°) on an inclined plane for 5 minutes. These two procedures were applied to all rats except the control group. The sham operation in Group 1 consisted of the same manipulation, but instead of blood, 0.25 mL of 0.09% NaCl (physiologic saline) was administered in the first procedure and 0.25 mL in the second procedure (24 hours later). Rats in G3 (100 mg/kg) and G4 (300 mg/kg) were administered HSP by oral gavage immediately after the first SAH procedure and every 12 hours for the following 48 hours. After all rats were euthanized with a high dose of anesthetic agent (pentobarbital, 200 mg/kg, Biovet, Ankara, Türkiye), samples were taken from the cerebral hemispheres (Fig. 1).

In addition, blood sampling from the tail artery was not performed due to our clinic's experience with tail blood collection. Percutaneous blood collection from the tail artery is difficult and prolongs surgical time. Open surgeries cause additional surgical stress. In this context, we preferred the homologous blood injection model described by Pedard et al.[20]

Morphometric Method of Basilar Artery Analysis

Cerebellum specimens sent to pathology and kept in 10% buffered formaldehyde for 48 hours were cut transversely from the midline to visualize the basilar artery and then blocked. The blocked specimens were processed, and 5-micron serial sections were taken and stained with hematoxylin and eosin. The preparations were examined with a Nikon Eclipse Ni-U (Japan) microscope and evaluated by a single pathologist. Basilar arteries were visualized using the NIS-Elements D version 5.02 program. Images were taken at 200× magnification, and basilar artery diameters were measured at four points (3, 6, 9, and 12 o'clock) with the ImageJ version 1.2 program, and the thickest wall thickness was recorded.[21]

Biochemical Analysis

Super Oxide Dismutase (SOD, U/ml)

The role of SOD is to accelerate the conversion of the toxic radical produced during oxidative energy processes into hydrogen peroxide and molecular oxygen. This method uses xanthine and xanthine oxidase to produce superoxide radicals that react with 2-(4-iodophenyl)-3-(4-nitrophenol)-5-phenyltetrazolium chloride to form a red formazan dye. Superoxide dismutase activity is then measured by the degree of inhibition of this reaction (Relassay, Türkiye).

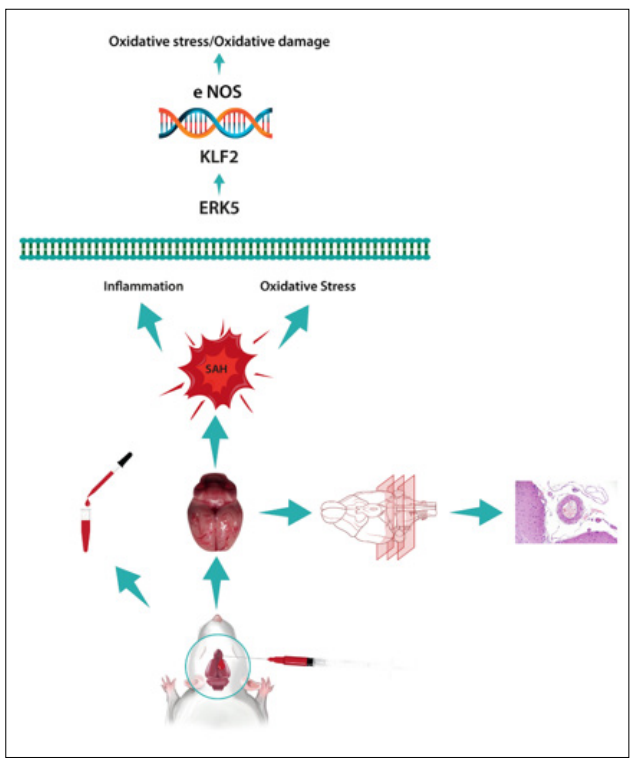

Figure 1. Schematic representation of the methodology used in this study. Blood and tissue samples were collected for histopathological and molecular analyses to assess oxidative stress markers and inflammatory responses. The diagram illustrates the experimental steps, including sample collection, oxidative stress assessment, and histological examination.

Catalase (CAT, U/ml)

This colorimetric assay consists of two steps. First, the sample is incubated with a known amount of hydrogen peroxide. The sample converts hydrogen peroxide into water and oxygen. This rate is proportional to the CAT concentration. The enzyme is then stopped, and after a fixed incubation time the remaining hydrogen peroxide is determined using a chromogen. The absorbance is measured at 405 nm and the results are expressed as U/ml (Relassay, Türkiye).

Glutathione Peroxidase (GPx, U/ml)

This method is based on the technique of Paglia and Valentine. Glutathione peroxidase (GPx) catalyzes the oxidation of glutathione by cumene hydroperoxide. In the presence of glutathione, it is immediately converted back to the reduced form by simultaneous oxidation of nicotinamide adenine dinucleotide phosphate (NADPH) to nicotinamide adenine dinucleotide phosphate (NADP). The decrease in absorbance at 340 nm is measured (Relassay, Türkiye).

Nitric Oxide (NO, µmol/L)

Nitric oxide measurement was carried out based on the Griess method. Since NO has a very short half-life, it is rapidly converted to its metabolites nitrite and nitrate. Nitrite is measured directly, and nitrate is measured after its reduction to nitrite using Griess reagent. In the Griess method, the amino group of sulfanilamide reacts with nitrite in an acid medium, undergoes diazotization, and forms a purple azo product with naphthylethylenediamine (NED). After the resulting color is read at a wavelength of 540 nm in a spectrometer, plasma NO levels are calculated indirectly according to the calibration curve prepared using nitrite standards (Relassay, Türkiye).

Western Blot Analysis

Basilar arteries were isolated and harvested 48 hours after SAH. Membrane proteins were extracted using a protein extraction kit (RIPA, Merck, KGaA, Darmstadt, Germany) according to the manufacturer's instructions. Western blotting was performed as previously described, using the following primary antibodies: anti-eNOS (Santa Cruz Biotechnology, Santa Cruz, CA, USA); anti-KLF2 and anti-p-Erk5 (Santa Cruz Biotechnology, CA, USA); and anti-Erk5 (ssc-398015, Santa Cruz Biotechnology, Santa Cruz, CA, USA) [22]. A chemiluminescence imaging system was used for imaging. Since this imaging system is based on the chemical luminol, a secondary antibody-specific substrate (enhanced chemiluminescence; ECL) was used. The membrane was incubated in an ECL solution prepared at a 1:1 ratio for 5 minutes in a dark

Table 1. The effects of hesperidin on superoxide dismutase (SOD), catalase (CAT), glutathione peroxidase (GPx), and nitric oxide (NOS) levels in rat brain tissue following experimental subarachnoid hemorrhage

Groups/Parameters	n	SOD	CAT	GPX	NOS
G1	8	181.25±15.50	110.50±36.10	481.00±93.73	61.28±8.35
G2	8	147.00±12.72	98.25±22.17	396.25±103.68	55.22±8.37
G3	8	96.63±11.50	41.50±7.98	268.75±102.81	35.07±10.74
G4	8	131.75±9.54	83.13±13.29	424.13±164.01	51.17±13.30
G5	8	150.25±7.50	96.75±16.30	435.88±132.83	53.01±15.62
p*		55.697 (<0.001)[a,b,c,d,e,l,j]	12.407 (<0.001)[c,e,l,j,]	3.438 (<0.05)[b]	5.641 (<0.01)[b,e]

Differences were evaluated by ANOVA and Kruskal-Wallis tests. Data are presented as mean±standard deviation. p* indicates significant differences at the 0.05 level. a: p<0.05 for G1 and G2 groups; b: p<0.05 for G1 and G3 groups; c: p<0.05 for G1 and G4 groups; d: p<0.05 for G1 and G5 groups; e: p<0.05 for G2 and G3 groups; f: p<0.05 for G2 and G4 groups; h: p<0.05 for G2 and G5 groups; i: p<0.05 for G3 and G4 groups; j: p<0.05 for G3 and G5 groups; k: p<0.05 for G4 and G5 groups.

environment, and imaging was initiated. Bands were detected with chemiluminescence imaging systems (G:BOX, Syngene, USA) and quantified according to band intensity using GeneSys software. β-Actin was used as an internal control.

Statistical Analysis

Data were analyzed using the Statistical Package for the Social Sciences version 22.0. Descriptive statistics for quantitative variables were expressed as mean and standard deviation. The Shapiro-Wilk test was used to assess normal distribution assumptions. Skewness and kurtosis coefficients and dispersion in Q-Q plot graphs were also examined. Since the data were normally distributed for the parameters, the groups were compared using analysis of variance (ANOVA, San Diego, CA). Since the distribution was not normal for catalase, the relationship between the groups was analyzed using the Kruskal-Wallis test. When variances were assumed to be unequal, the Games-Howell test was used to determine statistical significance based on the mean scores of the groups. Results were considered statistically significant if the P value was <0.05.

RESULTS

Superoxide dismutase, CAT, GPx, and NOS values in all groups were analyzed 48 hours after the surgical procedure (Table 1). According to the SOD results, it was observed that G1 (control group) (181.25±15.50 U/ml) had the highest value; G2 (147.00±12.72 U/ml), G4 (131.75±9.54 U/ml), and G5 (150.25±7.50 U/ml) formed a cluster with similar effects; and the lowest value was observed in G3 (96.63±11.50 U/ml) (Table 1). The treatment groups (G4 and G5) showed a significant difference from the G1 (p=0.00<0.001) (Table 1) and G3 (p=0.00<0.001) (Table 1) groups, and no statistical difference was observed compared with the G2 group (p>0.05) (Table 1). Although SOD results were higher in G5 than in G4, no statistically significant difference was observed between these two groups (p>0.05) (Table 1). When the effect of CAT measurement results on the groups was analyzed, the differences between G1 and G3 (p=0.01≤0.01), G2 and G3 (p=0.00<0.001), G4 and G3 (p=0.00<0.001), and G5 and G3 (p=0.00<0.001) were statistically significant (Table 1). When GPx results were analyzed, the highest value among the groups was observed in G1 (481.00±93.73 U/ml), followed by G5 (435.88±132.83 U/ml), G4 (424.13±164.01 U/ml), and G2 (396.25±103.68 U/ml), while the lowest value was observed in the G3 group (268.75±102.81 U/ml) (Table 1). A statistically significant difference between the groups was observed only between the G1 and G3 groups (p=0.03<0.05) (Table 1). When the NOS measurement results were analyzed, differences between the groups were observed between G1 and G2 (p=0.00<0.01) and between G2 and G3 (p=0.03<0.05) (Table 1).

Histopathologically, as expected, vessel samples from G1 showed a single layer of endothelium with elastic lamina and intima surrounded by smooth muscle cells, and the appearance of the intima was similar to that of the normal rat basilar artery (Fig. 2a). The arterial lumen was slightly dilated in the treatment groups (G4 and G5) compared to G1, G2, and G3. In G4 and G5, the epithelium appeared more intact, and flattening of the epithelium was observed compared to the other groups (Fig. 2b-c-d-e). While degenerative findings in the media layer increased in G2 and G3 compared to the other groups, the intima layer was also noted to be thicker in these groups compared to the other groups (Fig. 2b-c).

When the morphometric values of the basilar artery were evaluated, statistically significant differences were found between G4 and G5 compared to G3 (p=0.00<0.001), between G1 and G2 (p=0.03<0.05), and between G1 and G3 (p=0.00<0.01) (Table 2). However, no statistically significant difference was observed between G4 and G5 (p≥0.05) (Table 2). Regarding basilar artery wall thickness, no statistically significant differences were found, as similar results were observed in all groups (p>0.05) (Table 2).

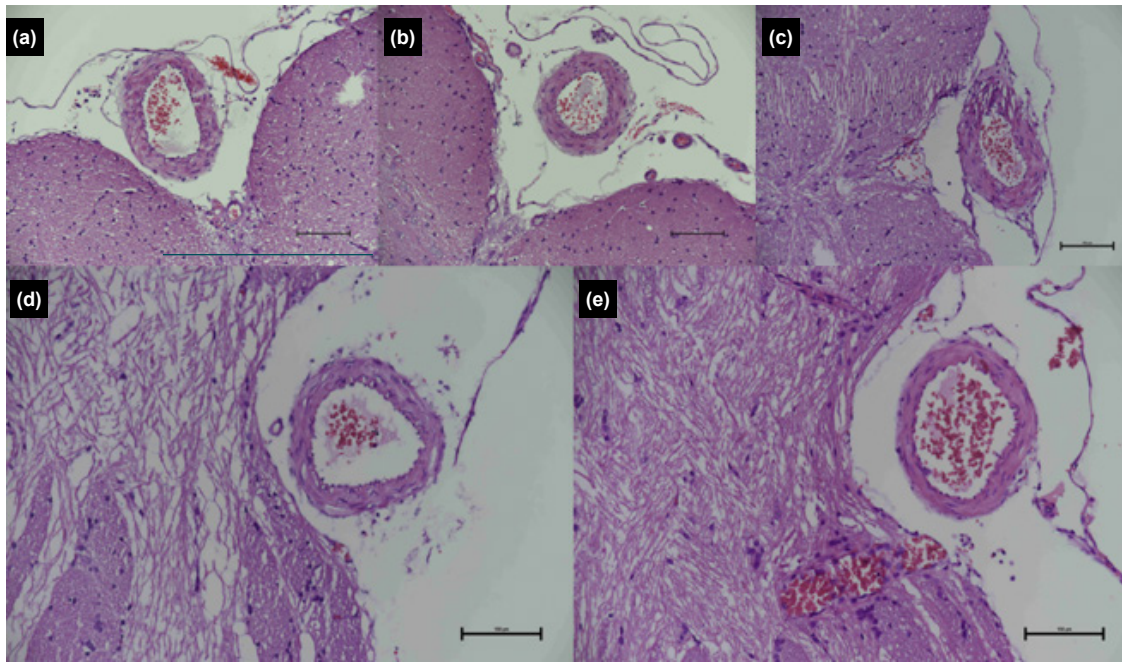

Figure 2. (a) Microscopic view of a normal basilar artery in Group 1 (hematoxylin and eosin, ×100). **(b)** Microscopic view showing increased basilar artery wall thickness and luminal narrowing in Group 2 compared with Group 1 (hematoxylin and eosin, ×100). **(c)** Microscopic view showing increased basilar artery wall thickness and luminal narrowing in Group 3 compared with Group 1 (hematoxylin and eosin, ×100). **(d)** Microscopic view showing decreased basilar artery wall thickness and increased luminal narrowing in Group 4 compared with Group 2 (hematoxylin and eosin, ×100). No statistically significant difference in basilar artery wall thickness was observed between Group 4 and Group 3, but basilar artery luminal diameters were markedly wider in Group 4. **(e)** Microscopic view showing decreased basilar artery wall thickness and increased luminal narrowing in Group 5 compared with Group 2 (hematoxylin and eosin, ×100). No statistically significant difference in basilar artery wall thickness was observed between Group 5 and Group 3, but basilar artery luminal diameters were markedly wider in Group 5.

When the KLF2/β-actin measurement results were analyzed, statistically significant differences were found between G1 and G2 (p=0.00<0.001), G3 (p=0.00<0.001), G4 (p=0.00<0.001), and G5 (p=0.00<0.01) (Fig. 3). Similarly, significant differences were observed between G2 and G4 (p=0.00<0.001) and G5 (p=0.00<0.001), and between G3 and G4 (p=0.00<0.001) and G5 (p=0.00<0.001). However, the differences between G2 and G3 and between G4 and G5 were not statistically significant (p>0.05) (Table 3, Fig. 3).

ERK5/β-actin measurement results were highest in G5 (0.91±0.05) and lowest in G1 (0.50±0.09). When the differ-

Table 2. Effect of hesperidin on rat basilar artery mean lumen diameter and wall thickness after experimental subarachnoid hemorrhage

Groups/Parameters	n	Wall Diameter	Wall Thickness
G1	8	121.63±24.49	39.46±7.03
G2	8	79.91±23.60	45.20±10.07
G3	8	69.98±7.69	47.76±5.24
G4	8	101.03±10.52	41.91±5.45
G5	8	107.32±12.60	41.07±6.42
p*		11.754 (<0.001)[a,b,l,j]	1.801 (>0.05)

Differences were evaluated by one-way ANOVA. Data are presented as mean±standard deviation. p* indicates a significant difference at the 0.05 level. a: p<0.05 for G1 and G2 groups; b: p<0.05 for G1 and G3 groups; c: p<0.05 for G1 and G4 groups; d: p<0.05 for G1 and G5 groups; e: p<0.05 for G2 and G3 groups; f: p<0.05 for G2 and G4 groups; h: p<0.05 for G2 and G5 groups; i: p<0.05 for G3 and G4 groups; j: p<0.05 for G3 and G5 groups; k: p<0.05 for G4 and G5 groups. No statistically significant differences were found between the groups with respect to wall thickness (p>0.05).

Table 3. Investigation of eNOS-β-actin, KLF2-β-actin, ERK5-β-actin, and p-ERK5-β-actin levels between groups

Group	n	eNOS-β-actin	KLF2-β-actin	ERK5-β-actin	pERK5-β-actin
G1	4	1.01±0.04	1.05±0.11	0.49±0.08	0.07±0.03
G2	4	0.88±0.09	0.31±0.04	0.59±0.10	0.11±0.02
G3	4	0.20±0.05	0.20±0.07	0.57±0.11	0.35±0.07
G4	4	0.77±0.07	0.73±0.04	0.74±0.08	0.76±0.04
G5	4	0.86±0.05	0.83±0.03	0.91±0.05	0.89±0.02
p		(<0.01)^{b,c,e,h,i}	(<0.01)^{a,b,c,d,f,g,h,i}	(<0.01)^{c,d,g,i}	(<0.01)^{b,c,d,e,f,g,h,i,j}

Statistical differences between groups are indicated by letters for p<0.01. Difference between Group 1 and Group 2 (a), difference between Group 1 and Group 3 (b), difference between Group 1 and Group 4 (c), difference between Group 1 and Group 5 (d), difference between Group 2 and Group 3 (e), difference between Group 2 and Group 4 (f), difference between Group 2 and Group 5 (g), difference between Group 3 and Group 4 (h), difference between Group 3 and Group 5 (i), difference between Group 4 and Group 5 (j).

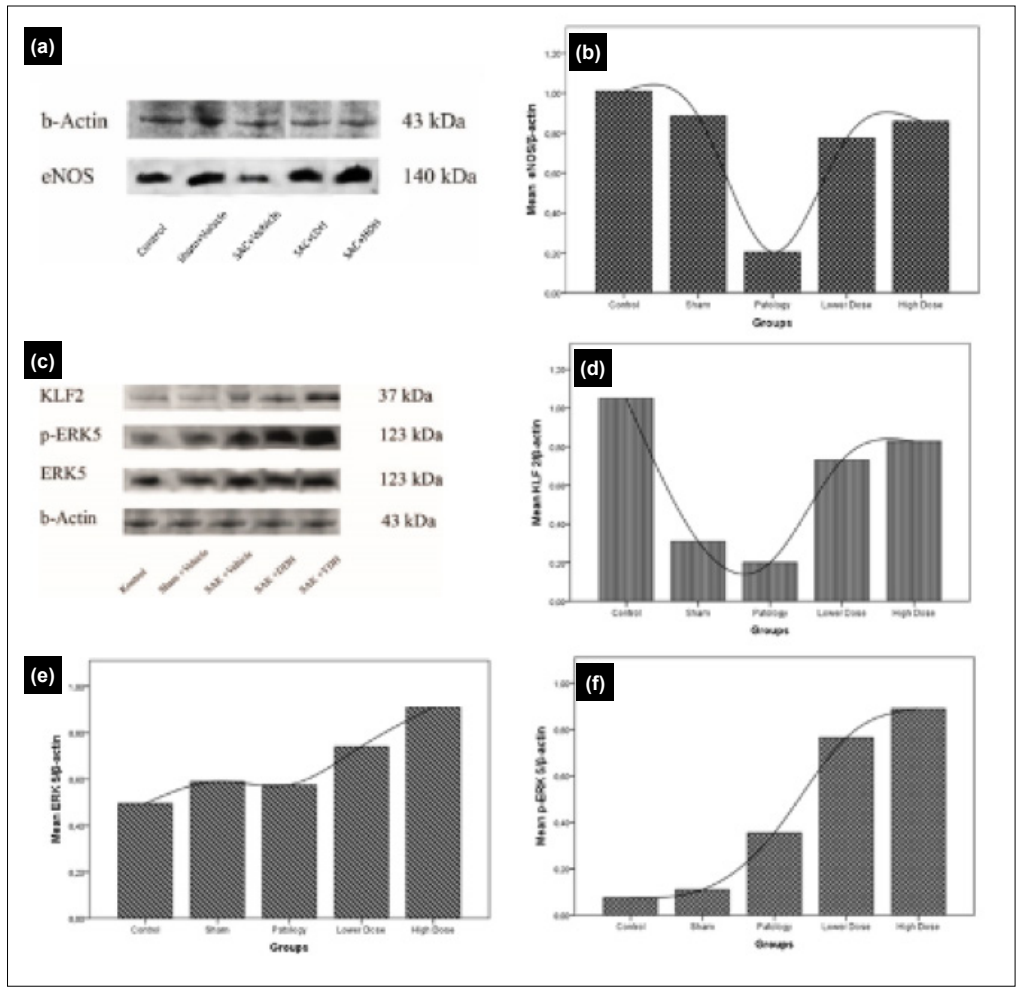

Figure 2. (a) Representative Western blot bands of eNOS expression in the hemisphere 48 hours after SAH. **(b)** Quantification analysis of eNOS expression in the hemisphere 48 hours after SAH (n=4). **(c)** Representative Western blot bands of Kruppel-like factor 2 (KLF2), phosphorylated-Erk5, and Erk5 expression. **(d)** Quantification analysis of KLF2 expression in the hemisphere 48 hours after SAH (n=4). **(e)** Quantification analysis of Erk5 expression in the hemisphere 48 hours after SAH (n=4). **(f)** Quantification analysis of p-Erk5 expression in the hemisphere 48 hours after SAH (n=4).

ences between the groups were analyzed, it was observed that the differences between G1 and G4 (p=0.03<0.05) and G5 (p=0.00<0.001), between G2 and G5 (p=0.00<0.01), and between G3 and G5 (p=0.00<0.01) were statistically significant (Table 3, Fig. 3).

When eNOS/β-actin results were analyzed, the differences between G1 and G3 (p=0.00<0.001) and G4 (p=0.00<0.01), and between G3 and G2 (p=0.00<0.001), G4 (p=0.00<0.001), and G5 (p=0.00<0.001) were statistically significant (Table 3, Fig. 3).

When p-ERK5/β-actin results were analyzed, it was found that only the difference between G1 and G2 was not statistically significant (p>0.05). Except for this comparison, it was observed that the differences between all other paired groups were statistically significant (Table 3, Fig. 3).

DISCUSSION

The first goal in the treatment of subarachnoid hemorrhage is to stop the bleeding and, if possible, address the underlying cause. Rebleeding is the most feared and most fatal complication, occurring in 40% of patients with a mortality rate of 80%. Even in cases where hemorrhage is completely controlled, guidelines recommend maintaining a mean arterial pressure above 110, systolic pressure in the range of 140-160, hemodilution, hypervolemia, normothermia, normoglycemia, normoglycemia, normonatremia, moderate hypercarbia (PaCO2), and preventing seizures, hydrocephalus, and increased intracranial pressure through close monitoring.[7,22-29]

Vasospasm is known to be the most common early-to-mid-term complication (days 3-14) of subarachnoid hemorrhage following rebleeding (40%). It is known that vasospasm, a condition that produces clinical findings through decreased cerebral perfusion leading to narrowing of the vessel lumen, causes delayed SCI in one-third of all subarachnoid hemorrhage cases.[23,24,28-30] The development of SCI worsens prognosis by increasing mortality and morbidity 1.5- to 4-fold.[28,31] Although there is no definitive cause of vasospasm, its pathophysiology is thought to be multifactorial and involves ischemia and immune destruction caused by blood elements crossing the blood-brain barrier, necrotic tissue damage, oxidative stress, and inflammation.[23,32-36]

Many studies have shown that subarachnoid hemorrhage causes vasospasm through both signaling pathways stimulated by inflammation and the vasoconstrictive effects of irritant metabolites formed from necrotic neural tissues and accumulated blood products around the vessel wall on vascular smooth muscle.[23,24,29,30,36-39] In addition to the above-mentioned measures taken to reduce risk factors, calcium-channel blockers and antagonists used to reduce vasospasm, which may be partially successful, can decrease the resulting vasoconstriction, but treatments capable of preventing vasospasm at the point where oxidant irritation begins have not yet been identified.[28,39] Both the tissue destruction resulting from ischemic tissue damage and the immune system elements involved in the inflammatory process caused by blood products (such as auto-oxidation of hemoglobin) increase oxidative stress in the tissue.[40-42] Therefore, the total damage to the tissue is correlated with oxidative stress, and an agent such as HSP, whose antioxidant and anti-inflammatory effects have been demonstrated in the literature, is expected to reduce tissue damage and thus the delayed state of SCI due to vasospasm.[34,35,43] This hypothesis is supported by literature demonstrating that treatments aimed at reducing the amount of blood in the subarachnoid space are successful in reducing vasospasm and GSI.[37,44]

There are various experimental models available to simulate SCI due to vasospasm that develops after subarachnoid hemorrhage.[20,45-47] Since the amount of blood in the subarachnoid space is among the parameters affecting the degree of vasospasm in this study, the model created by homologous blood injection into the cisterna magna, described by Pedard et al., a method in which the amount of blood in the subarachnoid space is known, was preferred.[20] Due to the dense anastomoses in rat cerebral artery anatomy, it is impractical to demonstrate ischemia in micropathological examination because ischemia does not produce necrotic scars in the tissue.[48] Therefore, the diameter of the basilar artery lumen examined in rapidly fixed specimens after decapitation was chosen as an indirect indicator of ischemia and a direct indicator of vasospasm.[20] In addition, oxidative stress, which is a common result of inflammation and damage caused by subarachnoid hemorrhage, was closely evaluated using oxidant stress parameters measured by ELISA (enzyme-linked immunosorbent assay) and Western blot techniques.

Hesperidin is a molecule that has been extensively studied in the literature, and its anti-inflammatory, antioxidant, and neuroprotective properties have been repeatedly demonstrated in different models.[49-55] Since this molecule is an antioxidant with neuroprotective effects, it appears suitable for use in SCI and vasospasm, where cerebral oxidant damage is prominent. Considering all these features, our study aimed to reveal the mechanism of the antioxidant effect of HSP, its relationship with the KLF2-ERK5-eNOS pathway, which is known to increase vasodilation and endothelial stability, and its effect on SCI.[16-19,43]

In the literature, many studies indicate that subarachnoid hemorrhage increases oxidative stress and that there is a correlation between the quantitative level of this oxidative stress, the degree of vasospasm, and consequently the extent of SCI.[34,35,40,42-44,56-60] Similar results were observed in our study. The number of oxidants in the environment decreases because of the activity of the SOD, CAT, and GPx enzymes, whose function is to neutralize free radicals. In this way, oxidants can be reduced, but the remaining oxidant capacity is also lowered. Therefore, the amount of decrease in these values is considered the portion of this capacity that is used in vivo and serves as an indicator of oxidative stress.[34,35,42,56,57,60] While

all neutralizing capacity parameters were relatively higher in G1 than in the other groups, they decreased in all groups in which oxidant exposure was partially present. The lowest values were measured in the untreated SAH group (G3) for all parameters. Although statistically significant differences were not observed, particularly in the measurements of glutathione peroxidase, an enzyme that indirectly provides a neutralizing effect, and in some other measurements (Table 1), an antioxidant effect was noted in the treatment groups in terms of oxidant exposure, which brought the neutralizing capacity closer to the values of the non-SAH treatment group (G2). Although it could not be demonstrated that this effect increased dose-dependently with statistical significance, it can be said that the antioxidant efficacy of high-dose HSP was higher, albeit by a small margin.

Nitric oxide is an intracellular signaling molecule and neurotransmitter that is also thought to increase vascular tone, insulin release, angiogenesis, local smooth muscle reciprocal regulation, hypotension, and the shock state in septic immune responses. The production and concentration of NO are controlled by three main enzymes, of which eNOS and neuronal-derived NO synthetase predominate in the routine functioning of the body.[61-63] However, during inflammatory processes, inducible NO synthetase (iNOS) becomes dominant, causing the oxidant character of NO to predominate. This promotes its use in the nonspecific immune response and enhances its vasodilatory effects, increasing the flow to the site and increasing the transport of inflammatory elements.[64-66] Although this is part of a mechanism to protect the body, it also causes damage to parenchymal tissues and promotes the growth of inflammation by suddenly and substantially increasing oxidative stress in the region. When these damaged tissues include the vessel walls, a vasospasm response may occur.[33,66-70] One of the active pathways that helps maintain eNOS dominance in NO production is the pathway initiated by the ERK5 receptor, which was examined in our study. The ERK5 receptor increases NO levels by upregulating eNOS production via the KLF2 transcription factor, in order to decrease intravascular flow velocity by stimulating endothelial cells in response to the entraining shear stress caused by the flow rate during intravascular flow. Since this increase in production occurs gradually over time, it allows adaptive mechanisms to develop to neutralize the oxidant stress caused by NO. In this way, while it does not create oxidant stress, it reduces shear stress through its vasodilating effect.[15,71-73]

When the results of our study were analyzed, a significant statistical difference in NO production was found only between the untreated control group (G1) and the placebo treatment group without bleeding (G2), and the untreated SAH group (G3). The fact that the NO measurements in the treatment groups (G4 and G5) were not significantly different from those in the nonbleeding groups (G1 and G2) showed that HSP was able to increase NO levels to near-normal values (Table 1). When we combine this finding with the observation that oxidative stress was also reduced in the treatment groups, we conclude that HSP both supports NO production from more gradual sources rather than explosive iNOS-induced production in the treated groups, and prevents NO from cyclically aggravating oxidative stress and the inflammatory response, thus preventing NO depletion and creating a stabilizing effect.

When the expression levels of ERK5-KLF2-eNOS involved in NO production were examined (Fig. 3), the finding that ERK5 levels were significantly different in the G5 group compared to all other groups, and were higher in the two treatment groups than in all other groups without correlation with other parameters, led to the conclusion that HSP treatment caused ERK5 receptor upregulation, even though the process occurred in an acute-subacute phase. The p-ERK5/ERK5 ratio reflects the degree of ERK5 receptor activation, the first key step in the ERK5-KLF2-eNOS pathway.[15] While ERK5 receptor activation was very low in the first two groups, a moderate level of activation was observed in G3. This partial increase in activation was interpreted as the effect of increased shear stress due to vasospasm. The higher ERK5 activation in both treatment groups compared to G3 suggests that one of the mechanisms by which HSP increases NO is through the KLF2-eNOS pathway. The parallel increase of eNOS and KLF2 expression and the significant differences in these values between the untreated SAH group (G3) and the treatment groups (G4 and G5) further suggest that activation of the eNOS pathway is enhanced by HSP and can lead to the end product, i.e., an increase in eNOS-derived NO, without encountering intracellular resistance. When these values are considered together, the ranking of ERK5 activation (with the treatment groups G4 and G5 followed by the untreated SAH group G3), contrasted with the intracellular conduction pathways (KLF2-eNOS) and the end product (NO) ranking last, supports both the idea that iNOS-induced NO production is dominant in G3 and that eNOS-induced production is somehow disrupted. It also supports the idea that NO is consumed by causing vascular and surrounding tissue irritation due to oxidative damage, rather than exerting a vasodilatory effect, since most of the NO produced in G3 is iNOS-derived and increases oxidative damage by rising suddenly. In light of this information, it was concluded that HSP exerts part of its protective vasodilatory and antioxidant effects against vasospasm via the ERK5-KLF2-eNOS pathway.

Since the results of morphometric evaluation are the most important findings that directly demonstrate vasospasm in vitro, this evaluation has the greatest impact on the conclusions. According to the results of the statistical analysis of lumen diameters (Table 2), the significant differences between the control group (G1), the bleeding-free procedure group (G2), and the untreated SAH group (G3) indicate that vasospasm was successfully induced in the experimental model. The fact that there was no statistically significant difference between the control group (G1) and the treatment groups

(G4 and G5), although the values were not exactly the same, shows that HSP was able to successfully prevent vasospasm in the treatment groups (G4 and G5), which were not statistically distinguishable from the control group (Table 2). The lack of a statistically significant difference in wall thickness is an expected result, since vascular remodeling seen in the chronic period has not yet begun in our study, which reflects the acute-subacute period.

CONCLUSION

The antioxidant effect of HSP in the treatment groups, the stabilizing effect that prevents NO depletion by reducing oxidant stress and limiting immune overreaction, and the vasodilatory effect caused by gradual NO production through the ERK5-KLF2-eNOS pathway, which brings the vessel lumen diameter almost to the level observed in tissues without subarachnoid hemorrhage, indicate that this natural flavonoid polymer may be a promising treatment option for vasospasm and late SCI that may develop after subarachnoid hemorrhage.

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DENEYSEL ÇALIŞMA - *ÖZ*

Sıçanlarda subaraknoid kanama sonrası serebral vazospazm üzerine hesperidinin nöroprotektif etkileri: Deneysel bir çalışma

AMAÇ: Subaraknoid kanama (SAK), yüksek morbidite ve mortalite oranlarıyla seyreden ciddi bir nörolojik acildir. Bu olumsuz sonuçların başlıca nedenleri vazospazm ve gecikmiş iskemidir. Doğal bir flavonoid olan hesperidin (HSP), güçlü antioksidan ve vazoprotektif etkilere sahiptir. Bu deneysel hayvan çalışmasında, HSP'nin SAK sonrası oksidatif stres ve vasküler yeniden yapılanma üzerindeki nöroprotektif rolü araştırılmış, özellikle Erk5-KLF2-eNOS sinyal yoluna odaklanılmıştır.

GEREÇ VE YÖNTEM: Çalışma 2021–2022 yılları arasında yürütüldü. Toplam 40 dişi Wistar albino sıçan beş gruba ayrıldı: Kontrol (G1, n=8), sham (G2, n=8), SAK + taşıyıcı (G3, n=8), düşük doz HSP (G4, n=8) ve yüksek doz HSP (G5, n=8). SAK modeli, cisterna magna'ya homolog kanın çift enjeksiyonu ile oluşturuldu. Subaraknoid kanamadan 48 saat sonra biyokimyasal belirteçler [Süperoksit Dismutaz (SOD), Katalaz (CAT), Glutatyon Peroksidaz (GPx), Nitrik Oksit (NOS)], baziler arter morfometrisi ve moleküler düzeyde Erk5, p-Erk5, KLF2 ve eNOS ekspresyonları değerlendirildi.

BULGULAR: Tedavi edilmeyen sıçanlarda (G3), SAK oksidatif stresi anlamlı düzeyde artırmış ve vasküler lümen çapını azaltmıştır. HSP ile tedavi edilen gruplarda (G4 ve G5) antioksidan enzim düzeylerinde (SOD, CAT, GPx) belirgin artış ve NOS düzeylerinde normale yakın değerler gözlenmiştir. Morfometrik analiz, HSP uygulanan gruplarda baziler arter lümen çapının anlamlı şekilde korunduğunu, duvar kalınlığında ise belirgin bir değişiklik olmadığını göstermiştir. Moleküler analiz sonuçları, Erk5-KLF2-eNOS yolunun yukarı regülasyonunu ortaya koyarak, vazodilatasyon ve oksidatif stresin azaltılmasında bu yolun rolünü desteklemiştir.

SONUÇ: Hesperidin, SAK'ye bağlı vazospazm ve oksidatif hasara karşı antioksidan kapasiteyi artırarak ve Erk5-KLF2-eNOS sinyal yolunu modüle ederek koruyucu etki göstermektedir. Bu bulgular, HSP'nin terapötik potansiyeline işaret etmektedir.

Anahtar sözcükler: Hesperidin; subaraknoid kanama; sıçan; vazospazm.

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ORIGINAL ARTICLE

Impact of early versus late-onset mediastinitis on outcomes after upper gastrointestinal surgery

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ABSTRACT

BACKGROUND: Mediastinitis is a rare but life-threatening complication after upper gastrointestinal (GI) surgery. Although advances in perioperative care have improved outcomes, the prognostic impact of the timing of onset remains unclear. Clarifying whether early-onset versus late-onset mediastinitis influences clinical, microbiological, and surgical outcomes is essential to guide management.

METHODS: We retrospectively analyzed 27 patients with mediastinitis after upper gastrointestinal surgery treated at our center between 2015 and 2025. Our institution is a tertiary-level, high-volume center performing complex upper GI procedures. During this period, 728 patients underwent upper GI surgery, among whom anastomotic leakage occurred in 44 (6.1%), and mediastinitis developed in 27 (3.7%). Patients were classified into early-onset (≤14 days) and late-onset (>14 days) mediastinitis groups based on the postoperative interval. Demographic and clinical variables, comorbidities, smoking history, malignancy status, microbiological culture results, surgical interventions, intensive care unit (ICU) admission and duration, hospital stay, duration of antibiotic treatment, complications, and mortality were recorded and compared.

RESULTS: During the 10-year study period, 728 patients underwent upper gastrointestinal surgery at our institution, and mediastinitis developed in 27 patients (3.7%) following esophageal or gastric procedures. The median age was 64 years [interquartile range: 54–74.5], and 55.6% were male. Malignancy was present in 70.4%, most frequently gastric adenocarcinoma (n=6). Overall, ICU admission was 81.5%, with a median ICU stay of two days, and mortality occurred in eight patients (29.6%). Culture positivity was observed in 16 patients (59.3%), most commonly with Klebsiella pneumoniae, Proteus mirabilis, and Enterobacter spp. Compared with late-onset mediastinitis, early-onset mediastinitis was associated with significantly shorter ICU stay (median 1 vs. 6.5 days, p=0.020), hospital stay (16 vs. 41 days, p=0.003), and antibiotic duration (14 vs. 35 days, p=0.002). The early-onset group demonstrated a lower mortality rate than the late-onset group (17.6% vs. 50.0%, p=0.102). Late-onset mediastinitis correlated with higher culture positivity and a greater need for complex surgical procedures, including video-assisted thoracic surgery (VATS), thoracotomy, and endoscopic stenting. Reoperations were required in 13 patients (48.1%). When stratified into abdominal and thoracic procedures, abdominal reoperations were more frequently observed in the late-onset group (5/8, 62.5%), whereas thoracic reoperations predominated in the early-onset group (4/5, 80%). Patients without reoperation constituted 51.9% of the cohort (14/27).

CONCLUSION: Early-onset mediastinitis after upper GI surgery is associated with improved outcomes. It correlates with better survival, shorter ICU and hospital stay, reduced antibiotic treatment, and a lower need for complex surgical procedures, whereas late-onset mediastinitis is linked to higher microbial burden, more frequent reoperations, and poorer outcomes.

Keywords: Mediastinitis; upper gastrointestinal surgery; early diagnosis; postoperative complications; surgical management.

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INTRODUCTION

Mediastinitis remains an uncommon but devastating complication after upper gastrointestinal (GI) surgery, with mortality rates ranging from 14% to 47% despite advances in perioperative care.[1,2] The main etiologies include iatrogenic or spontaneous esophageal perforations, anastomotic leaks, and postoperative infections.[3-5] Early-onset mediastinitis is a decisive prognostic factor; Mureşan et al.[5] reported significantly lower mortality when onset occurred within 24 hours.[6] The following four management principles have been emphasized: (1) source control through repair or diversion, (2) wide mediastinal debridement and drainage, (3) broad-spectrum antibiotics including antifungals, and (4) maintenance of adequate nutrition.[7] While most previous studies have focused on esophageal perforations or cardiothoracic surgery, mediastinitis following upper GI procedures has been less frequently investigated. Our study presents a 10-year single-center experience analyzing 27 patients with mediastinitis after upper GI surgery, comparing early-onset and late-onset disease with respect to clinical outcomes, microbiological findings, and surgical interventions.

MATERIALS AND METHODS

We retrospectively analyzed patients who developed mediastinitis after upper gastrointestinal surgery between 2015 and 2025 at our center. Our institution is a tertiary, high-volume referral center specializing in upper GI surgery. During these 10 years, 728 patients underwent upper GI operations, including esophagectomy and gastrectomy. Anastomotic leakage occurred in 44 patients (6.1%), and mediastinitis developed in 27 patients (3.7%), who constituted the study cohort.

All patients with suspected mediastinitis referred to our department during this period were reviewed. The diagnosis of mediastinitis was established either radiologically, based on computed tomography (CT) findings, or intraoperatively. Patients with mediastinitis secondary to cardiothoracic surgery, trauma, or descending oropharyngeal infections were excluded from the study.

Collected variables included demographic characteristics (age, sex, comorbidities, smoking history, malignancy status), perioperative parameters, postoperative day of onset, microbiological culture results (thoracic and abdominal specimens), and therapeutic interventions [tube thoracostomy, thoracentesis, video-assisted thoracic surgery (VATS), thoracotomy, endoscopic stenting, and reoperations]. Clinical outcomes such as intensive care unit (ICU) admission and duration, hospital length of stay, antibiotic duration, postoperative complications, and mortality were also recorded.

Patients were stratified into two groups according to the timing of onset following surgery: early-onset mediastinitis (≤14 days after the index operation) and late-onset mediastinitis (>14 days after the index operation). Culture positivity was defined as the presence of microbial growth other than "no growth" or "panel only" results.

This study was approved by the İstanbul University Ethics Committee (Date: 28.08.2025, Decision no: 2025/1332). All procedures were conducted in accordance with the principles of the Declaration of Helsinki.

Statistical Analysis

Statistical analyses were conducted using SPSS software (version 29.0; IBM Corp., Armonk, NY, USA). The Kolmogorov–Smirnov test was used to assess the distribution of continuous data. Categorical variables were analyzed using the Chi-square or Fisher's exact test, as appropriate in contingency tables, and Student's t-test was used to compare continuous variables. A p-value of <0.05 was considered indicative of statistical significance.

RESULTS

During the 10-year study period, 728 patients underwent upper gastrointestinal surgery at our institution, of whom 27 (3.7%) developed mediastinitis following esophageal or gastric procedures.

A total of 27 patients with mediastinitis after upper gastrointestinal surgery were analyzed. The median age of the cohort was 64 years [interquartile range (IQR): 54-74.5], and 55.6% were male. Nineteen patients (70.4%) had malignant disease, most frequently gastric adenocarcinoma (6/19, 31.6%), followed by esophageal squamous cell carcinoma (SCC) (3/19, 15.8%), gastrointestinal stromal tumor (GIST) (2/19, 10.5%), and others including colorectal adenocarcinoma, pancreatic cancer, sarcoma, and lymphoma (8/19, 42.1%). The distribution of malignancy types between the early-onset (≤14 days) and late-onset (>14 days) mediastinitis groups was similar, with no statistically significant difference (p=0.910) (Table 1). The median postoperative day of onset was 11 [IQR 3.5–15.5] and the median smoking exposure was 35 pack-years [IQR 30–40].

Overall, ICU admission was required in 22 patients (81.5%), with a median ICU stay of 2 days [IQR: 1-8]. The median hospital stay after onset of mediastinitis was 22 days [IQR: 16-41], and the median duration of antibiotic therapy was 20 days [IQR: 14-35].

Mortality occurred in eight patients (29.6%). When stratified by timing of onset, mortality was 17.6% in the early-onset group (3/17) and 50.0% in the late-onset group (5/10) (p=0.102).

Patients with early-onset mediastinitis had significantly shorter ICU stay (median 1 vs. 6.5 days, p=0.020), hospital stay (16 vs. 41 days, p=0.003), and antibiotic duration (14 vs. 35 days, p=0.002) compared with those with late-onset mediastinitis. ICU admission was required in 70.6% of early-onset cases versus 100% of late-onset cases (p=0.13).

Among the 27 patients evaluated, culture positivity was observed in nine (52.9%) of the early-onset cases and in seven (70.0%) of the late-onset cases. Although culture positivity was numerically higher in the late-onset group, the difference

Table 1. Demographic characteristics and clinical outcomes of patients with mediastinitis after upper gastrointestinal (GI) surgery according to timing of diagnosis (early vs. late)

Variable	Total (N=27)	Early (≤14 days) (N=17)	Late (>14 days) (N=10)	p-value
Age, years (median [IQR])	64 [54–74.5]	62 [53–71]	67 [56–78]	0.410
Sex, N (%)				
Male	15 (55.6%)	10 (58.8%)	5 (50%)	0.700
Female	12 (44.4%)	7 (41.2%)	5 (50%)	
Smoking, pack-years (median [IQR])	35 [30–40]	34 [28–39]	37 [30–42]	0.520
Malignancy present, N (%)	19 (70.4%)	11 (64.7%)	8 (80%)	0.670
Malignancy type, N (%)				
Gastric adenocarcinoma	6 (31.6%)	4 (36.4%)	2 (25%)	0.910
Esophageal SCC	3 (15.8%)	2 (18.2%)	1 (12.5%)	
GIST	2 (10.5%)	1 (9.1%)	1 (12.5%)	
Others	8 (42.1%)	4 (36.4%)	4 (50%)	
Postoperative diagnosis day, median [IQR]	11 [3.5–15.5]	7 [3–10]	21 [17–27]	<0.001
ICU admission, N (%)	22 (81.5)	12 (70.6)	10 (100.0)	0.130
ICU stay, days (median [IQR])	2 [1–8]	1.0 [0–4]	6.5 [2.5–8]	0.020
Hospital stay, days (median [IQR])	22 [16–41]	16 [15–26]	41 [35–51]	0.003
Antibiotic duration, days (medi-an [IQR])	20 [14–35]	14 [14–23]	35 [26–49]	0.002
Culture Result				
Negative	11 (40.7%)	8 (47.1%)	3 (30.0%)	0.448
Positive	16 (59.3%)	9 (52.9%)	7 (70.0%)	
Mortality, N (%)	8 (29.6%)	3 (17.6%)	5 (50%)	0.102

IQR: interquartile range, SCC; squamous cell carcinoma, GIST; gastrointestinal stromal tumor.

Table 2. Distribution of microorganisms isolated from thoracic and abdominal cultures

Microorganism	Thoracic cultures N (%)	Abdominal cultures N (%)	Total N (%)
Klebsiella pneumoniae	4 (14.8%)	0 (0)	4 (14.8%)
Proteus mirabilis	2 (7.4%)	1 (3.7%)	3 (11.1%)
Enterobacter spp.	2 (7.4%)	2 (7.4%)	4 (14.8%)
Escherichia coli	0 (0)	2 (7.4%)	2 (7.4%)
Pseudomonas aeruginosa	0 (0)	2 (7.4%)	2 (7.4%)
Streptococcus α-hemolytic	2 (7.4%)	0 (0)	2 (7.4%)
Streptococcus β-hemolytic	0 (0)	1 (3.7%)	1 (3.7%)
Aspergillus spp.	1 (3.7%)	0 (0)	1 (3.7%)
Corynebacterium spp.	0 (0)	1 (3.7%)	1 (3.7%)
Citrobacter spp.	0 (0)	1 (3.7%)	1 (3.7%)
Total positive cultures	11 (40.7%)	10 (37%)	16 (59.3%)

was not statistically significant (p=0.448) (Table 1).

Thoracic cultures were obtained from all 27 patients, of which 11 (40.7%) demonstrated microbial growth. The most frequent isolate was Klebsiella pneumoniae (n=4, 14.8%), including one polymicrobial case in combination with Proteus mirabilis. Other thoracic isolates included Proteus mirabi-

Table 3. Surgical and interventional procedures according to the timing of diagnosis

Intervention	Total (N=27)	Early diagnosis ≤14 days (N=17)	Late diagnosis >14 days (N=10)	p-value
Tube thoracostomy	20 (74.1%)	14 (82.4%)	6 (60%)	0.210
Thoracentesis (diagnostic/therapeutic)	10 (37.0%)	7 (41.2%)	3 (30%)	0.700
VATS exploration/empyema enucleation	3 (11.1%)	1 (5.9%)	2 (20%)	0.250
Thoracotomy with repair/fistula closure	2 (7.4%)	0	2 (20%)	0.130
Endoscopic stent placement	2 (7.4%)	0	2 (20%)	0.130

VATS; video-assisted thoracic surgery.

Table 4. Distribution of abdominal and thoracic reoperations according to timing of diagnosis

Category	Early diagnosis ≤14 days (n=17)	Late diagnosis >14 days (n=10)	Total (n=27)
Abdominal reoperations (laparotomy, laparoscopy, abscess drainage)	3 (17.6%)	5 (50.0%)	8 (29.6%)
Thoracic reoperations			
(VATS, thoracotomy, stent, fistula repair)	4 (23.5%)	1 (10.0%)	5 (18.5%)
No reoperation	10 (58.8%)	4 (40.0%)	14 (51.9%)
Total	17 (100%)	10 (100%)	27 (100%)

VATS; video-assisted thoracic surgery.

lis (n=2), Enterobacter spp. (n=2; one in combination with Streptococcus α-hemolytic), Streptococcus α-hemolytic (n=2), and Aspergillus spp. (n=1).

Abdominal cultures were positive in 10 patients (37.0%). The most common isolates were Enterobacter spp. (n=2), Escherichia coli (n=2), and Pseudomonas aeruginosa (n=2). Less frequent microorganisms included Proteus mirabilis, Streptococcus β-hemolytic, Corynebacterium spp., and Citrobacter spp. (n=1 each).

Overall, 16 thoracic and 17 abdominal cultures showed no growth. On a patient basis, 11 individuals (40.7%) had no growth in either culture, while two patients demonstrated polymicrobial growth, underscoring the potential for mixed infections in mediastinitis (Table 2).

In the early-onset group, most patients were managed successfully with tube thoracostomy (14/17, 82.4%) and thoracentesis (7/17, 41.2%). In contrast, late-onset cases more frequently required complex procedures, including video-assisted thoracic surgery exploration (2/10, 20.0%), thoracotomy with fistula repair (2/10, 20.0%), and endoscopic stent placement (2/10, 20.0%). Although these complex procedures were numerically more common in the late-onset group, the difference did not reach statistical significance (Table 3).

When reoperations were stratified into abdominal and thoracic procedures, abdominal reoperations were more frequently observed in the late-onset group (5/8, 62.5%), whereas thoracic reoperations predominated in the early-onset group (4/5, 80%). Patients without reoperation accounted for 51.9% of the cohort (14/27) (Table 4).

DISCUSSION

This study demonstrates that the timing of onset significantly impacts outcomes in mediastinitis after upper GI surgery. Early-onset mediastinitis was associated with shorter ICU and hospital stay, reduced antibiotic duration, and lower mortality. Beyond these outcome measures, early-onset disease also minimized the need for complex surgical procedures, underscoring the clinical importance of prompt intervention.

Delayed diagnosis likely leads to poorer outcomes through several interrelated mechanisms. Prolonged mediastinal contamination permits bacterial proliferation and biofilm formation, resulting in extensive tissue necrosis and persistent sepsis. Continued inflammatory and catabolic responses contribute to metabolic exhaustion, malnutrition, and impaired wound healing, while delayed source control further perpetuates infection. These factors collectively explain the higher rates of reoperation, prolonged hospitalization, and increased mortality observed in late-onset cases.

Consistent with our findings, previous studies on esophageal perforation and mediastinal infections have shown that delayed diagnosis promotes sepsis progression, increases microbial burden, and significantly worsens survival outcomes. Early recognition and prompt intervention have repeatedly been emphasized as key prognostic factors in esophageal perforation management. Jones and Ginsberg highlighted the persistent challenges associated with delayed diagnosis and treatment,[7] while Whyte et al.[8] demonstrated the value of early primary repair in intrathoracic perforations. Wright et al.[9] and Bufkin et al.[10] further advocated reinforced or early surgical repair to optimize outcomes. Improved survival following esophageal perforation has also been reported in pediatric populations.[11] Moreover, Iannettoni et al.[12] showed that functional outcomes after surgical treatment can be favorable when intervention is timely. In the broader context of thoracic trauma, Gabor et al.[13] identified clear indications for surgical management in tracheobronchial ruptures, underscoring the importance of early operative strategies in airway and mediastinal injuries.

Importantly, our study extends current knowledge by focusing specifically on mediastinitis after upper GI surgery, a relatively underreported subgroup. We demonstrate that early-onset mediastinitis not only improves survival but also reduces microbiological burden and surgical complexity. Late-onset mediastinitis was associated with a substantially higher likelihood of requiring thoracotomy, stent placement, and reoperations, reflecting greater disease severity and increased resource utilization. These findings highlight that early-onset disease is not only prognostically important but also critical for optimizing surgical decision-making and reducing healthcare costs.

This study has limitations. Its retrospective design and relatively small sample size may limit statistical power, particularly for subgroup analyses of specific interventions. Nevertheless, given the rarity of mediastinitis in this context, our data offer valuable insight into management and emphasize the importance of early recognition. Future multicenter prospective studies are warranted to validate these findings and to establish standardized protocols for the diagnosis and management of mediastinitis following upper GI surgery.

Although the mortality difference between the two groups did not reach statistical significance, the late-onset cohort demonstrated an almost 50% mortality rate compared with only 17.6% in the early-onset group. This notable disparity underscores the clinical significance of timely recognition, even in the absence of statistical confirmation. Our findings suggest that delayed diagnosis may carry a markedly higher risk of death, which is consistent with prior reports emphasizing the adverse prognostic impact of delayed intervention in mediastinal and esophageal infections.

CONCLUSION

Early-onset mediastinitis after upper GI surgery is associated with improved outcomes. It reduces ICU and hospital stay, shortens antibiotic treatment, decreases mortality, and minimizes the need for advanced surgical procedures. In contrast, late-onset mediastinitis is linked to higher culture positivity, greater surgical complexity, and poorer outcomes.

Our findings emphasize the importance of recognizing the timing of onset in this rare but severe condition. Establishing standardized protocols and adopting a proactive approach may further improve prognosis. Future multicenter studies with larger cohorts are warranted to validate these results and guide evidence-based management strategies.

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ORİJİNAL ÇALIŞMA - *ÖZ*

Üst gastrointestinal cerrahiler sonrası mediastinitte erken ve geç tanının klinik sonuçlara etkisi

AMAÇ: Üst gastrointestinal (GIS) cerrahiler sonrası gelişen mediastinit nadir ancak yaşamı tehdit eden bir komplikasyondur. Perioperatif takipteki gelişmelere rağmen tanı zamanlamasının prognoz üzerindeki etkisi net değildir. Erken gelişen ve geç dönem gelişen mediastinitin klinik, mikrobiyolojik ve cerrahi sonuçlar üzerindeki etkisinin ortaya konması, yönetim stratejileri için kritik öneme sahiptir.

GEREÇ VE YÖNTEM: 2015–2025 yılları arasında merkezimizde üst gis cerrahisi sonrası mediastinit tanısı alan 27 hasta retrospektif olarak incelendi. Hastalar, cerrahi sonrası mediastinit gelişim zamanına göre erken (≤14 gün) ve geç dönem (>14 gün) gruplara ayrıldı. Demografik veriler, ek hastalıklar, sigara öyküsü, malignite varlığı, tanı zamanı, kültür sonuçları, cerrahi girişimler, yoğun bakım ihtiyacı, yoğun bakım kalış süresi, hastanede yatış süresi, antibiyoterapi süresi, komplikasyonlar ve mortalite oranları karşılaştırıldı.

BULGULAR: Median yaş 64 [IQR 54–74.5] olup, hastaların %55.6'sı erkekti. Olguların %70.4'ünde malignite mevcuttu, en sık mide adenokarsinomu (n=6) izlendi. Yoğun bakım ünitesi (YBÜ) ihtiyacı %81.5 olup median kalış süresi 2 gündü; mortalite 8 hastada (%29.6) görüldü. Kültür pozitifliği 16 hastada (%59.3) idi; en sık Klebsiella pneumoniae, Proteus mirabilis ve Enterobacter spp. izole edildi. Erken gelişen mediastinit grubunda YBÜ kalış süresi (median 1 ve 6.5 gün, p=0.020), hastanede yatış süresi (16 ve 41 gün, p=0.003) ve antibiyoterapi süresi (14 ve 35 gün, p=0.002) istatistiksel olarak anlamlı şekilde daha kısaydı. Erken gelişen grupta mortalite oranı, geç dönem gelişen gruba kıyasla daha düşük saptandı (%17.6 ve %50, p=0.102). Geç dönemde gelişen grupta kültür pozitifliği daha yüksekti. Bu grupta kompleks cerrahi girişimler video yardımlı torakoskopik cerrahi (VATS), torakotomi, endoskopik stent daha fazla uygulandı. Toplam 13 hastada (%48.1) reoperasyon gerekti. Reoperasyonlar batın ve toraks cerrahisi girişimleri olarak sınıflandırıldığında, batın cerrahisi reoperasyonları daha çok geç dönem gelişen grupta (5/8, %62.5), toraks cerrahisi reoperasyonları ise erken gelişen grupta (4/5, %80) gözlendi. Reoperasyon uygulanmayan hastalar kohortun %51.9'unu oluşturdu (14/27).

SONUÇ: Üst GIS cerrahisi sonrası gelişen mediastinitte erken tanı prognozu belirgin olarak iyileştirmektedir. Erken tanı; mortaliteyi, yoğun bakım ve hastane kalış süresini, antibiyotik tedavi süresini ve kompleks cerrahi ihtiyacını azaltmaktadır. Geç tanı ise yüksek mikrobiyal yük, sık reoperasyon ve olumsuz klinik sonuçlarla ilişkilidir.

Anahtar sözcükler: Cerrahi tedavi; erken tanı; mediastinit; postoperatif komplikasyonlar; üst GIS cerrahisi.

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ORIGINAL ARTICLE

A new score for predicting incidental appendiceal neoplasms in patients aged ≥40 years with acute appendicitis: a multicenter retrospective cohort study

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ABSTRACT

BACKGROUND: This multicenter retrospective cohort study aimed to develop a novel five-parameter scoring model to predict incidental appendiceal neoplasia in patients aged ≥40 years diagnosed with acute appendicitis. Previous literature has reported a significant increase in the risk of neoplasia, particularly after age 40, and this cut-off value was used as the basis for our study design.

METHODS: A multicenter retrospective cohort analysis was conducted across six tertiary hospitals between January 2019 and December 2024. Adult patients aged ≥40 years who underwent appendectomy with preoperative contrast-enhanced computed tomography (CT) and had available laboratory data were included. Predictive variables were identified using multivariate logistic regression. The scoring system incorporated age, female sex, appendix diameter, absence of CT wall enhancement, and low neutrophil count. Diagnostic performance was assessed via receiver operating characteristic (ROC) analysis.

RESULTS: Of 2,143 patients analyzed, 122 (5.7%) had incidental neoplasia. The scoring system yielded an area under the ROC curve of 0.641 (95% confidence interval: 0.594–0.690). Using a cutoff score ≥3, sensitivity was 56.6%, specificity 65.4%, positive predictive value 9%, and negative predictive value 96.1%. Patients with a maximum score of 5 had a 33.3% incidence of neoplasia.

CONCLUSION: This five-parameter scoring system demonstrates a high negative predictive value and may help identify low-risk patients in whom standard appendectomy can be safely performed. This model, which allows low-risk patients to be safely excluded thanks to its high negative predictive value, provides an innovative contribution to clinical decision-support systems.

Keywords: Appendiceal neoplasms; acute appendicitis; risk stratification; computed tomography; neutrophil.

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INTRODUCTION

Acute appendicitis, defined as inflammation of the vermiform appendix, is a prevalent surgical emergency worldwide, with a lifetime risk of approximately 8.6% in men and 6.7% in women.[1] The global incidence of the condition ranges from 86 to 160 cases per 100,000 population per year, depending on the region.[2] Although benign pathologies are typically observed in this common surgical procedure, clinically significant incidental appendiceal neoplasms may be found in the tissue removed during appendectomy. The reported incidence of incidental neoplasia ranges from 0.2% to 2.5% across various case studies.[3,4] Recent studies suggest that the incidence is higher in older populations, highlighting the need for improved preoperative risk stratification. The most prevalent histologic types are neuroendocrine tumors (NETs) and low-grade mucinous neoplasms.[4] These lesions are typically clinically silent preoperatively and often difficult to identify radiologically.[5] The presence of unidentified incidental tumors may adversely affect prognosis due to inadequate resection and incomplete staging. Recent studies have shown that right hemicolectomy may offer a survival advantage over appendectomy, particularly for T2–T3 stage appendiceal tumors.[6] Additionally, the National Comprehensive Cancer Network (NCCN) guidelines recommend right hemicolectomy with at least 12 lymph node dissections for adenocarcinoma and goblet cell types.[7] These findings underscore the importance of stage-specific surgical planning for incidental tumors.

The development of several predictors has been identified as a means to enhance preoperative diagnostic accuracy. Increased appendix diameter, thickening of the appendiceal wall, and calcification of the appendix on computed tomography (CT) may raise suspicion of neoplasia.[5] Clinical parameters, including advanced age and lower white blood cell counts, have also been associated with increased risk.[8] In the study by Er et al.,[9] three parameters were identified as predictive factors: appendiceal diameter above 11.5 mm, absence of wall contrast, and low neutrophil count. However, due to the use of propensity score matching, factors such as age and gender were not incorporated into the study design. Notably, multiple studies have reported a clear increase in the risk of neoplasia after the age of 40, suggesting that both age and gender may have an important influence on predictive modeling.[10]

This multicenter retrospective cohort study was conducted to address this gap. The primary aim was to develop and validate a novel five-parameter scoring system that integrates age, gender, appendix diameter on CT, absence of wall contrast enhancement, and neutrophil count to improve preoperative prediction of incidental appendiceal neoplasms in patients aged ≥40 years. We hypothesized that incorporating demographic parameters with clinical and radiologic findings would enhance predictive performance compared to existing models. Given the prognostic implications of undiagnosed neoplasms, an effective risk stratification tool could better guide surgical planning and postoperative management. This scoring system may be useful in the clinical decision-making process during the preoperative period for risk classification and surgical planning. It may also be valuable intraoperatively for determining the surgical approach in high-risk patients based on frozen section evaluation, and postoperatively for monitoring pathological results and prioritizing colonoscopy and oncologic follow-up. This system was developed as a complementary tool to existing appendicitis diagnostic scoring systems, not as an independent diagnostic method intended to replace them.

MATERIALS AND METHODS

Study Design and Population

This was a multicenter retrospective cohort study involving six tertiary healthcare institutions. Patients who underwent appendectomy with a preliminary diagnosis of acute appendicitis between January 2019 and December 2024 were retrospectively screened using electronic patient record systems. All participating centers followed a standardized protocol for data extraction and analysis.

Study Population and Rationale

At the onset of the study, a total of 8,110 patients aged ≥18 years underwent retrospective evaluation. The final analysis included 6,130 patients who met the predetermined inclusion and exclusion criteria. Preliminary evaluation of the entire population showed that age was the strongest predictor of neoplasia. The area under the curve (AUC) obtained for age in the receiver operating characteristic (ROC) analysis was 0.732 (95% confidence interval [CI]: 0.691-0.773). The cut-off value of 40 years yielded a sensitivity of 68.5% and a specificity of 70.2%. Additionally, the literature has shown that the risk of appendiceal neoplasia varies significantly after the age of 40.[11-13] Based on these findings, further analysis was limited to a subgroup of patients aged over 40 years to increase clinical relevance. The study flow diagram is presented in Figure 1, summarizing patient selection, exclusions, and final cohort composition.

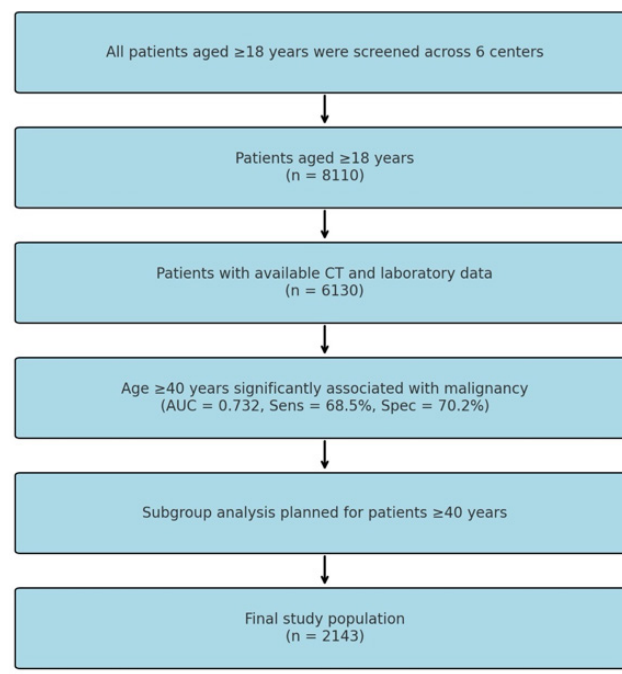

Figure 1. Patient selection flow diagram.

Table 1. Distribution of patients according to histopathologic diagnoses

Histopathologic Diagnosis	Benign/ Neoplasia	N (%)
Acute appendicitis	Benign	1406 (65.6%)
Phlegmonous appendicitis	Benign	268 (12.5%)
Gangrenous appendicitis	Benign	104 (4.9%)
Perforated appendicitis	Benign	149 (7.0%)
Plastron appendicitis	Benign	6 (0.3%)
Lymphoid hyperplasia	Benign	69 (3.2%)
Diverticula	Benign	8 (0.4%)
Endometriosis	Benign	1 (0.05%)
No significant findings	Benign	10 (0.5%)
Fibrous obliteration	Neoplasia	32 (1.5%)
Sessile serrated lesions	Neoplasia	21 (1.0%)
Gastrointestinal stromal tumor	Neoplasia	1 (0.05%)
Mucocele	Neoplasia	1 (0.05%)
Mucinous cystadenoma	Neoplasia	1 (0.05%)
Tubular/villous adenoma	Neoplasia	1 (0.05%)
Mucinous neoplasia	Neoplasia	46 (2.1%)
Neuroendocrine tumor (NET)	Neoplasia	11 (0.5%)
Adenocarcinoma	Neoplasia	7 (0.3%)

This study was retrospective in design, and no power analysis was performed beforehand to determine sample size. All cases meeting the specified criteria were included in the analysis.

Ethics Approval

This study was approved by the institutional review boards of all participating centers (Approval No: TABED-2-25-1329). Informed consent was waived due to the retrospective design. The study was conducted in accordance with the principles of the Declaration of Helsinki.

Inclusion and Exclusion Criteria

The inclusion criteria were as follows: patients aged 40 years or older who underwent appendectomy for acute appendicitis, received preoperative contrast-enhanced abdominal computed tomography (CT), had preoperative neutrophil levels recorded in the laboratory system, and had histopathologic examination results available.

The exclusion criteria were:pregnant women; patients with a known history of malignancy; those who underwent incidental appendectomy during other abdominal surgery (e.g., gynecologic procedures); and patients with incomplete or inconsistent data records.

Data Collected and Variables

Data were obtained from the hospital's automated systems and patient files. The following variables were recorded at all centers using a standardized data collection form:

- Age (years),

- Gender (female, male),

- Diameter of the appendix (mm; widest transverse measurement on CT),

- Wall contrast uptake on CT (present, absent) (the absence of wall contrast was defined as a lack of mural contrast retention compared to the adjacent bowel wall. Due to the multicenter design, minor differences existed in CT scanning protocols and pathology reporting criteria; this was noted as a study limitation),

- Preoperative neutrophil count (10^9/L),

- Histopathologic diagnosis (binary coding as neoplasia/benign).

Histopathologic diagnoses were classified into benign and neoplasia categories based on established oncologic criteria (Table 1). Cases with missing critical variables were excluded from the analysis.

Scoring System

A scoring system was proposed based on age, female gender, appendix diameter, absence of wall contrast enhancement on tomography, and low neutrophil count (Table 2). The total score ranged from 0 to 5.

Table 2. Scoring system

Parameter	Points	Description
Over 50 years of age	1 point	ROC analysis: AUC=0.605 (95% CI=0.550-0.660), p<0.001). Cut off: 50 years (Sensitivity=59.8%, Specificity=53.0%)
Female gender	1 point	-
Neutrophils <6.78 ×10^9/L	1 point	Er et al. study[7]
Appendiceal diameter >11.5 mm	1 point	Er et al. study[7]
No enhancement of appendiceal wall	1 point	Er et al. study[7]

ROC: Receiver Operating Characteristic; AUC: Area Under the Curve; CI: Confidence Interval.

Statistical Analysis

Data were analyzed using IBM SPSS Statistics for Windows, Version 22.0 (IBM Corp., Armonk, NY, USA). Continuous variables were expressed as mean±standard deviation, and categorical variables were expressed as frequency and percentage.

The diagnostic performance of the scoring system was evaluated using ROC analysis. The AUC, 95% confidence interval, and p-value were calculated. In addition, diagnostic performance measures such as sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), positive likelihood Ratio (LR+), and negative likelihood ratio (LR-) were reported for different threshold values. Univariate and multivariate logistic regression analyses were conducted to identify independent predictors. Missing data were managed through case-wise deletion. Statistical significance was set at $p<0.05$.

RESULTS

After applying the inclusion and exclusion criteria, a total of 2,143 patients aged 40 years and older were included in the final analysis. The cohort consisted of 952 female patients (44.4%) and 1,191 male patients (55.6%), with a mean age of 52.64±10.70 years. All patients underwent appendectomy for suspected acute appendicitis, and histopathologic examination was performed for every specimen collected.

Histopathologic evaluation revealed incidental appendiceal neoplasia in 122 patients (5.7%), with the detailed distribution of diagnoses presented in Table 1. Comparative analysis demonstrated a statistically significant difference in age between patients with neoplasia and those with benign findings (57.29±13.17 years vs. 52.36±10.47 years, $p<0.001$). The proportion of female patients was significantly higher in the neoplasia group compared to the benign group (7.1% vs. 4.5%; $p=0.010$). Neutrophil counts were significantly lower among patients diagnosed with neoplasia ($8.27\pm3.72\times10^9$/L vs. $10.01\pm4.03\times10^9$/L, $p<0.001$). Furthermore, the mean appendix diameter was larger in patients with neoplasia (12.19±6.76 mm versus 10.48±2.75 mm, $p<0.001$). The absence of contrast enhancement on computed tomography was also observed more frequently in the neoplasia group ($p=0.009$). Detailed characteristics and comparative data of the study population are provided in Table 3.

Univariate and multivariate logistic regression analyses identified age, neutrophil count, appendix diameter, and absence of contrast enhancement as independent predictors of neopla-

Table 3. Patients' data

	Benign	Neoplasia	P-value
Age, mean±SD	52.36±10.47	57.29±13.17	<0.001
Gender			
Female	884 (92.9%)	68 (7.1%)	0.010
Male	1137 (95.5%)	54 (4.5%)	
Neutrophil value, 10^9/L, mean±SD	10.01±4.03	8.27±3.72	<0.001
Appendicitis diameter, mm, mean±SD	10.48±2.75	12.19±6.76	<0.001
Enhancement of appendiceal wall			
Absent	1569 (93.6%)	107 (6.4%)	0.009
Present	452 (96.8%)	15 (5.7%)	

Table 4. Univariate and multivariate regression analysis

	Univariate Analysis			Multivariate Analysis		
	β -coefficient	OR (95%CI)	P value	β -coefficient	OR (95%CI)	P value
Age	0.038	1.038 (1.023-1.649)	<0.001	0.30	1.030 (1.014-1.047)	<0.001
Female	0.482	1.620 (1.121-2.340)	0.010	0.367	1.444 (0.988-2.110)	0.058
Neutrophil value	-0.122	0.885 (0.840-0.932)	<0.001	-0.121	0.896 (0.840-0.935)	<0.001
Appendix diameter	0.115	1.122 (1.072-1.175)	<0.001	0.115	1.122 (1.068-1.178)	<0.001
No enhancement of appendiceal wall	0.720	2.055 (1.185-3.563)	0.010	0.724	2.062 (1.170-3.624)	0.012

OR: Odds Ratio; CI: Confidence Interval.

Table 5. Effectiveness of scoring in the patient group

Risk Group	Points	Benign	Neoplasia	p-value	Benign	Neoplasia	p-value
Low risk	0 points	148 (100%)	0				
	1 point	429 (96.2%)	17 (3.8%)		1321 (96.1%)	53 (3.9%)	
	2 points	744 (95.4%)	36 (4.6%)				
Moderate risk	3 points	525 (91.9%)	46 (8.1%)	<0.001	688 (91.6%)	63 (8.4%)	<0.001
	4 points	163 (90.6%)	17 (9.4%)				
High risk	5 points	12 (66.7%)	6 (33.3%)		12 (66.7%)	6 (33.3%)	

Table 6. Confusion matrix for cut-off ≥3

	Actual Neoplasia (+)	Actual Neoplasia (–)
Score ≥3 (Test +)	69 (TP)	699 (FP)
Score <3 (Test –)	53 (FN)	1322 (TN)

TP (True Positive): Patients with neoplasia correctly identified by the score (≥3). FP (False Positive): Patients without neoplasia incorrectly identified as high-risk (≥3). FN (False Negative): Patients with neoplasia incorrectly classified as low-risk (<3). TN (True Negative): Patients without neoplasia correctly identified as low-risk (<3).

sia. Female gender showed borderline statistical significance in the multivariate analysis (odds ratio: 1.44; p=0.058). The β coefficients, odds ratios, confidence intervals, and p-values are summarized in Table 4.

The diagnostic performance of the five-parameter scoring system was assessed using receiver operating characteristic analysis. The area under the curve was 0.641 (95% confidence interval: 0.594–0.690; p<0.01). When a threshold score of three or higher was used to predict neoplasia, the sensitivity was 56.6% and the specificity was 65.4%. The positive predictive value was 9%, and the negative predictive value was 96.1%. The positive likelihood ratio was 1.63, and the negative likelihood ratio was 0.66. Notably, patients who achieved the maximum score of 5 had the highest observed incidence of neoplasia, reaching 33.3%. The distribution of neoplasia rates according to scoring categories is shown in Table 5.

In addition to sensitivity, specificity, PPV, and NPV, a confusion matrix was constructed for the primary threshold (≥3 points) to provide a clearer representation of diagnostic accuracy. The distribution of true positives, false positives, true negatives, and false negatives is shown in Table 6. This matrix highlights the relatively high negative predictive value of the score, with most patients classified as low risk (<3 points) correctly identified as benign.

DISCUSSION

This multicenter retrospective cohort study presented a new five-parameter score, comprising age, sex, appendix diameter on CT, absence of wall contrast enhancement, and neutrophil count, to predict incidental appendiceal neoplasms in patients aged ≥40 years with acute appendicitis. The model's discriminatory power (AUC≈0.64), and particularly its high negative predictive value (≈95–96%), allowed for confident discrimination among low-risk patients. The incidence was significantly higher in the high-risk group (≈33% at the highest score level of 5 points). This indicates that the proposed model may serve as a reliable adjunct to stratify patients into low- and high-risk groups, supporting integrated risk assessment with imaging and pathology rather than clinical decision-making based on the score alone.

Each parameter in the model was assigned one point. This decision was made because weighting based on statistical coefficients would only slightly increase the area under the curve but would complicate clinical application. Equal scoring provides an approach that is simple for clinicians to use in daily practice. Therefore, our model aims to balance performance and applicability.

The key strength of this study is its reliance on a multicenter, large patient series. This allowed the development of a new scoring model that integrates both clinical and radiological parameters, focusing on patients aged ≥40 years. While previous scores have primarily focused on identifying the inflammatory process, our study is one of the first large-scale attempts to predict the risk of incidental neoplasia. Furthermore, the inclusion of the parameter absence of wall enhancement represents an innovative contribution to the literature. Clinically, this scoring system may provide additional decision support in patients aged ≥40 years undergoing appendectomy, par-

ticularly by informing the extent of resection and the need for thorough histopathological follow-up.

In the literature, large series have demonstrated that advanced age and increased appendix diameter are associated with malignancy. In particular, the combination of age over 40 and an appendix diameter greater than 10 mm on CT has been shown to increase the risk of malignancy more than threefold.[11] Similarly, large databases have reported that the likelihood of appendiceal adenocarcinoma increases with age, with most adenocarcinomas occurring around age 40.[14] In our series, the risk of malignancy was also found to increase in individuals over 40 years (AUC=0.732). This supports the view that predicting malignancy risk is clinically important, especially in this age group.

Various clinical scoring systems have long been used in the diagnosis of acute appendicitis. The Alvarado score was the first system based on symptoms, physical examination findings, and laboratory values, and is still widely used.[15] The Appendicitis Inflammatory Response (AIR) score and the Adult Appendicitis Score (AAS), developed subsequently, aimed to improve diagnostic accuracy and reduce negative appendectomy rates.[16,17] The World Society of Emergency Surgery (WSES) 2020 guideline also stated that AIR and AAS are the clinical scores with the highest discriminatory power in adults.[18] However, all of these scores are designed solely to distinguish inflammatory processes and lack the ability to predict incidental appendiceal neoplasms. Our proposed score differs by specifically addressing neoplasia prediction rather than inflammation, thereby complementing existing clinical tools. While AIR and AAS have demonstrated high diagnostic accuracy in differentiating uncomplicated from complicated appendicitis,[16] none of these systems include oncologic endpoints. Thus, our score should be considered complementary, providing oncologic risk stratification that existing clinical scores do not address.

Attempts to develop a scoring system to predict appendiceal neoplasia are quite limited in the literature. Although contrast enhancement of the appendiceal wall has been demonstrated as a valuable diagnostic feature in acute appendicitis—with sensitivity around 75% and specificity around 85% on contrast-enhanced CT[19]—this parameter has not previously been applied to neoplasia prediction. To our knowledge, Er et al.[9] were the first to report the absence of wall enhancement as a factor associated with incidental neoplasia. This study builds on that evidence and makes an innovative contribution by incorporating the absence of wall enhancement into a validated neoplasia risk score for the first time in the literature.

In this study, the analysis population was limited to patients aged 40 years and older, who are considered to have a significantly increased risk of incidental appendiceal neoplasia in the literature.[11-13] However, subgroup ROC analysis demonstrated that age 50 represents an additional risk threshold (AUC=0.605); therefore, age 50 was included in the scoring system as ≥1 point. Thus, the model not only targeted the population aged ≥40 years but also reflected the gradual increase in risk within this group. This suggests that age may act as a stepwise rather than linear risk factor, enabling more refined risk stratification in clinical practice.

To enhance the clinical applicability of our model, we determined how to interpret the proposed score across different patient subgroups. Patients scoring 0-2 points (low risk) have a very low probability of incidental neoplasia (NPV >95%), and standard appendectomy with routine follow-up appears sufficient for these patients. Patients scoring 3-4 points (intermediate risk) may be considered for intraoperative frozen section, if technically feasible, and should be prioritized for postoperative colonoscopy and closer oncological follow-up. In contrast, patients scoring 5 points (high risk) demonstrate a neoplasia probability of approximately one-third, and intraoperative frozen section or even extended resection (e.g., right hemicolectomy), along with close oncological surveillance, may be necessary for these patients.

However, this study has some limitations. The retrospective design increases the risk of selection bias, and potential differences in CT protocols between centers may have led to standardization issues, particularly regarding wall enhancement assessment. Nonetheless, it should be noted that this study was conducted at tertiary centers, with imaging evaluated by experienced radiologists. Furthermore, the model's discriminatory power was found to be moderate (AUC≈0.64); therefore, it should be interpreted as an adjunct tool rather than a standalone clinical decision-maker. Another limitation is the lack of prospective validation, which will be essential to confirm reproducibility across different healthcare settings and geographic regions. Another limitation of the study was that IT protocols and pathology assessments were not fully standardized between centers. However, common definitions were used to reduce inter-observer variability.

In summary, this novel five-parameter score represents an innovative step toward predicting incidental appendiceal neoplasia in patients aged ≥40 years with acute appendicitis. By combining age, sex, CT findings, and laboratory parameters, it may guide clinicians in tailoring surgical strategies, optimizing pathology evaluation, and avoiding unnecessary interventions in low-risk patients. Future studies should prospectively validate this model and assess its integration with molecular biomarkers and artificial intelligence (AI)-assisted imaging to further enhance risk prediction.

CONCLUSION

This multicenter retrospective cohort study introduced a novel five-parameter score—including age, sex, appendix diameter, absence of wall contrast enhancement, and neutrophil count—to predict incidental appendiceal neoplasms in patients aged ≥40 years with acute appendicitis. The model showed moderate discriminatory power (AUC≈0.64) but a

high negative predictive value (≈95–96%), supporting its use as an adjunct for risk stratification.

Unlike traditional appendicitis scores, this tool specifically targets neoplasia prediction and may guide surgical decision-making by identifying high- and low-risk patients. Prospective validation and integration with molecular or AI-based methods are needed to enhance predictive performance.

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ORİJİNAL ÇALIŞMA - *ÖZ*

40 yaş ve üzeri akut apandisitli hastalarda insidental saptanan apendiks neoplazmlarını tahmin etmek için yeni bir skorlama: Çok merkezli retrospektif kohort çalışması

AMAÇ: Bu çok merkezli retrospektif kohort çalışmanın amacı, akut apandisit tanısı almış ve ≥40 yaş hastalarda rastlantısal apendiks neoplazisini öngörmek için yeni 5 parametreli bir skorlama modeli geliştirmekti. Literatürde, özellikle 40 yaşından sonra neoplazi riskinde önemli bir artış bildirilmiş olup, bu sınır değer çalışma tasarımımız için temel alınmıştır.
GEREÇ VE YÖNTEM: Ocak 2019 ile Aralık 2024 tarihleri arasında altı üçüncü basamak hastanede çok merkezli retrospektif kohort analizi gerçekleştirildi. Ameliyat öncesi kontrastlı bilgisayarlı tomografi (BT) ve mevcut laboratuvar verileriyle apendektomi geçiren ≥40 yaş yetişkin hastalar çalışmaya dahil edildi. Tahmini değişkenler, çok değişkenli lojistik regresyon kullanılarak belirlendi. Puanlama sistemi yaş, kadın cinsiyeti, apendiks çapı, BT duvar kontrastlanmasının olmaması ve düşük nötrofil sayısını içeriyordu. Tanı performansı, alıcı işletim karakteristiği (ROC) analizi ile değerlendirildi.
BULGULAR: Analiz edilen 2.143 hastanın 122'sinde (%5.7) rastlantısal neoplazi saptandı. Puanlama sistemi, ROC eğrisi altında 0.641'lik bir alan (95% CI, 0.594-0.690) gösterdi. ≥3 kesme puanı kullanıldığında duyarlılık %56.6, özgüllük %65.4, pozitif öngörü değeri %9 ve negatif öngörü değeri %96.1 olarak bulundu. Maksimum puanı 5 olan hastalarda neoplazi görülme sıklığı %33.3 idi.
SONUÇ: Bu puanlama sistemi yüksek negatif öngörü değeri göstermekte olup, standart apendektominin güvenle yapılabileceği düşük riskli hastaların belirlenmesine yardımcı olabilir. Yüksek negatif öngörü değeri sayesinde düşük riskli hastaların güvenli bir şekilde dışlanmasına olanak tanıyan bu model, klinik karar destek sistemlerine yenilikçi bir katkı sağlamaktadır.

Anahtar sözcükler: Apendiks neoplazmları; akut apandisit; risk sınıflandırması; bilgisayarlı tomografi; nötrofil.

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ORIGINAL ARTICLE

Comparison of autologous and custom-made titanium cranioplasty following decompressive craniectomy for traumatic brain injury: A 7-year clinical experience

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ABSTRACT

BACKGROUND: Traumatic brain injury (TBI) is one of the common reasons for decompressive craniectomy (DC). The management of DC must include cranioplasty procedures. Although both procedures may cause several complications, postoperative outcomes are of greater concern for patients. The timing of cranioplasty (CP) and the type of CP material are the main parameters evaluated retrospectively in this report in terms of their impact on postoperative complications and cosmetic results.

METHODS: A total of 47 patients who underwent autologous cranioplasty (n=22) or custom-made titanium cranioplasty (n=25) due to TBI between January 2017 and January 2024 in our department were retrospectively analyzed. The groups were compared in terms of demographic characteristics, complication rates, and operative parameters. Cosmetic results and one-year mortality rates were also reported. The Odom criteria were used for the assessment of cosmetic results.

RESULTS: Baseline characteristics and overall complication rates did not differ significantly between the groups. Blood loss was significantly lower in titanium cranioplasty compared to autologous cranioplasty (126.2±47.9 ml vs. 215.5±35.6 ml, p<0.001). The highest complication rate was observed in cranioplasties performed 3–6 months after DC. In the early period (<3 months), autologous grafts were associated with significantly more complications than titanium (5/7 vs. 0/7, p=0.021). Cosmetic outcomes were significantly better with titanium, while timing had no effect on cosmetic results. One-year mortality rates were similar between the groups.

CONCLUSION: The timing of cranioplasty and the type of cranioplasty material may influence postoperative outcomes in patients with TBI. Titanium plates could be a preferable option for early cranioplasty if autologous bone cannot be used for reconstruction, whereas late cranioplasty appears to be associated with fewer complications overall. Further studies are needed to support these findings.

Keywords: 3D implant; titanium; cranioplasty; traumatic brain injury; decompressive craniectomy.

INTRODUCTION

Traumatic brain injury (TBI) refers to injury of the cerebral parenchyma and can result from several types of head trauma.[1] It is one of the major causes of morbidity and mortality worldwide.[2] TBI is most commonly associated with motor vehicle accidents and falls, but it can also occur in the context of large-scale disasters such as earthquakes or explosions during military operations. Other risk factors include mining accidents, construction site incidents, and infrastructure col-

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lapses.[3] Due to the risk of complications, decompressive craniectomy (DC) is often performed in emergency situations to reduce intracranial pressure (ICP) caused by TBI, making a cranioplasty procedure after DC necessary.[4-7] DC involves removal of the affected portion of the skull. If the removed portion of the skull is intact, it can be stored in the patient's anterior abdominal wall or frozen and preserved under sterile conditions at -80°C.[5,6,8] Otherwise, allogenic materials such as titanium can be used to reconstruct the calvarial defect. Custom-made titanium implants offer well-established biocompatibility, good cosmetic outcomes, and low infection rates.[9,10] Nevertheless, autologous bone grafts are the most commonly used option, with bone resorption being the most frequent complication, often leading to increased infection rates and the need for revision cranioplasty.[11]

In this study, we analyzed patients with TBI who underwent DC followed by cranioplasty. A retrospective evaluation was conducted to assess the impact of using autologous bone and titanium plates for cranioplasty on patient outcomes and complication rates.

MATERIALS AND METHODS

Patient Population

A total of 47 patients with TBI who were admitted to our department between January 2017 and January 2024 were included in this study. All patients were divided into two groups according to the type of cranioplasty material used: the autologous cranioplasty (AC) group (n=22) and the custom-made titanium cranioplasty (TC) group (n=25). The decision to perform DC was based on clinical and radiological criteria. Clinically, DC was considered in patients with refractory intracranial hypertension, unresponsive pupils, or rapid neurological deterioration. Radiologically, indications included significant midline shift (>5 mm), cerebral edema, space-occupying lesions, or signs of herniation. The decision was made by the attending neurosurgeon in the context of each patient's overall clinical status.

The decision to perform cranioplasty in the early (<3 months), intermediate (3–6 months), or late (>6 months) period was based on clinical stability, neurological recovery, absence of infection, soft tissue condition, and logistical factors such as implant availability and surgical prioritization. Patients with satisfactory wound healing and stable general condition were considered for early cranioplasty, whereas those requiring further recovery or delayed implant production were scheduled for later procedures.

Patients were included in the study if they met the following criteria:

1. Underwent DC due to TBI;

2. Subsequently underwent cranioplasty (with autologous bone or a titanium plate) at the same center;

3. Were ≥18 years of age.

Patients were excluded if they met any of the following criteria:

1. Had a history of craniectomy due to tumors, vascular malformations, infections, or congenital cranial defects;

2. Underwent bilateral DC;

3. Had missing or incomplete clinical or imaging data;

4. Underwent revision cranioplasty with only data available from the revision surgery.

Baseline characteristics such as sex, age, chronic diseases (hypertension, diabetes mellitus), presence of scalp deformity, and preoperative Glasgow Coma Scale (GCS) score; operative parameters such as operation time, blood loss, cranial defect area (CDA), DC region (DCR), use of a ventriculoperitoneal (VP) shunt, and the time interval between DC and cranioplasty; and postoperative outcomes such as length of hospital stay, presence of postoperative complications, and one-year mortality rate were recorded. The Odom criteria (excellent, good, fair, or poor) were used to evaluate postoperative cosmetic satisfaction.

All patients underwent cranial computed tomography (CT) at the time of admission and both before and after the cranioplasty procedures. The CDA were defined in a three-dimensional (3D) environment using CT images obtained before and after cranioplasty.

Surgical planning and the production of titanium plates were performed at the Medical Design and Production Center of our institution. CT data were transferred via the Digital Imaging and Communications in Medicine (DICOM) interface and processed using the Mimics Innovation Suite (Materialise, Belgium) to design the implant in a 3D environment. The titanium plate was produced using selective laser melting (M2 Wallet, Concept Laser, Germany) with medical-grade Ti6Al4V (grade 23 ELI). A patient-specific skull model was also created to assess the fit prior to sterilization and surgical use.

This study was approved by the Ethics Committee for Non-Interventional Scientific Research of Gülhane Training and Research Hospital (Date: 24.01.2024, No: 2024/23) and was conducted in accordance with the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines.[12] All patients or their families provided informed consent for cranial surgery. Consent for the use of patients' images was obtained directly from the patients. The study was conducted in accordance with the Declaration of Helsinki.

Cranioplasty Procedures

Autologous cranioplasty was performed for patients with preserved bone grafts, while custom-made TC was used for those without. Hemostasis was achieved at each stage of the procedure. A Hemovac drain was placed at an appropriate distance at the end of the operation, and the layers were closed anatomically. The operation was completed without complications.

Autologous Cranioplasty

The patient was placed in the supine position. The CDA and the autologous bone graft, which had been stored in the anterior abdominal wall, the lateral thigh region, or frozen and stored under sterile conditions during the previous surgery, were prepared. After skin disinfection, the surgical field was isolated with sterile covers. The skin and subcutaneous tissue were incised along the previous incision, taking the defect margins into account. The scalp was separated from the dura using a scalpel, dissector, and surgical scissors. The borders of the CDA and the intact bone were clearly identified. The autologous bone grafts were then carefully retrieved from the previous storage site through the skin and subcutaneous tissue. The dura was attached to the bone graft at specific points using silk suspension sutures. The bone graft was fixed to the intact bone tissue with mini plates and screws (Fig. 1).

Custom-Made Titanium Cranioplasty

The CDA, scalp deformities, and the 3D-printed sample model of the patient were photographed for documentation. The patient was placed in the supine position according to the defect location. After skin cleaning, the surgical field was isolated with sterile covers. The skin and subcutaneous tissue were incised along the previous incision, taking the defect margins into account. The scalp was separated from the dura using a scalpel, dissector, and surgical scissors. The borders of the CDA and intact bone structures were clearly identified. The compatibility of the titanium plate with the defect area was verified. The dura was attached to the titanium plate at specific points using silk suspension sutures. After confirming that the defect was successfully closed, the titanium plate was fixed to the intact bone tissue using the predesigned number and size of mini plates and screws (Fig. 2).

The patient presented in Figure 2 had sustained a traumatic brain injury during the earthquakes that occurred in southeastern Türkiye on February 6, 2023. A custom-made titanium cranioplasty was performed following decompressive craniectomy. According to the Odom criteria, the cosmetic result was classified as "excellent," and satisfactory functional recovery was also achieved.

Statistical Analysis

Data normality was assessed using the Shapiro-Wilk test. The chi-squared ($\chi 2$) test and Fisher's exact test were used to compare categorical variables, while the independent samples t-test and Mann-Whitney U test were used to compare continuous variables. For normally distributed continuous variables, descriptive statistics were presented as means±standard deviations (SD), whereas categorical variables were expressed as numbers and percentages. To evaluate the relationship between the timing of cranioplasty and the presence of complications, both general and stratified analyses were performed. Pairwise comparisons were conducted to assess the significance between time intervals. A p value of <0.05 was considered statistically significant. Data analyses were performed using IBM SPSS Statistics for Windows, Version 25.0 (IBM Corp., Armonk, NY, USA).

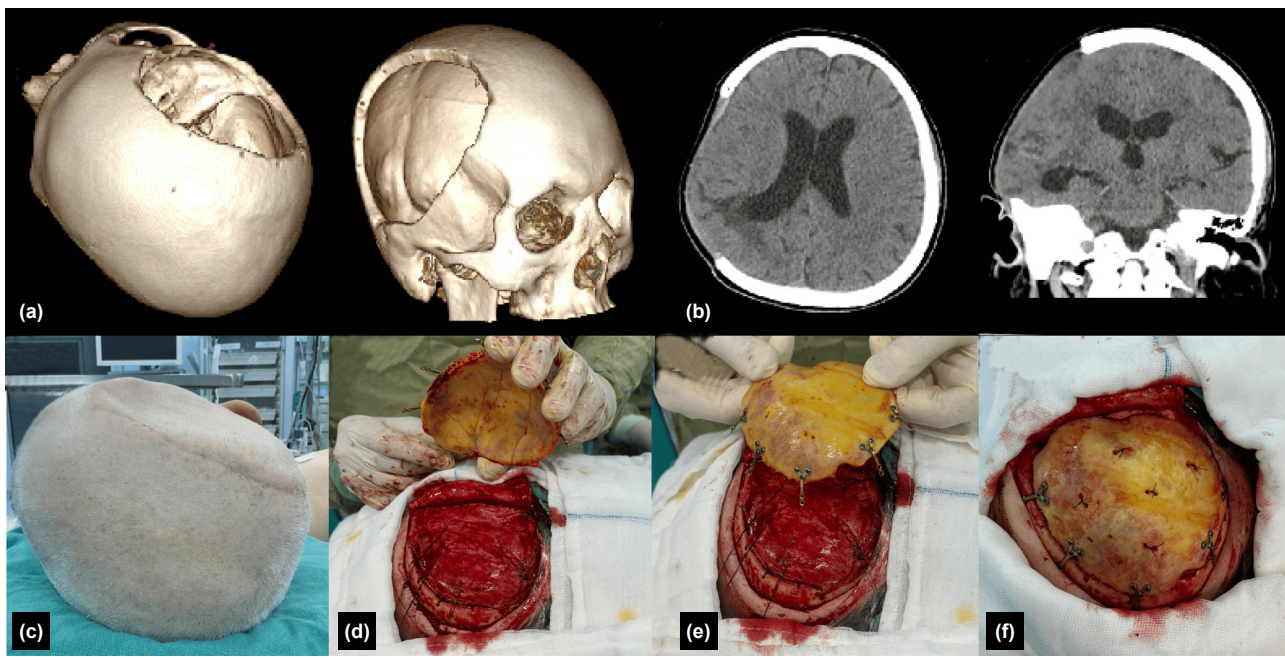

Figure 1. Autologous cranioplasty. **a)** 3D images of the patient's cranial defect area. **b)** Computed tomography (CT) images showing the craniectomy site before cranioplasty. **c)** Cranial defect area with previous incision scars. **d)** Autologous bone graft and defect area. **e)** Attachment of the dura to the bone graft using silk suspension sutures. **f)** Fixation of the bone graft with titanium plates and screws.

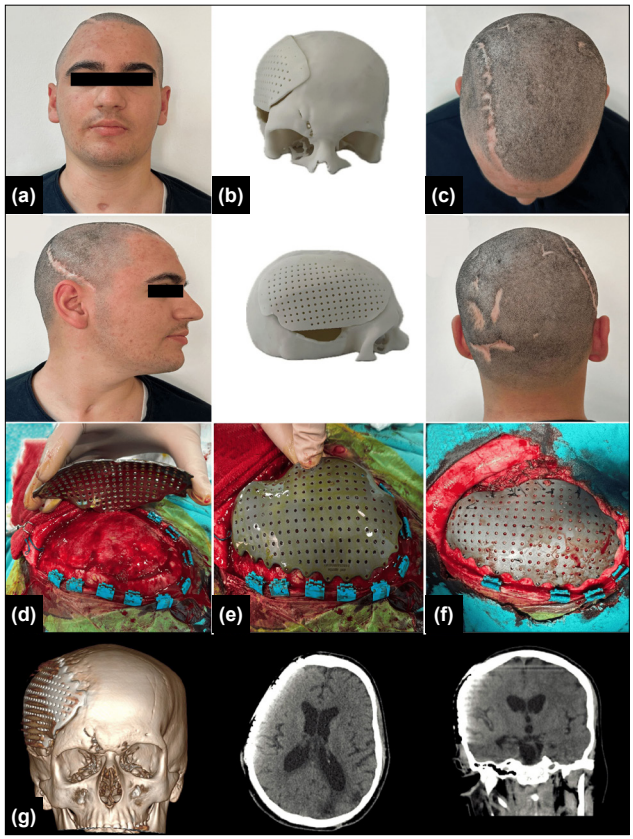

Figure 2. Titanium cranioplasty. **a)** Preoperative images of the patient from anterior and lateral views showing cranial deformity due to craniectomy. **b)** Sample kit produced using a 3D printer. **c)** Preoperative images of the patient from superior and posterior views showing previous incision scars and scalp deformities. **d)** Titanium plate and cranial defect area. **e)** Intraoperative demonstration of the fit between the implant and the defect area. **f)** Attachment of the dura to the implant using silk suspension sutures and fixation of the implant with predesigned plates and screws. **g)** Postoperative 3D and computed tomography (CT) images showing successful closure of the defect area.

RESULTS

Baseline Characteristics of Patients

A total of 47 patients with TBI resulting from various traumatic events were examined, with a median age of 45 years (range: 13-86), of whom 24 (51.1%) were female. Twenty-two (46.8%) patients underwent AC and 25 (53.2%) underwent TC. No significant differences were found between the groups in terms of age (49.8±22.5 vs. 46±23.5 years, p=0.55), sex (female: 50% vs. 52%, p=0.89), hypertension (54.5% vs. 32%, p=0.12), diabetes mellitus (31.8% vs. 24%, p=0.55), preoperative GCS score (13.8±2.4 vs. 13.7±2.4, p=0.84), or scalp deformity (50% vs. 53.2%, p=0.68) (Table 1).

Operative Parameters

There were no significant differences between the groups in terms of operation time (104.0±27.7 min. vs. 104±27.7 min., p=0.80), DCR (54.5% vs. 48%, p=0.65), CDA (46.4±13.1 vs. 49.5±12.4, p=0.41), use of VP shunt (4.6% vs. 8%, p=1.0), or length of hospital stay (7.3±2.4 days vs. 7.7±2.1 days, p=0.59). Blood loss was significantly greater in the AC group than in the TC group (215.5± 35.6 ml vs. 126.2 ±47.9 ml, p<0.001) (Table 2).

Complications and Mortality

Postoperative complications occurred in 19 patients (40.4%) overall, while resorption was observed only in the AC group (four patients, 18.2%). All affected patients subsequently underwent revision cranioplasty with 3D custom-made TC. Overall, two patients experienced dehiscence (one [4.5%] in the AC group and one [4%] in the TC group). No surgical intervention was required for the patient with AC who developed dehiscence, whereas skin revision was performed afterwards for the patient with TC. Surgical site infection occurred in three patients overall (two [9.1%] in the AC group and one [4%] in the TC group). Autologous grafts were removed from these patients, while the patient in the TC group did not require implant removal. Three patients developed postoperative hydrocephalus: one (4.5%) in the AC group and two (8%) in the TC group, and all of them underwent VP shunt surgery. Postoperative hemorrhage occurred in three patients (two [9.1%] in the AC group and one [4%] in the TC group). Two patients with AC had subdural hematomas, and the patient with TC had an intracerebral hematoma. None of the patients required surgical intervention for postoperative hematoma. Seizures occurred in four patients overall (two [9.1%] in the AC group and two [8%] in the TC group) and

Table 1. Baseline characteristics at admission

	All (n=47)	Autologous Cranioplasty (n=22)	Titanium Cranioplasty (n=25)	P-value
Age, years, mean±SD	47.8±22.8	49.8±22.5	46±23.5	0.55
Sex, women, n (%)	24 (51.1)	11 (50)	13 (52)	0.89
Hypertension, n (%)	20 (42.6)	12 (54.5)	8 (32)	0.12
Diabetes mellitus, n (%)	13 (27.7)	7 (31.8)	6 (24)	0.55
Scalp deformity, n (%)	25 (53.2)	11 (50)	14 (56)	0.68
Preoperative GCS, mean±SD	13.7±2.3	13.8±2.4	13.7±2.4	0.84

GCS: Glasgow Coma Scale; SD: Standard deviation.

Table 2. Operative parameters and postoperative outcomes

	All (n=47)	Autologous Cranioplasty (n=22)	Titanium Cranioplasty (n=25)	P-value
Operation time, min, mean±SD	103.1±27.0	104.0±27.7	104.0±27.7	0.80
Blood loss, ml, mean±SD	168.0±61.7	215.5±35.6	126.2±47.9	<0.001
CDA, cm2, mean±SD	48.1±12.7	46.4±13.1	49.5±12.4	0.41
DCR, right, n (%)	24 (51.1)	12 (54.5)	12 (48)	0.65
VP shunt, n (%)	3 (6.4)	1 (4.6)	2 (8)	1.0*
Time interval, n (%)				0.94
Early (<3 months)	14 (29.8)	7 (31.8)	7 (28)	
Intermediate (3-6 months)	17 (36.2)	8 (36.4)	9 (36)	
Late (>6 months)	16 (34)	7 (31.8)	9 (36)	
Length of hospital stay, days, mean±SD	7.5±2.2	7.3±2.4	7.7±2.1	0.59
Presence of postoperative complication, n (%)	19 (40.4)	12 (54.5)	7 (28)	0.06
Resorption	4 (8.5)	4 (18.2)	0	
Dehiscence	2 (4.3)	1 (4.5)	1 (4)	
Seizure	4 (8.5)	2 (9.1)	2 (8)	
Surgical site infection	3 (6.4)	2 (9.1)	1 (4)	
Postoperative hemorrhage	3 (6.4)	2 (9.1)	1 (4)	
Postoperative hydrocephalus	3 (6.4)	1 (4.5)	2 (8)	
One-year mortality, exitus, n (%)	5 (10.6)	3 (13.6)	2 (8)	0.65*

CDA: Cranial defect area; DCR: Decompressive craniectomy region; VP: Ventriculoperitoneal shunt; SD: Standard deviation. *Fisher's exact test.

Table 3. Comparison of postoperative complications according to time interval and cranioplasty material

Time Interval	Autologous Cranioplasty (Yes/No)	Titanium Cranioplasty (Yes/No)	P-value
Early (<3 months)	5/2	0/7	0.021
Intermediate (3-6 months)	6/2	5/4	0.620
Late (>6 months)	1/6	2/7	1.000

GCS: Glasgow Coma Scale; SD: Standard deviation.

represented the second most common complication. Time intervals (early: <3 months; intermediate: 3–6 months; and late: >6 months) were compared between the AC and TC groups. In the AC group, 31.8% of patients underwent early cranioplasty, 36.4% intermediate, and 31.8% late. Similarly, in the TC group, 28.0% underwent early cranioplasty, 36.0% intermediate, and 36.0% late. There was no statistically significant difference in the timing distribution between the two groups (p=0.94). Mortality was observed in 10.6% of patients overall (13.6% vs. 8%, p=0.65) (Table 2).

When the data were stratified by material and time interval (Table 3), complications were significantly more frequent in the AC group during the early period (<3 months) compared

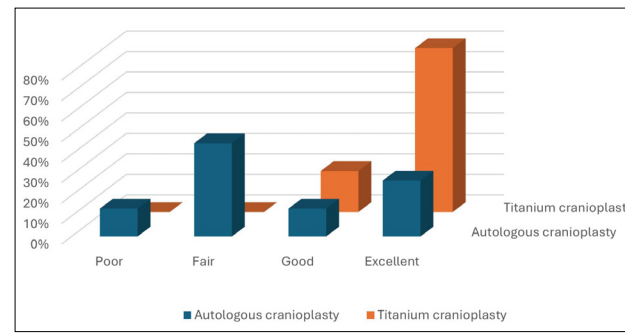

Figure 3. Comparison of cosmetic results between groups. Titanium cranioplasty provided significantly better cosmetic results than autologous cranioplasty.

Table 4. Comparison of postoperative complications according to time interval

Time Interval			
Presence of complication	**Early(<3 months) (n=14)**	**Intermediate (3–6 months) (n=17)**	**Late (>6 months) (n=16)**
No, n (%)	9 (64.3)	6 (35.3)	13 (81.2)
Yes, n (%)	5 (35.7)	11 (64.7)	3 (18.8)
		P-value	
Pairwise comparison	Early vs. Intermediate	0.21	
	Intermediate vs. Late	**0.02**	

Table 5. Comparison of cosmetic results and time interval between groups

	Autologous Cranioplasty	**Titanium Cranioplasty**	**P value**
Cosmetic result			
Poor, n (%)	3 (13.6)	0 (0)	<0.001
Fair, n (%)	10 (45.5)	0 (0)	
Good, n (%)	3 (13.6)	5 (20)	
Excellent, n (%)	6 (27.3)	20 (80)	
Time interval			
<3 months, n (%)	7 (31.8)	7 (28)	0.94
3-6 months, n (%)	8 (36.4)	9 (36)	
>6 months, n (%)	7 (31.8)	9 (36)	

to the TC group (5/7 vs. 0/7, p=0.021). No significant differences were observed in the intermediate (3–6 months) or late (>6 months) periods between the AC and TC groups (p=0.620 and p=1.000, respectively).

When analyzed independent of material (Table 4), complication rates varied significantly across time intervals. The intermediate period (3–6 months) had the highest complication rate (64.7%), followed by the early period (35.7%) and late period (18.8%). The difference between the intermediate and late periods was statistically significant (p=0.02), while the early vs. intermediate comparison did not reach significance (p=0.21).

Cosmetic Results

According to the Odom criteria, outcomes were rated as excellent in 26 patients (55.3%), good in eight (17%), fair in 10 (21.3%), and poor in three (6.4%) overall. A significant difference was observed in cosmetic outcomes according to the type of cranioplasty material (p<0.001), but not according to the time interval between DC and cranioplasty (p=0.94). Whether surgery was performed before 3 months, between 3-6 months, or after 6 months did not significantly affect cosmetic results (p=0.501). Patients who underwent TC had better cosmetic outcomes according to the Odom criteria, whereas those with AC more often had poor results (Table 5, Fig. 3).

DISCUSSION

Traumatic brain injury remains one of the most common causes of mortality and morbidity worldwide.[2] Although most TBIs are associated with motor vehicle accidents, falls, and assaults, large-scale disasters such as earthquakes may also cause TBI, particularly due to building collapses and entrapment under debris.[13,14] However, in clinical practice, the etiology of TBI does not significantly alter the surgical approach once DC is required. The increase in ICP resulting from TBI is a condition that needs to be alleviated by DC as a last-line of intervention.[7,15-17] Once the increased ICP has been relieved, cranioplasty procedures must be performed to restore skull integrity.[4-7,17] Cranioplasty following DC can help facilitate the hydrodynamics of cerebrospinal fluid (CSF) and cerebral blood flow (CBF), thereby improving neurological status.[4-8,17]

Both DC and cranioplasty procedures are inevitably associated with complications, which may depend on the time

interval between DC and cranioplasty.[4-8,17-23] Tomar et al.[8] reported postoperative complications in 7 of 31 patients (22.6%) who underwent AC. The overall complication rates were reported as 18.75% and 26.66% for early (<3 months) and late (>3 months) cranioplasty, respectively, with no statistically significant difference. Resorption occurred in only two patients, both in the late cranioplasty group. A systematic review revealed an increased risk of postoperative hydrocephalus following early cranioplasty (<3 months), although early intervention has been suggested to improve CSF hydrodynamics and clinical recovery.[5,24] Early cranioplasty is often considered for patients with neurological deterioration due to loss of skull integrity, such as in sinking skin flap syndrome (SSFS). This condition results from an imbalance of atmospheric pressure and impaired cerebrospinal fluid dynamics and is particularly associated with postural neurological deficits and cognitive slowing.[25,26] None of the patients in this study had this condition.

Schuss et al.[6] reported that among 243 patients who underwent AC after DC, early cranioplasty (<2 months) was associated with a significantly higher overall complication rate than late cranioplasty (>2 months) (25.9% vs. 14.2%). Fifty percent of the early cranioplasty patients in that study had TBI, which may explain the higher complication rate observed in the early period. According to a multicenter study,[4] early cranioplasty was associated with an increased risk of postoperative hydrocephalus and a significant risk of postoperative seizures, in contrast to the findings of Ozoner et al.,[27] who reported that late cranioplasty carries a risk of postoperative hydrocephalus in TBI patients (80% vs. 20%).

We conducted this study in patients with TBI, and postoperative complications were observed in 40.4% of cases (19 out of 47 patients). We did not find any significant differences in terms of complication rates between the AC and TC groups. While the overall complication rate was highest in the 3–6-month group, the late cranioplasty (>6 months) group had the lowest rate, regardless of the type of cranioplasty material. These findings indicate that late cranioplasty may be a safer option for patients with TBI. In contrast, some studies have reported that the optimal timeframe for cranioplasty following DC is 3-6 months.[6,23] Cerebral recovery after severe to mild TBI occurs most rapidly within this period.[28,29] Altering this timeframe may negatively affect postoperative recovery and increase the incidence of complications. In the current literature, rare but life-threatening events such as paradoxical herniation have also been reported, particularly in cases of late cranioplasty, where the skull defect fails to protect the brain from external pressure gradients.[30] Although we did not observe such cases in our series, this complication highlights the critical importance of individualized timing decisions based on radiological and clinical findings rather than rigid temporal protocols.

Subgroup analysis revealed that early cranioplasty using autologous bone was associated with significantly higher complication rates compared to titanium implants. Given this increased risk, TC appears to be a safer and more reliable option in early cranioplasty scenarios. Nevertheless, autologous bone grafts should still be considered the first-line material due to their biocompatibility and cost-effectiveness, particularly when the graft is well preserved and structurally intact. However, if the autologous bone is compromised-for example, due to improper preservation, fragmentation, infection, or substantial resorption-the use of custom-made titanium implants represents a highly viable and preferable alternative. This approach not only reduces complication rates but also offers enhanced structural integrity and superior cosmetic outcomes, particularly in patients with TBI, in whom tissue healing may be impaired due to skin breakdown and damage to the bone itself. DC has also been shown to impair wound healing in TBI patients, which may influence the choice of cranioplasty material.[6,31] Therefore, alternative cranioplasty materials such as titanium should be considered. Previous studies have reported surgical site infection rates of up to 10% in autologous cranioplasty and 4–8% in titanium-based cranioplasty, which is consistent with our findings.[10,11,32-34] Notably, the relatively small sample size of our study may limit the generalizability of these results.

Yeap et al.[34] reported that the most common etiologic factor for bone resorption is trauma. The cranioplasty procedure itself can lead to complications such as loss of skin quality, deterioration of the skin's blood supply, and reopening of the incision line due to scar tissue formation at the surgical site.[29,35,36] Consequently, with advancements in software technology and 3D printing, the use of 3D custom-made titanium implants has become increasingly feasible. First, a 3D template is designed based on the patient's CT images using specialized software and then produced with a 3D printer. The 3D template assists the surgeon in assessing the compatibility between the defect area and the titanium implant, helping to avoid unnecessary costs and additional intraoperative shaping of the implant. However, this process involves specific costs and requires expertise at each stage, from production to surgery, which can be considered a limitation in daily neurosurgical procedures.

Another problem encountered in cranioplasty surgeries is the reduction in the volume and quality of the skin covering the defect, which increases in direct proportion to the size of the CDA.[36] In this study, there was no significant difference in CDA between the AC and TC groups. Therefore, CDA was not a significant parameter influencing the postoperative complication rate in this study.

In a randomized controlled trial[11] comparing custom-made titanium and AC, the one-year mortality rates did not differ from our findings. When the follow-up period was extended to two years, it was reported that the use of titanium instead of autologous bone reduced the need for revision cranioplasty. The one-year mortality rate observed in our study was not statistically significant.

We used the Odom criteria to evaluate patients' cosmetic satisfaction. Compared with the AC group, the TC group demonstrated significantly better outcomes, whereas the AC group showed mostly poor results. For the reconstruction of skull defects, 3D custom-made titanium implants provide well-established cranial symmetry and optimal aesthetic outcomes.[9,10,35,37] The effectiveness of this approach has been demonstrated by its ability to produce favorable cosmetic results, reduce infection rates, and minimize the need for subsequent cranioplasty procedures. This may be because titanium inhibits the colonization of microorganisms, as it does not provide a nutrient medium for them compared with other materials and cannot form a biofilm layer due to its perforated structure.[10,11,22,34,35] Following TBI, increased cerebral vulnerability, resulting from ongoing edema, disrupted autoregulation, and impaired brain compliance—may reduce the safety of using autologous bone.[6,38] The restoration of cerebral and scalp functions may take time; therefore, custom-made titanium implants can be considered the most preferable alloplastic material. Moreover, we did not find any significant association between cosmetic outcomes and the time interval between DC and cranioplasty; however, the use of titanium as a cranioplasty material was associated with significantly better cosmetic results.

Limitations

This study has several limitations. First, we did not include other alloplastic materials used in cranioplasty for comparison. Second, the sample size of our study is relatively small compared with that of several other studies, which could lead to some complexity in determining statistical significance. Third, this is a retrospective, single-center study; therefore, patient selection bias, institutional preferences, and surgical experiences may limit the generalizability of the findings. Lastly, cosmetic outcomes were evaluated using the Odom criteria, which are inherently subjective and may vary depending on the evaluator's perspective.

CONCLUSION

Traumatic brain injury can result in unfavorable conditions affecting the patient's scalp and bone. To ensure optimal management following DC due to TBI, both the timing of cranioplasty and the choice of cranioplasty material play crucial roles. Based on the findings of this study, two main considerations can be proposed. First, while autologous bone grafts remain the first-line choice, custom-made titanium implants may serve as a reliable alternative in early cranioplasty when the graft is not well preserved or carries a high risk of resorption or fragmentation, owing to their lower complication rates and superior structural integrity. Second, regardless of the material used, late cranioplasty (≥6 months) appears to be associated with the lowest overall complication rates. Therefore, both timing and material selection should be carefully considered during surgical planning, with individualized decisions tailored to patient-specific factors. Further large-scale prospective studies are warranted to support these observations.

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ORİJİNAL ÇALIŞMA - *ÖZ*

Travmatik beyin hasarında dekompresif kraniyektomi sonrası otolog ve özel yapım titanyum kraniyoplastinin karşılaştırılması: 7 yıllık klinik deneyim

AMAÇ: Travmatik beyin hasarı (TBH), dekompresif kraniyektominin (DK) en sık uygulanma sebeplerinden biridir. Dekompresif kraniyektominin yönetimi kraniyoplasti prosedürlerini de içermelidir. Her iki prosedür de çeşitli komplikasyonlara sebep olabilse de, kozmetik sonuçlar gibi kraniyoplasti sonrası postoperatif sonuçlar, hastalar için önem arz etmektedir. Kraniyoplastinin zamanlaması ve kullanılan kraniyoplasti materyali, bu çalışmada kozmetik ve postoperatif sonuçlar adına retrospektif olarak değerlendirilen esas parametrelerdir.

GEREÇ VE YÖNTEM: Ocak 2017 ve Ocak 2024 tarihleri arasında, travmatik beyin hasarı dolayısıyla kliniğimizde otolog kraniyoplasti (n=22) ve özel yapım titanyum kraniyoplasti (n=25) operasyonları geçiren toplam 47 hasta retrospektif olarak analiz edildi. Hastalar demografik özellikleri, komplikasyon oranları ve operasyonel parametreler bazında karşılaştırıldı. Kozmetik sonuçlar ve 1 yıllık mortalite oranları da ayrıca rapor edildi. Kozmetik sonuçların değerlendirilmesinde Odom kriterleri kullanıldı.

BULGULAR: Gruplar arasında, temel özellikler ve genel komplikasyon oranları anlamlı farklılık göstermemiştir. Kan kaybı titanyum kraniyoplastide otolog kraniyoplastiye kıyasla anlamlı olarak daha düşüktür (126.2±47.9 ml ve 215.5±35.6 ml, p<0.001). En yüksek komplikasyon oranı DK'den 3-6 ay sonra yapılan kraniyoplastilerde gözlenmiştir. Erken dönemde (<3 ay), otolog greftler titanyumdan, anlamlı olarak daha fazla komplikasyonla ilişkilendirilmiştir (5/7 ve 0/7, p=0.021). Kozmetik sonuçlar titanyum ile anlamlı derecede daha iyi iken, zamanlamanın kozmetik sonuçlar üzerine etkisi olmamıştır. 1 yıllık mortalite oranları gruplar arasında benzerdir.

SONUÇ: Kraniyoplastinin zamanlaması ve kraniyoplasti materyali TBH hastalarında ameliyat sonrası sonuçları etkileyebilir. Otolog kemik rekonstrüksiyon için kullanılamıyorsa, titanyum plaklar erken kraniyoplastide tercih edilebilir bir seçenek olabilirken, geç kraniyoplasti genel olarak daha az komplikasyonla ilişkili görünmektedir. Bu bulguları desteklemek için daha fazla çalışmaya ihtiyaç vardır.

Anahtar sözcükler: Dekompresif kraniyektomi; kraniyoplasti; titanyum; travmatik beyin hasarı; 3D implant.

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ORIGINAL ARTICLE

Evaluation of critical parameters for optimizing the therapeutic approach in pediatric patients with compartment syndrome during the 2023 Türkiye earthquake disaster

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ABSTRACT

BACKGROUND: The 2023 Türkiye earthquake resulted in a large number of pediatric victims with musculoskeletal trauma, many of whom developed compartment syndrome (CS) and crush-related complications. This study aimed to identify clinical and biochemical parameters associated with disease severity, renal failure, and limb loss in children affected by the disaster.

METHODS: A retrospective analysis was conducted on 103 pediatric patients (0–18 years) admitted after the earthquake. Demographic data, duration of entrapment, laboratory values (creatine kinase [CK], myoglobin, aspartate aminotransferase [AST], alanine aminotransferase [ALT], urea, potassium), and therapeutic interventions (fasciotomy, negative-pressure wound therapy [NPWT], hyperbaric oxygen therapy [HBOT], hemodialysis, and amputation) were evaluated. Receiver operating characteristic (ROC) analyses were used to determine cut-off values predicting adverse outcomes.

RESULTS: Forty-seven patients (45.6%) developed compartment syndrome involving 68 limbs and underwent fasciotomy. Thirteen patients (12.6%) required limb amputation, and 19 (18.4%) underwent hemodialysis due to acute kidney injury. An entrapment duration exceeding 8 hours (area under the curve [AUC]=0.84, p<0.001), CK>10,000 U/L, and myoglobin >4,000 ng/mL were independent predictors of renal failure, fasciotomy, and amputation. NPWT was applied in 66% and HBOT in 85% of patients with necrosis, contributing to an 82% limb salvage rate. No amputations occurred in patients without persistent necrosis. Three patients (2.9%) died from severe crush-related injuries and multi-organ failure.

CONCLUSION: Prolonged entrapment and markedly elevated CK and myoglobin levels are reliable indicators of adverse outcomes in pediatric earthquake victims with compartment syndrome. Early recognition, timely decompression, and structured wound management (NPWT and HBOT) are essential for improving survival and limb salvage when early surgical intervention is not feasible in large-scale disasters.

Keywords: Compartment syndrome; pediatric trauma; earthquake; fasciotomy; crush injury; amputation; negative-pressure wound therapy (NPWT); hyperbaric oxygen therapy (HBOT); renal failure.

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INTRODUCTION

On February 6, 2023, southeastern Türkiye and northern Syria experienced one of the most devastating earthquakes in recent history, measuring 7.8 in magnitude, followed by another significant tremor of 7.5. This catastrophic event affected approximately 15 million individuals, a substantial number of whom were children.[1] In Türkiye, approximately 21.3% of the country's child population resides in the southeastern regions impacted by the 2023 earthquake. This proportion highlights the considerable pediatric population at risk in the disaster zone, underscoring the need for child-focused medical response strategies.[2] The earthquake caused extensive structural collapses, trapping many individuals under debris for varying durations—from hours to several days—before rescue efforts reached them. The healthcare infrastructure in the region sustained severe damage, necessitating the transfer of injured patients to medical facilities across the country, including our institution.

This study aims to evaluate the factors influencing the severity of compartment syndrome in pediatric patients affected by the earthquake. Additionally, it assesses the therapeutic interventions provided, including both surgical and non-surgical treatments, and their respective outcomes. By identifying critical determinants of morbidity and treatment efficacy, this analysis seeks to inform future disaster preparedness protocols, optimize emergency response systems, and reduce the risk of amputations and long-term complications in pediatric populations during large-scale disasters.

MATERIALS AND METHODS

This retrospective study reviewed the medical records of pediatric earthquake victims referred to or admitted to at a tertiary referral center following the disaster. Ethical approval for the study was obtained from the institutional ethics committee (number: E2-24-458, date: 10/09/2024), and the study was conducted in accordance with the principles of the Declaration of Helsinki. Pediatric patients aged 0 to 18 years who were referred to or admitted to our institution with earthquake-related musculoskeletal trauma between February 6 and March 31, 2023, were included in the study. Patients with incomplete medical records, those admitted for non-traumatic conditions, or individuals with pre-existing neuromuscular disorders were excluded.

Clinical Setting and Multidisciplinary Management

At our tertiary referral center, all patients were evaluated by a multidisciplinary team dedicated to pediatric surgery, orthopedics, and plastic surgery, supported by surgical intensive care, pediatric intensive care, burn intensive care, and a specialized wound unit. These teams worked in shifts to ensure continuous (24/7) bedside monitoring and serial clinical–laboratory reassessment. Patients were co-managed by pediatric nephrology, cardiology, hematology, and infectious diseases as clinically indicated.

Patients were enrolled starting on the day of the earthquake (February 6, 2023) and followed until discharge or death, with the final date of follow-up being April 15, 2023. The median follow-up duration was 28 days (range: 3–65 days). Of the 107 pediatric patients initially admitted, four were excluded from the analysis due to incomplete clinical data, resulting in a final study population of 103 patients. The variables analyzed included age, gender, city of residence at the time of the earthquake, family health status, duration of entrapment under rubble, type of injury, laboratory values, presence of crush syndrome, fasciotomy status, medical and surgical treatments administered, and the occurrence of acute renal failure.

Laboratory Assessments

Laboratory parameters including serum creatine kinase (CK), myoglobin, aspartate aminotransferase (AST), alanine aminotransferase (ALT), urea, creatinine, potassium, albumin, and troponin I were routinely measured upon admission and monitored daily during the acute phase of hospitalization (first 7–10 days), or more frequently when clinically indicated. Serial measurements were used to assess trends and guide therapeutic decisions, particularly regarding fasciotomy, renal support, and surgical debridement.

Adjunctive Therapeutic Treatment Options

Negative-pressure wound therapy (NPWT) was employed for open wounds with infected or serous discharge to reduce edema and prevent infection. The frequency of NPWT changes was determined by the presence of infection and the volume of exudate. During follow-up, cultures were obtained from patients who developed wound infections, and appropriate treatments were initiated. Wounds deemed suitable after serial debridement were closed. Hyperbaric oxygen therapy (HBOT) was administered for patients with muscle necrosis, with treatment discontinued once necrotic tissue was no longer present in the fasciotomy wounds.

Clinical Indications for Fasciotomy

Patients presenting with tense, edematous limbs and sensory or motor deficits due to compromised vascular circulation were diagnosed with compartment syndrome. Fasciotomy was indicated for clinically diagnosed acute compartment syndrome in accordance with institutional protocol and prior guidance.[3] Given the disaster setting, diagnosis was primarily clinical and included: (i) severe pain (often out of proportion) and pain with passive stretch; (ii) tense swelling; (iii) paresthesia or hypoesthesia; (iv) motor weakness; (v) progressive neurovascular compromise; and (vi) absent distal pulses (considered a late sign). When documented, elevated intercompartmental pressures (ICP >30 mmHg) or a perfusion pressure ΔP (diastolic blood pressure − ICP) <30 mmHg supported the diagnosis. Because specific fasciotomy indications were not prospectively coded as discrete variables across referring centers, we report standardized criteria and a narrative description rather than a quantitative breakdown of individual triggers.

Patients who underwent fasciotomy within the first 24 hours were classified as early fasciotomy cases. In instances where fasciotomy had been performed at an outside facility but signs of compromised circulation persisted, fasciotomy revisions or extensions were undertaken.

Clinical Indications for Amputation

Definitive amputation was considered in patients with irreversible ischemia, progressive soft tissue and muscle necrosis, absent distal perfusion despite fasciotomy, severe infection unresponsive to debridement and antibiotics, or systemic deterioration due to sepsis. The decision to amputate was made by consensus within the multidisciplinary team and was delayed when feasible to allow adequate reassessment of tissue viability.

Amputations were performed at the lowest feasible level and reserved for cases in which limb-salvage measures (serial debridement and targeted antimicrobial therapy) failed and there was persistent infection or refractory limb ischemia with progressive osseous or soft-tissue necrosis, motor-sensory dysfunction consistent with irreversible neural compromise and/or systemic sepsis.

Clinical Indications for Hemodialysis

The initiation of hemodialysis was determined in consultation with pediatric nephrologists for patients with uremia, oliguria, resistant electrolyte imbalances (e.g., hyperkalemia), or acidosis. All patients with crush syndrome were closely monitored by pediatric nephrologists and intensive care specialists, and necessary medications were administered to prevent and treat rhabdomyolysis and acute renal failure.

Statistical Analyses

Data analysis was conducted using the Statistical Package for the Social Sciences (SPSS) version 22.0 (IBM Corp., Armonk, New York, USA). Descriptive statistics for continuous variables were presented as median (minimum-maximum) values, while categorical variables were summarized as n (%). The Shapiro-Wilk test was used to assess the normality of continuous variables. For variables that did not conform to a normal distribution, the Mann-Whitney U test was used for group comparisons. A p-value <0.05 was considered statistically significant.

Receiver operating characteristic (ROC) curve analysis was performed to determine cut-off values for key laboratory and clinical parameters associated with poor outcomes. Cut off assessment was conducted using pre specified thresholds for CK and myoglobin, along with exploratory evaluation of other laboratory markers; optimal thresholds were considered only when discrimination was clinically acceptable Optimal cut off values were determined using Youden's index (J = sensitivity + specificity − 1), and areas under the curve (AUC) were reported. Two sided p values <0.05 were considered statistically significant.

RESULTS

A total of 103 pediatric patients were referred to our hospital following the earthquake. Of these, 95 were admitted to the pediatric surgery intensive care unit and surgical wards, while eight were treated in the orthopedic ward. The mean age of the patients was 9.47±4.82 years (range: 0.1-17 years), and the male-to-female ratio was 45:58 (44%:66%). Seventy percent (n=72) had lost at least one parent or sibling during the earthquake. The mean duration of entrapment under the rubble was 9.47 hours (range: 0-120 hours). Among these, 59 patients (57.3%) were extricated from the rubble within the first 24 hours following the earthquake. Six patients were intubated upon arrival. The types of injuries sustained by the 103 patients trapped under the rubble are detailed in Table 1. Seven patients had cranial injuries, 21 had facial abrasions and hematomas, four had pneumothorax, four had lung contusions, one had a rib fracture, one had pericardial effusion, two had liver lacerations, two had splenic hematomas, and one had a right adrenal hematoma. Additionally, one patient sustained a urethral injury. A total of 86 patients (83.4%) sustained injuries characterized by crush trauma to either the lower or upper extremities.

Indications for Fasciotomy

Among the 103 patients, 47 were diagnosed with compartment syndrome, affecting a total of 68 extremities. These patients underwent fasciotomy either at the referring hospitals or at our center. A total of 68 fasciotomies were performed in 47 patients. Of these, 40 (58.8%) involved the upper extremities and 28 (41.2%) the lower extremities. Fasciotomy indications included progressive compartment symptoms such as swelling, pain, neurovascular compromise, and motor-sensory dysfunction. In nine patients, fasciotomy extensions were required due to inadequate initial decompression, and in 13 patients, fasciotomies were initiated de novo at our institution based on clinical progression.

Risk Stratification for Fasciotomy Based on Laboratory Cut-Off Values

The comparison between patients who underwent fasciotomy and those who did not is presented in Table 2. Patients who underwent fasciotomy were older, had longer durations of entrapment under the rubble, and experienced longer hospital stays, with significantly higher levels of aspartate

Table 1. Sites of injury (n=103)

Upper extremity	49 (47.5%)
Lower extremity	37 (35.9%)
Head and neck	28 (27.1%)
Thorax	10 (9.7%)
Abdomen	5 (4.8%)
Urogenital	1 (0.9%)

Table 2. Clinical characteristics and laboratory findings of patients undergoing fasciotomy

Parameters	Fasciotomy (+)	Fasciotomy (-)	P value
Age (years)	10.71 (±4.24)	8.60 (±5.04)	0.03
Time Trapped in Rubble (hours)	25.94 (±26.01)	14.32 (±20.93)	0.02
Length of Hospital Stay (days)	43.38 (±26.65)	22.60 (±27.72)	0.001
AST (U/L)	2520	596	0.001
ALT (U/L)	239	187	0.001
Amylase (U/L)	48	76	0.35
Lipase (U/L)	21	24	0.71
Creatinine (mg/dL)	0.36	1.35	0.55
CK (U/L)	123973	13205	0.001
CK-MB (ng/mL)	166.32 (±532.86)	85.60 (±338.92)	0.43
Myoglobin (ng/mL)	1171.95	261	0.001
Troponin-I (ng/mL)	40	183	0.01
Albumin (g/dL)	20.04 (±7.82)	19.83 (±11.80)	0.95
Uric Acid (mg/dL)	6.28 (±6.58)	4.91 (±4.29)	0.23
Urea (mg/dL)	48.77 (±50.62)	29.06 (±23.28)	0.01
Potassium (mmol/L)	4.69 (±1.1)	4.41 (±0.89)	0.18

AST: Aspartate aminotransferase; ALT: Alanine aminotransferase; CK: Creatine kinase; CK-MB: Creatine kinase–myocardial band.

aminotransferase, alanine aminotransferase, creatine kinase, myoglobin, and urea compared with those managed without fasciotomy. Significant differences in laboratory values were also found between patients with and without muscle necrosis. Twenty-three patients with severe muscle necrosis detected during fasciotomy received hyperbaric oxygen therapy. Patients with muscle necrosis were younger, had longer durations of entrapment under the rubble, and required extended hospitalization. They exhibited significantly higher levels of AST, ALT, creatine kinase, myoglobin, troponin-I, urea, and potassium, along with lower albumin levels compared to those without muscle necrosis (Table 3). Among the fasciotomy cohort, 24 patients (34 extremities) presented with persistent soft tissue necrosis and/or severe circulatory compromise and were managed with a stepwise limb salvage protocol (serial surgical debridement under anesthesia, broad spectrum antibiotics, NPWT, and HBOT as indicated). Median NPWT duration was 3.8 days (range 1–5), and the median time to definitive fasciotomy closure was 16.3 days (range 2–28), with 31/47 (66%) achieving primary closure and 16/47 (34%) requiring split thickness skin grafts.

Indications for Amputation

Amputation decisions were made based on comprehensive clinical evaluation, including signs of vascular compromise, irreversible motor-sensory loss, progressive bone and muscle necrosis, and systemic signs of sepsis. These interventions were undertaken despite prior aggressive medical and surgical management.

Despite the aforementioned measures involving fasciotomy, NPWT, and HBOT, 6/34 extremities (17.6%) ultimately required amputation, whereas 28/34 (82.4%) were salvaged. Notably, amputations occurred exclusively within the "persistent necrosis" subgroup; no amputations were recorded in extremities without persistent necrosis (Table 4). A total of 13 patients underwent limb amputation, representing 12.6% of the entire cohort. Of these, seven amputations were performed at the referring hospitals before transfer. After admission to our center, four patients underwent revision amputations due to ongoing infection or tissue necrosis, while six new amputations were performed during follow-up because of progressive ischemia, widespread soft-tissue necrosis, or sepsis. In addition to crush-related ischemia, other causes of amputation included persistent infection (n=2) and progressive necrosis despite decompression (n=1). Furthermore, among patients who received fasciotomy at the referring institution and those who underwent fasciotomy extension at our facility, none required amputation.

Amputation Versus Non Amputation Comparison

A consolidated analysis is presented in Table 5. In unadjusted comparisons of continuous variables, age, entrapment duration, creatine kinase–myocardial band (CK MB), myoglobin, and troponin I were broadly comparable between groups (all $p>0.05$). By contrast, ALT, CK, urea, and albumin showed nominal between group differences (Table 5). Given the small amputation subgroup and variable level missingness, these findings should be interpreted cautiously and without causal

Table 3. Comparison of laboratory findings and clinical outcomes in patients with and without muscle necrosis

	Muscle Necrosis (+)	Muscle Necrosis (-)	P value
Age (years)	8 (±3.54)	12 (±5.87)	0.01
Time Trapped in Rubble (hours)	28.6 (±22.01)	25.8 (±14.93)	0.008
Length of Hospital Stay (days)	43.38 (±26.65)	22.60 (±27.72)	0.001
AST (U/L)	1271 (1025)	1001 (596)	0.034
ALT (U/L)	514 (241)	284 (187)	0.018
Amylase (U/L)	48	76	0.35
Lipase (U/L)	21	24	0.71
Creatinine (mg/dL)	0.88	0.88	0.55
CK (U/L)	65150.4 (26945)	48847.04 (15032)	0.001
CK-MB (ng/mL)	144.07 (±765.86)	95.72 (±65.92)	0.03
Myoglobin (ng/mL)	1168 (1000)	1000 (1000)	0.032
Troponin-I (ng/mL)	455.2 (300)	239.2 (25)	0.024
Albumin (g/dL)	17.4 (±8.82)	19.33 (±9.80)	0.03
Uric Acid (mg/dL)	7.96 (±7.58)	5.71 (±3.29)	0.57
Urea (mg/dL)	54.8 (±40.62)	51.8 (±18.28)	0.02
Potassium (mmol/L)	5.9 (±1.2)	4.8 (±0.9)	0.04

AST: Aspartate aminotransferase; ALT: Alanine aminotransferase; CK: Creatine kinase; CK-MB: Creatine kinase–myocardial band.

Table 4. Surgical interventions and wound management among pediatric patients with compartment syndrome

Domain/Variable	n (%, denominator)
Patients with clinically diagnosed compartment syndrome who underwent fasciotomy	47/103 (45.6%)
Extremities decompressed by fasciotomy	68
Upper extremity fasciotomies	40/68 (58.8%)
Lower extremity fasciotomies	28/68 (41.2%)
Fasciotomy performed de novo at our center	13/47 (27.7%)
Fasciotomy extension/revision at our center	9/47 (19.1%)
Negative-pressure wound therapy (NPWT) after fasciotomy	26
Fasciotomy wound closure – primary	31/47 (66.0%)
Fasciotomy wound closure – split thickness skin graft (STSG)	16/47 (34.0%)
Hyperbaric oxygen therapy (HBOT) in severe intraoperative muscle necrosis	23
Patients undergoing limb amputation	16/103 (15.5%)
Amputation performed prior to transfer	7/16 (43.8%)
New amputation performed at our center	5/16 (31.2%)
Revision amputation at our center	4/16 (25.0%)

inference. Dialysis requirements did not differ by amputation status (2/13 [15.4%] vs. 13/90 [14.4%]; Fisher's exact p=1.00).

Indications for Hemodialysis

Nineteen patients with crush syndrome required hemodialysis. The laboratory parameters of these patients are detailed in Table 6. Patients requiring hemodialysis exhibited significant differences in various clinical parameters compared to those who did not. Specifically, hemodialysis patients had a longer duration of entrapment under the rubble and longer hospital stays. Additionally, laboratory values revealed significantly elevated levels of aspartate aminotransferase and ala-

Table 5. Comparison of clinical and laboratory characteristics by amputation status

Parameter (unit)	Amputation (+) (n=13) Mean±SD	Amputation (–) (n=90) Mean±SD	p value
Age (years)	8.29±2.36	9.87±4.77	0.319
Time trapped under rubble (hours)	28.57±42.77	17.10±21.41	0.673
Length of hospital stay (days)	45.43±31.19	30.00±28.69	0.095
AST (U/L)	879.86±707.10	441.33±818.18	0.057
ALT (U/L)	309.00±229.37	161.85±231.24	0.030
CK (U/L)	27,146.86±22,563.12	18,976.34±54,714.65	0.042
CK MB (ng/mL)	115.00±94.93	167.82±537.54	0.234
Myoglobin (ng/mL)	668.43±457.30	484.95±1,113.50	0.154
Troponin I (ng/mL)	130.14±225.75	145.57±427.65	0.125
Urea (mg/dL)	46.29±22.19	36.93±39.21	0.047
Albumin (g/dL)	18.43±10.81	8.60±11.35	0.026
Dialysis (n, %)*	2 (15.4%)	13 (14.4%)	1.00

*Fisher's exact test.

Table 6. Comparison of laboratory findings and clinical outcomes in hemodialysis and non-hemodialysis patients

Parameter	Hemodialysis (+) (n=19)	Hemodialysis (–) (n=64)	p
Age	11.12 (±3.54)	111.27 (±5.87)	0.68
Time Trapped in Rubble	29.55 (±22.01)	19.12 (±14.93)	0.028
Length of Hospital Stay	69.5 (±26.65)	41.4 (±27.72)	0.005
AST	2050 (1614)	610 (421)	0.001
ALT	548.4 (490)	230 (175)	0.001
Amylase	116.12	64.66	0.11
Lipase	45.75 (27)	31.05 (19)	0.09
Creatinine	1.93 (1.85)	0.41 (0.36)	0.001
CK-MB	195.45 STD	64.81 STD	0.009
CK	131938 STD	16426.38 STD	0.001
Myoglobin	2125 (3181)	696.55 (377)	0.001
Troponin-I	793.87 (91.02)	52.75 (65.35)	0.001
Albumin	16.5 (±8.82)	20.05 (±9.80)	0.019
Uric Acid	10.47 (±7.58)	4.22 (±3.29)	0.42
Urea	89.75 (101)	35.77 (19)	0.001
Potassium	5.9 (±1.2)	4.8 (±0.9)	0.04

AST: Aspartate aminotransferase; ALT: Alanine aminotransferase; CK: Creatine kinase; CK-MB: Creatine kinase–myocardial band.

nine aminotransferase in the hemodialysis cohort. Creatinine levels were markedly increased, and creatine kinase levels were significantly higher. Myoglobin and troponin-I levels also demonstrated significant differences. Furthermore, albumin levels were lower in the hemodialysis group, and potassium levels were significantly elevated.

An entrapment duration of more than 8 hours was found to significantly correlate with the development of acute kidney injury (AKI), fasciotomy, and subsequent limb amputation

Table 7. Receiver operating characteristic (ROC) performance and pre specified threshold metrics for hemodialysis

Predictor	AUC	95% CI	Threshold	Sensitivity	Specificity
Creatine kinase (CK), U/L	0.85	0.71-0.98	>10.000	0.80	0.85
Myoglobin, ng/mL	0.89	0.81-0.95	>4.000	0.07	1.00
Entrapment duration (hours)	0.51	0.37-0.66	–	–	–

(AUC=0.84, p<0.001). Similarly, creatine kinase levels exceeding 10,000 U/L and myoglobin levels greater than 4,000 ng/mL were associated with a significantly higher incidence of systemic complications and surgical interventions (p<0.01).

Risk Stratification for Hemodialysis Based on Laboratory Cut-Off Values

Receiver operating characteristic analyses (primary endpoint: hemodialysis/AKI) showed strong discrimination for CK and myoglobin (AUC=0.85 and 0.89, respectively), whereas entrapment duration had limited discrimination (AUC=0.51) (Table 7). Using pre specified thresholds, CK >10,000 U/L yielded sensitivity/specificity of 0.80/0.85 (p<0.001), while myoglobin >4,000 ng/mL was highly specific (1.00) but poorly sensitive (0.07) and did not reach statistical significance (Table 7). AST, ALT, and urea did not demonstrate sufficient discrimination to justify clinically meaningful cutoffs in this cohort.

Among the cohort, patients with serum creatine kinase levels greater than 5,000 U/L and myoglobin levels above 3,000 ng/mL demonstrated significantly higher rates of fasciotomy, muscle necrosis, acute kidney injury, and amputation (p<0.01).

All patients were evaluated in their beds by child psychiatrists. Twenty-six patients (25%) required medication, and treatment was provided to 16 patients (41%) who underwent fasciotomy (p=0.001). During follow-up, three patients died. Two of these patients, who had crush syndrome, were intubated and transferred from the referring hospital: an eight-year-old boy and a 15-year-old girl. The third patient was a 10-year-old boy with a subarachnoid hemorrhage and compartment syndrome, who underwent fasciotomy but ultimately succumbed to his injuries.

DISCUSSION

Severe earthquakes are associated with substantial morbidity and mortality, with most deaths occurring in the immediate aftermath due to severe trauma and prolonged entrapment under debris.[4] Crush injury is defined as prolonged compression of muscle tissue, leading to ischemia, cellular disruption, and necrosis. Progression to crush syndrome occurs when intracellular contents such as myoglobin, potassium, and creatine kinase enter the circulation, resulting in systemic complications including acute kidney injury and electrolyte disturbances.

Acute compartment syndrome, in contrast, is a localized condition caused by elevated intercompartmental pressure that impairs tissue perfusion and requires urgent fasciotomy to prevent irreversible damage. In our cohort, 83 patients sustained crush injuries, of whom 22.8% (n=19) met the diagnostic criteria for crush syndrome. These patients demonstrated progressive deterioration in key laboratory parameters, characterized by marked increases in creatine kinase, myoglobin, and serum potassium levels, accompanied by a decline in urine output. Crush injuries and crush syndrome present a high risk in these situations.[5] Musculoskeletal injuries are the most common injuries during earthquakes.[6,7] However, injuries to critical regions such as the head, abdomen, and thorax frequently lead to fatal outcomes, as many patients succumb before receiving adequate medical attention.[8] In our study, 83% of patients sustained extremity trauma, while thoracic and abdominal trauma together accounted for 14.5% of cases (Table 1). Data from previous disasters indicate that approximately 80% of trapped victims die quickly from severe injuries, with 10% experiencing crush injuries and another 10% sustaining minor trauma.[9,10] Of those with crush injuries, 40–70% develop crush syndrome.[4,11] In our cohort, 22.8% (n=19) of the 83 patients with crush injuries developed crush syndrome.

It is important to highlight that, due to our hospital's geographic location outside the epicenter, all patients included in this study were admitted no earlier than 24 hours after being extricated from collapsed structures. As such, none of the cases met the criteria for early fasciotomy, which is generally defined in the literature as surgical decompression performed within the first 6 to 12 hours of ischemic insult. This inherent delay limited our ability to evaluate the potential benefits of early intervention on limb salvage and systemic outcomes. Therefore, our findings predominantly reflect the clinical course and complications associated with delayed fasciotomy, offering relevant insights into scenarios where early access to surgical care is not feasible during disaster responses.

In line with prior guidance,[12] fasciotomy was performed for clinically diagnosed acute compartment syndrome, defined by progressive pain and swelling with neurovascular compromise, motor–sensory deficits, and—when documented—elevated intercompartmental pressures; absent distal pulses were considered a late sign. However, the indication and

timing of fasciotomy remain controversial. Early fasciotomy performed within 6 to 12 hours can prevent muscle necrosis; however, delayed fasciotomy generally results in poorer outcomes.[13] Some authors have argued that fasciotomy may be less effective in the setting of crush syndrome because irreversible muscle necrosis can precede a rise in compartment pressure, shifting the therapeutic priority toward renal preservation.[14,15] In our cohort, fasciotomy was performed in 47 patients (68 extremities) with clinically diagnosed compartment syndrome (Table 5).

Previous studies have elucidated the risks associated with fasciotomy in the context of crush syndrome, including uncontrollable hemorrhage, sepsis, and wound infections. Greaves et al.[16] and Erek et al.[17] reported significantly elevated rates of sepsis and increased dialysis requirements among patients undergoing fasciotomy. While fasciotomy in pediatric patients with crush syndrome-related acute kidney injury did not correlate with increased mortality, a strong association was observed between the number of fasciotomy incisions and the onset of sepsis.[17] In our study, patients who underwent fasciotomy were older, exhibited longer median durations of entrapment and hospital stays, and demonstrated significantly higher levels of transaminases, creatine kinase, urea, and myoglobin compared to those managed without fasciotomy. These differences were statistically significant. Significant differences in laboratory values were also observed between patients with and without muscle necrosis.

Patients with muscle necrosis were younger, had longer durations of entrapment, and experienced longer hospital stays. They exhibited significantly higher levels of aspartate aminotransferase, alanine aminotransferase, creatine kinase, myoglobin, troponin I, urea, and potassium, along with lower albumin levels compared to those without muscle necrosis.

Surgical debridement, antibiotic therapy, and hyperbaric oxygen therapy were performed on 34 extremities with persistent necrosis, but six extremities ultimately required amputation. These findings indicate that limb loss clustered among extremities with persistent soft tissue necrosis and severe circulatory compromise, despite an aggressive salvage pathway (serial debridement, antibiotics, NPWT, HBOT). By contrast, no amputations occurred in extremities without persistent necrosis, suggesting that necrosis status—and the underlying injury severity it reflects—was the principal driver of amputation rather than the wound care modality.

Among the patients with muscle necrosis, 23 (85%) received hyperbaric oxygen therapy, and 17 (63%) were treated with negative-pressure wound therapy. These therapies were primarily administered to individuals exhibiting more severe systemic and local tissue damage. When compared to patients without muscle necrosis, those who received NPWT or HBOT showed significantly higher levels of biochemical markers such as AST, ALT, CK, myoglobin, troponin-I, and urea, as well as elevated potassium levels and prolonged hospital stays. In contrast, albumin levels were notably lower. These findings suggest that the use of NPWT and HBOT was concentrated among the most critically affected patients and may have contributed to limb salvage in selected cases. Notably, only six patients in the muscle necrosis group required amputation, reflecting a potentially beneficial role of advanced wound management strategies in mitigating irreversible limb damage. Further prospective studies are warranted to evaluate the independent impact of these interventions on functional outcomes in pediatric crush injury victims.

Among these, 24 patients presented with severe circulatory compromise and extensive soft tissue necrosis; six ultimately underwent amputation. Amputation was indicated when limb physiology remained unsalvageable despite decompression and serial debridement—namely, persistent ischemia with non viable muscle, progressive necrosis after fasciotomy, or uncontrolled infection/sepsis (Table 7). Because the decision to perform fasciotomy was driven by the severity of limb ischemia (i.e., confounding by indication) and all cases presented >24 hours after extrication, our observational data cannot establish that fasciotomy per se increased the risk of amputation. Rather, amputation clustered with markers of injury severity, while comparative analyses did not show significant differences in key systemic parameters between amputated and non amputated patients ($p>0.05$).

Additionally, while the majority of amputations were performed in patients with extensive soft tissue necrosis and prolonged entrapment, a subset of cases required limb removal due to progressive ischemia, uncontrolled infection, or sepsis, highlighting the multifactorial nature of limb loss in this context.

Furthermore, in a comparative analysis of patients who underwent amputation versus those who did not, no statistically significant differences were observed regarding dialysis requirements, mean age, duration of entrapment, and laboratory parameters, including AST, ALT, troponin I, myoglobin, CK, CK-MB, urea, creatinine, and potassium levels ($p>0.05$). Additionally, none of the patients who underwent fasciotomy at the referring hospital or received fasciotomy extension at our institution required subsequent amputation. These findings suggest that although severe tissue damage is a major contributor to limb loss, fasciotomy—when appropriately indicated and executed—may not independently predict amputation risk in delayed-access disaster scenarios.

The likelihood of limb salvage is lower in cases involving significant bone loss, extensive soft tissue damage, distal sensory and motor function loss due to peripheral nerve injury, and major vascular damage requiring reconstruction. Guidelines recommend limiting amputation to cases where the limb is unsalvageable or when injuries result in uncontrollable bleeding, sepsis, or severe systemic inflammation. If amputation is indicated, it should be performed as promptly as possible.[18,19] We performed amputation in 25% of patients with crush

syndrome. These patients had a prolonged duration of entrapment under the rubble, exhibited no circulation, or had severe muscle necrosis.

Furthermore, our analysis identified specific thresholds for clinical and biochemical risk factors associated with adverse outcomes. In particular, entrapment durations exceeding 8 hours, serum creatine kinase levels greater than 10,000 U/L, and myoglobin levels above 4,000 ng/mL were significantly correlated with an increased risk of acute kidney injury, need for fasciotomy, and limb amputation ($p<0.01$). These cut-off values, determined by receiver operating characteristic curve analysis, provide valuable guidance for early risk stratification in similar disaster settings. Additionally, while the majority of amputations were performed in patients with extensive soft tissue necrosis and prolonged entrapment, a subset of cases required limb removal due to progressive ischemia, uncontrolled infection, or sepsis, underscoring the multifactorial nature of limb loss in this context.

Fasciotomy has been associated with increased dialysis requirements in some studies, with Kantarci et al.[20] identifying it as a strong indicator of dialysis need. Sever et al.[21] reported that dialysis was required in 83.9% of fasciotomy patients compared to 65.2% of those who did not undergo the procedure. Matsuoka et al.,[22] however, found no significant difference in hemodialysis requirements between patients with or without fasciotomy. In our study, patients requiring hemodialysis showed significant differences in clinical parameters compared to those who did not. Specifically, the hemodialysis group experienced a longer duration of entrapment under the rubble and an extended hospital stay. Laboratory analyses revealed markedly elevated levels of aspartate aminotransferase and alanine aminotransferase, along with increased creatinine and creatine kinase levels. Myoglobin and troponin I levels also differed significantly, while albumin levels were lower and potassium levels were significantly elevated in the hemodialysis cohort ($p<0.05$).

Consistent with prior reports,[5] dialysis requirement did not differ significantly by amputation status in our cohort (amputation 2/7 [28.6%] vs. no amputation 13/88 [14.8%]; $p>0.05$). In unadjusted comparisons, age, duration of entrapment, AST, CK MB, myoglobin, and troponin I did not differ significantly between amputated and non amputated patients (all $p>0.05$) (Table 5). By contrast, ALT, CK, urea, and albumin showed nominal between group differences ($p=0.030$, 0.042, 0.047, and 0.026, respectively) (Table 5); these findings should be interpreted cautiously given the small amputation subgroup ($n=7$) and variable missingness.

Oda et al.[23] reported a mortality rate of 13.4% among patients with crush syndrome, with a significantly elevated rate of 50% in those with abdominal injuries. Sever et al.[21] observed a 30.5% mortality rate among amputated patients, highlighting thoracic and abdominal trauma as significant predictors of mortality. Overall, the mortality rate for crush syndrome approaches 20%, increasing further in cases of multi-organ failure.[24,25] In our study, three patients died during follow-up, including two intubated patients with crush syndrome transferred from the referring hospital—an eight-year-old boy and a 15-year-old girl. The third patient was a 10-year-old boy with subarachnoid hemorrhage and compartment syndrome, who ultimately succumbed to his injuries despite undergoing fasciotomy.

In addition to these acute fatalities, the literature reports that delayed deaths may occur in the post-earthquake period as a consequence of environmental factors. For instance, cold exposure in makeshift shelter settings was the cause of over 370 hypothermia deaths in the Haicheng earthquake, while frostbite affected thousands more.[26] Moreover, delayed casualties in several disasters have been attributed to dehydration, hypothermia, wound infection, or sepsis.[27,28] Although such phenomena were not observed in our cohort—likely because our referral patients were already past the immediate environmental exposure period.

CONCLUSION

This single center cohort highlights the need for prompt recognition and coordinated multidisciplinary care for pediatric earthquake–related compartment syndrome. Across the dataset, prolonged entrapment, marked rhabdomyolysis, and extensive muscle necrosis were the principal correlates of adverse outcomes (acute kidney injury and limb loss). In ROC analyses, entrapment >8 hours (AUC=0.84), CK >10,000 U/L, and myoglobin >4,000 ng/mL identified children at increased risk and predicted the need for higher acuity care (Intensive Care Unit [ICU] admission, renal replacement therapy, or urgent surgical intervention), supporting early triage in disaster settings. At the bedside, operational triggers of CK >5,000 U/L and myoglobin >3,000 ng/mL aligned with increased rates of fasciotomy, muscle necrosis, AKI, and amputation. When feasible, early surgical decompression combined with a staged limb salvage pathway—negative pressure wound therapy for edema control and wound bed optimization, and hyperbaric oxygen therapy in selected cases—formed an integral component of care; however, given delayed presentation and the observational design, causal inferences about any single adjunct are not warranted.

Prospective, multicenter studies are needed to validate these cutoffs and to determine whether protocolized use of NPWT/HBOT, alongside timely early fasciotomy, improves limb salvage and renal outcomes in pediatric populations.

Limitations

The retrospective nature of data collection presents inherent challenges, particularly in disaster settings where patient records may be incomplete or fragmented. In this single-center study, while the available records were sufficient, variability in surgical techniques and indications exists. Moreover, due to the geographic distance of our hospital from the earth-

quake zone, all patients were referred after initial stabilization and arrived at least 24 hours post-extrication. This timing precluded any assessment of early fasciotomy outcomes, a limitation that restricts direct comparison with studies evaluating early surgical intervention (within 6–12 hours). Nonetheless, the clinical findings provide valuable insights that may contribute to enhancing disaster management strategies and informing future surgical decision-making, particularly in settings where delayed access to definitive care is inevitable.

Ethics Committee Approval: This study was approved by the Ankara City Hospital Clinical Research Ethics Committee (Date: 10.09.2024, Decision No: E2-24-458).

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ORİJİNAL ÇALIŞMA - *ÖZ*

2023 Türkiye depreminde kompartman sendromu gelişen çocuk hastalarda tedavi yaklaşımının optimizasyonunda kritik parametrelerin değerlendirilmesi

AMAÇ: 2023 Türkiye depremi, kas-iskelet sistemi yaralanmaları olan çok sayıda çocuk hastanın ortaya çıkmasına neden olmuş, bu hastaların önemli bir kısmında kompartman sendromu (KS) ve crush ile ilişkili komplikasyonlar gelişmiştir. Bu çalışma, afetten etkilenen çocuklarda hastalık şiddeti, böbrek yetmezliği ve ekstremite kaybı ile ilişkili klinik ve biyokimyasal parametreleri belirlemeyi amaçlamaktadır.

GEREÇ VE YÖNTEM: Deprem sonrasında hastaneye kabul edilen 0–18 yaş aralığındaki 103 pediatrik hasta retrospektif olarak analiz edildi. Demografik veriler, enkaz altında kalma süresi, laboratuvar değerleri (CK, miyoglobin, AST, ALT, üre, potasyum) ve uygulanan tedavi girişimleri (fasyotomi, negatif basınçlı yara tedavisi [NPWT], hiperbarik oksijen tedavisi [HBOT], hemodiyaliz, ampütasyon) değerlendirildi. Olumsuz klinik sonuçları öngören kesme (cut-off) değerlerini belirlemek amacıyla ROC (Receiver Operating Characteristic) analizi kullanıldı.

BULGULAR: Kırk yedi hastada (%45.6) toplam 68 ekstremiteyi etkileyen kompartman sendromu gelişmiş olup tümüne fasyotomi uygulanmıştır. On üç hasta (%12.6) ekstremite ampütasyonu gerektirmiş, 19 hasta (%18.4) ise akut böbrek hasarı nedeniyle hemodiyalize alınmıştır. Enkaz altında kalma süresinin 8 saati aşması (AUC=0.84, p<0.001), CK>10.000 U/L ve miyoglobin >4.000 ng/mL düzeyleri, böbrek yetmezliği, fasyotomi ve ampütasyon gereksinimi için bağımsız öngörücü parametreler olarak saptanmıştır. Nekrozu bulunan olguların %66'sında negatif basınçlı yara tedavisi (NPWT) ve %85'inde hiperbarik oksijen tedavisi (HBOT) uygulanmış; bu yaklaşımlar sayesinde ekstremite kurtarma oranı %82'ye ulaşmıştır. Süreğen nekrozu olmayan hiçbir hastada ampütasyon gereksinimi oluşmamıştır. Üç hasta (%2.9) ise ağır crush yaralanması ve çoklu organ yetmezliği nedeniyle kaybedilmiştir.

SONUÇ: Uzamış enkaz altında kalma süresi ile belirgin yüksek CK ve miyoglobin düzeyleri, deprem sonrası kompartman sendromu gelişen çocuk hastalarda olumsuz klinik sonuçların güvenilir göstergeleridir. Erken tanı, zamanında cerrahi dekompresyon ve NPWT ile HBOT'u içeren yapılandırılmış yara bakım yaklaşımları, geniş ölçekli afet koşullarında erken cerrahi müdahalenin mümkün olmadığı durumlarda yaşam ve ekstremite korunma oranlarını anlamlı biçimde artırmaktadır.

Anahtar sözcükler: Ampütasyon; böbrek yetmezliği; crush yaralanması; çocuk travması, deprem, fasyotomi; HBOT; kompartman sendromu; NPWT.

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ORIGINAL ARTICLE

The usefulness of tuning-fork-assisted vibration sensation as a proprioceptive measurement method in cases of acute anterior talofibular ligament rupture: A single-center study

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ABSTRACT

BACKGROUND: This study aimed to investigate changes in vibration sensation in patients with anterior talofibular ligament (ATFL) rupture following acute ankle sprain and to assess its potential use as a proprioceptive assessment tool.

METHODS: A 128 Hz tuning fork was applied to the ATFL region—identified as ruptured via ultrasound—while the ankle was positioned in inversion and plantar flexion. Vibration duration was measured using a stopwatch. Data were compared with those from a healthy population and from patients with lateral ankle edema following acute sprain without rupture. The study was prospectively designed.

RESULTS: A total of 81 patients (48 male, 33 female) were included, with a mean age of 29.19 years. Among the 27 patients with ATFL rupture, nine had an additional calcaneofibular ligament (CFL) injury and five had an additional posterior talofibular ligament (PTFL) injury (Grade 2–3). The mean vibration duration in ATFL rupture patients was 5.72 seconds on the injured side and 7.87 seconds on the uninjured side, showing a statistically significant difference (p=0.001). At the 12-week follow-up, the mean vibration time improved to 7.65 seconds, which was also statistically significant (p=0.001).

CONCLUSION: Proprioceptive impairment due to acute ATFL rupture was associated with reduced vibration sensation at the rupture site. As proprioception improved, vibration sensation also recovered. Therefore, vibration measurement using a tuning fork may serve as a practical proprioceptive assessment tool and an adjunctive diagnostic method.

Keywords: Anterior talofibular ligament (ATFL); tuning fork; proprioception; vibration.

INTRODUCTION

Ankle injuries are commonly seen in young men due to high-energy trauma and in elderly women due to low-energy trauma. The severity of the injury increases with the impact of the trauma, and in high-energy cases, soft tissue damage becomes more pronounced, making the treatment process more complex.[1]

The lateral ankle ligament complex comprises the anterior talofibular ligament (ATFL), calcaneofibular ligament (CFL), and posterior talofibular ligament (PTFL).[2] The ATFL is the

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weakest of the three lateral ligaments and is the most commonly injured component of this complex structure.[3] Initial conservative management, based on rest, ice, compression, limb elevation, and functional rehabilitation, is recommended for acute lateral ligament injuries.[4]

Kinesthesia studies in patients with a history of anterior talofibular ligament rupture and recurrent ankle sprains have shown impairment of proprioception.[5] Proprioception and vibration sensation from the entire body, except for the head, are conveyed to the cerebral cortex via the dorsal column-medial lemniscus pathway.[6,7] The objective of this study was to investigate the interaction between these two senses, measure vibration using a tuning fork, and correlate the vibration measurement technique developed with a proprioceptive measurement method.

MATERIALS AND METHODS

The study was conducted according to a prospective design approved by our institution's ethics committee. Ethical approval for this study was obtained from our Ethics Committee on 01/08/2022 (Protocol number: 2022/250). The study was conducted in accordance with the Declaration of Helsinki. It included patients who presented to the emergency orthopedic service with an ankle sprain between January 2023 and September 2023. The study adhered to ethical research principles, and informed consent was obtained from all participants. The confidentiality and rights of the patients were protected throughout the research process. The study included patients with acute ankle sprains or injuries, without comorbidities, and exhibiting peripheral neurological symptoms. Exclusion criteria were as follows: the presence of an ankle fracture, a chronic ATFL rupture, diabetes mellitus, age over 65 years, and patients with a neurological disease.

Ultrasonography is 94% sensitive for detecting ligament rupture[8] and is also a reliable and accurate diagnostic method.[8] Due to the high reliability of ultrasonography (USG), patients were primarily diagnosed using this method. ATFL rupture was evaluated with long-axis imaging. The study included patients diagnosed with total ATFL rupture. The CFL and PTFL were not assessed by ultrasonography. Magnetic resonance imaging (MRI) was used to evaluate additional injury patterns.

A single leg-loading (SLL) test was conducted to assess the severity of the injury, and the resulting levels were recorded.[9] Level 1 indicates difficulty in single-leg standing, level 2 represents single-leg standing, level 3 is single-leg heel raising, and level 4 is single-leg hopping.

The study was designed with three distinct groups. Group 1 comprised 27 patients presenting with acute ATFL rupture. Group 2 included 27 patients with no rupture but marked edema and tenderness in the lateral ankle region, who reported it as a result of a sprain. Group 3 consisted of 27 patients randomly selected from a healthy population without a history of recurrent sprains. A tuning fork was placed on bilateral ATFL areas in all groups, and vibration times were recorded (for comparison with the contralateral side). Visual Analogue Scale (VAS) and American Orthopaedic Foot and Ankle Society (AOFAS) scores were recorded at the time of injury for Group 1 patients.

Pain and edema management involved the use of an elastic bandage (with a short leg splint applied to three patients) in conjunction with nonsteroidal anti-inflammatory treatment for the first week. In the second week, proprioceptive exercises were initiated. These exercises included balancing on one leg with eyes open and closed, squatting on one leg, tight-rope walking, and reverse lunges. Subsequently, patients were monitored using ankle splints to enhance their proprioceptive perception. The proprioceptive exercises and splinting were continued until the 12th week. A 128 Hz tuning fork-assisted vibration time measurement was used to evaluate improvement in proprioceptive sense at the 12th week of follow-up.

In the case of ankle inversion and plantar flexion (Fig. 1), a 128 Hz tuning fork was applied to ATFL tracings identified as ruptured by ultrasound (Samsung HM70 EVO, probe: 2-8 MHz) (Fig. 2), and vibration times were measured using a stopwatch. The tuning fork measurement was also applied to intact ATFL tracings. The prongs of the tuning fork were pinched with two fingers until maximum tension was reached, at which point

Figure 1. When the ankle was in plantar flexion and inversion, the probe was positioned at a 45-degree angle, providing the most precise image of the anterior talofibular ligament (ATFL).

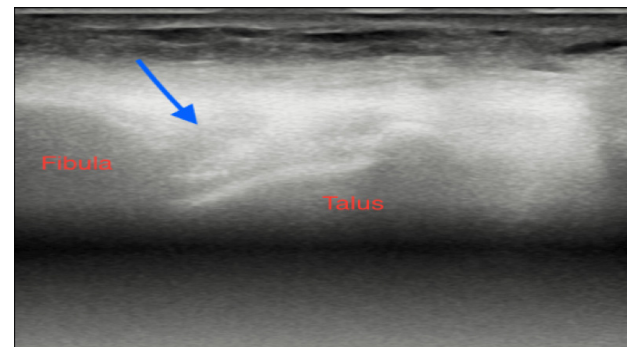

Figure 2. A complete anterior talofibular ligament (ATFL) rupture was observed between the talus and fibula, accompanied by disruption of the delta sign, as indicated by the blue arrow.

Figure 3. The prongs of the tuning fork are clamped on both sides at maximum tension.

Figure 4. The stem of the tuning fork is applied to the anterior talofibular ligament (ATFL) trace, and the time is recorded with a stopwatch.

the contact between the fingers was released (Fig. 3). Once finger contact was discontinued, it was ensured that no further contact was made with the prongs. As soon as vibration commenced, the stem of the tuning fork was placed on the ATFL trace, and vibration time was measured with a stopwatch (Fig. 4). The stopwatch was stopped when patients indicated cessation of vibration. Measurements were repeated at least twice, and average vibration times were recorded.

Statistical Investigations: Statistical analyses were performed using IBM SPSS Statistics for Windows, Version 26.0 (IBM Corp., Armonk, NY, USA). Descriptive statistical methods (mean, standard deviation, median, frequency, percentage, minimum, maximum) were used to summarize the study data. The normality of quantitative variables was assessed using the Shapiro–Wilk test and graphical evaluation. For non-normally distributed quantitative variables, comparisons between two groups were performed using the Mann–Whitney U test, while comparisons among more than two groups were conducted using the Kruskal–Wallis test followed by Dunn–Bonferroni post-hoc analysis. For normally distributed quantitative variables, comparisons among more than two groups were performed using one-way analysis of variance (ANOVA) with Bonferroni-corrected pairwise evaluations, and intra-group comparisons were performed using the paired samples t-test. For non-normally distributed intra-group comparisons, the Wilcoxon signed-ranks test was used. Qualitative variables were compared using the Pearson chi-square test and Fisher's exact test. Relationships between quantitative variables were analyzed using Spearman correlation analysis. Statistical significance was set at $p<0.05$. All statistical analy-

Table 1. Difference in vibration duration in Group 2 (patients with no rupture but marked edema and tenderness in the lateral ankle region)

Group 2	Right Side	Left Side	Difference	p
Vibration Duration (sec.)				
Mean±SD	7.01±1.72	7.03±1.87	0.02±0.51	[g]0.885
Median (Min-Max)	6.7 (3.8-12.2)	6.3 (4.5-12.3)	0.05 (-0.8-0.7)	

Wilcoxon Signed Ranks Test. SD: Standard deviation; Sec.: Seconds.

Table 2. Difference in vibration duration in Group 3 (in healthy population)

Group 3	Right Side	Left Side	Difference
Vibration Duration (sec.)			
Mean±SD	6.16±1.38	6.34±1.40	-0.18±0.34
Median (Min-Max)	6.3 (3.8-9.0)	6.5 (3.9-9.3)	-0.2 (-0.9-0.5)

SD: Standard deviation; Sec.: Seconds.

ses were conducted under the supervision of an independent statistician (Empiar İstatistik, Istanbul, Türkiye)

RESULTS

The study was conducted with 81 patients, of whom 59.3% (n=48) were male and 40.7% (n=33) were female. The patients' ages ranged from 14 to 59 years, with a mean age of 29.19±12.45 years.

The results of tuning fork-assisted vibration measurements on both sides in Group 2 patients did not show a statistically significant difference (Table 1).

The difference in vibration duration between the two sides in Group 3 was found to be similar, in contrast to Group 1 patients (Table 2).

A statistically significant difference was observed in the duration of tuning fork-assisted vibrations between the ruptured and intact (contralateral) sides of Group 1 patients (Table 3).

The results of vibration measurements with the tuning fork did not reveal any significant differences in relation to injury severity (Table 4).

Table 3. Comprasion of vibration duration between intact and ruptured sides in Group 1 (Paired Samples Test)

Group 1	Intact Side	Ruptured Side	Difference	p
Vibration Duration (sec.)				
Mean±SD	7.87±1.23	5.72±1.06	-2.16±0.66	[d]0.001**
Median (Min-Max)	7.6 (5.9-10)	5.6 (4.0-7.6)	-2 (-3.9-1.2)	

[d]Paired Samples Test; **p<0.01. SD: Standard deviation; Sec.: Seconds.

Table 4. Difference in vibration duration between injury severity levels (Mann Whitney U test / Kruskal-Wallis Test)

Vibration Duration(sec.) Difference Between the Intact Side and Injured Side After Trau-ma in Group 1 Patients				
Group 1	**n**	**Mean±SD**	**Median (Min-Max)**	**p**
SLL Level				
Level 1	15	-2.19±0.83	-1.9 (-3.9-1.2)	[f]0.739
Level 2	7	-2.11±0.16	-2.1 (-2.3-1.9)	
Level 3	5	-2.16±0.66	-2.0 (-3.9-1.2)	

[e]Mann-Whitney U Test; fKruskal Wallis Test. SLL: Single leg-loading test; SD: Standard deviation; Sec.: Seconds.

Table 5. Difference in vibration duration between injury severity levels (Mann Whitney U test / Kruskal-Wallis Test)

Group 1	During Trauma	Week 12	Difference	p
AOFAS Score				
Mean±SD	51.52±13.98	91.56±4.49	40.04±14.48	[g]0.001**
Median (Min-Max)	56 (33-70)	90 (87-98)	40 (17-64)	
VAS Score				
Mean±SD	7.52±1.09	2.41±1.87	-5.11±1.74	[g]0.001**
Median (Min-Max)	8 (4-9)	2 (0-5)	-5 (-7--1)	
Intact (Contralateral) Side Vibration Duration (sec.)				
Mean±SD	7.87±1.23	7.65±1.30	-0.22±0.80	[d]0.161
Median (Min-Max)	7.6 (5.9-10.0)	7.5 (4.8-9.8)	-0.2 (-2-1.3)	
Ruptured Side Vibration Du-ration (sec.)				
Mean±SD	5.72±1.06	7.65±1.28	1.93±1.00	[d]0.001**
Median (Min-Max)	5.6 (4-7.6)	7.4 (4.8-9.5)	2 (-0.44-3.4)	

[d]Paired Samples Test; gWilcoxon Signed Ranks Test; **p<0.01. SD: Standard deviation; Sec.: Seconds; VAS: Visual Analogue Scale; AOFAS: American Orthopaedic Foot and Ankle Society.

Table 6. Difference in vibration duration between injury severity levels (Mann Whitney U test / Kruskal-Wallis Test)

	n (%)
Additional Pathology in MR	
Isolated ATFL Rupture	11 (47.8)
CFL Injury	9 (39.1)
PTFL Injury	5 (21.7)
Risk of Chronic Instability	
None	20 (74.1)
Present	7 (25.9)
Chronic Instability Risk and Recurrent Sprain Before Trauma	
None	5 (71.4)
Present	2 (28.6)

MR: Magnetic Resonance; ATFL: Anterior talofibular ligament; PTFL: Posterior talofibular ligament; CFL: Calcaneofibular ligament. n is replaced by mean±SD, and % is replaced by median.

Improvement in vibration duration observed after treatment was statistically significant (Table 5).

A comprehensive overview of the accompanying pathologies and chronic instability data is provided in Table 6.

DISCUSSION

In a study conducted on patients with ATFL rupture, 68% were male and 32% were female.[10] In our study, 17 of the 27 patients who experienced a rupture were male (63%), while 10 were female (37%).

A further epidemiological study found that 35% of ATFL ruptures involved CFL injuries, while 12% involved PTFL injuries.[11] In our study, nine patients had CFL injuries and five had PTFL injuries (Grade 2 or 3). Based on these data, our study indicates that 39.1% of patients had a concomitant CFL injury and 21.7% exhibited a PTFL injury.

In patients who have sustained injuries to the lateral ligament complex, chronic ankle instability syndrome may develop in up to 30% of cases, characterized by recurrent ankle sprains.[12] If left untreated, ATFL injury can result in chronic lateral ankle instability, leading to premature arthritis.[13] Consequently, timely treatment of both bone and soft tissue lesions in the ankle is crucial. In our study, patients with a history of at least one recurrent sprain and moderate-to-severe pain (VAS score of 3 and above) at the 12-week follow-up were considered to be at risk of developing chronic ankle instability. Among the 27 patients with ATFL injury, seven reported at least one recurrent sprain at the three-month follow-up. According to the World Health Organization (WHO) classification, they exhibited moderate pain. These patients were considered positive for chronic ankle instability. In light of these data, the risk of developing chronic ankle instability in our study was 25.9%.

The dorsal column–medial lemniscus (DCML) pathway conveys mechanosensory inputs—including vibration, fine touch, and proprioception—to the cerebral cortex through a somatotopically organized relay system. First-order axons originating from low-threshold mechanoreceptors, such as Pacinian corpuscles and muscle spindles, ascend ipsilaterally within the dorsal columns to synapse in the gracile and cuneate nuclei of the medulla. Vibration signals transmitted by peripheral Pacinian corpuscles contribute to the encoding of dynamic tactile stimuli, whereas proprioceptive input from muscle spindles and Golgi tendon organs provides essential information regarding limb position and movement. Lesions of the dorsal columns result in impaired proprioceptive acuity and diminished capacity for active tactile exploration, highlighting the functional interdependence between proprioceptive and vibratory modalities in spatial perception. The anatomical organization of the DCML system supports the integration of these sensory modalities, thereby facilitating accurate cortical representation of both static limb position and dynamic tactile input.[14]

Proprioception is crucial for controlling muscle movements, ensuring the precision of bodily actions, and maintaining joint stability.[15] It refers to the ability to sense the position and movement of the extremities and body without relying on vision. Proprioception consists of two components: the sense of fixed position of the extremities (position sense) and the sense of movement of the extremities (kinesthesia).[16]

Many proprioception measurement methods have been described in sports injuries. A multitude of variables influencing the process renders measurement of proprioceptive levels challenging.[16] The main disadvantages of proprioceptive measurement techniques are their inherent complexity and lack of specificity to particular tissues. The relationship between proprioception and vibration has been highlighted in numerous studies.[16] Despite these studies, the use of vibration as a proprioceptive method has yet to be defined.[17] This study proposes that a vibration measurement and comparison technique can be employed as a proprioceptive tool, specifically targeting pathological tissue. A review of the literature revealed no studies evaluating the use of vibration with a tuning fork in the treatment of ankle ligament injuries. This study represents the first instance of measuring ligament-specific vibrations using a tuning fork.

In light of evidence suggesting that proprioceptive exercises following ligament injuries enhance impaired proprioception,[18,19] isokinetic and proprioceptive exercises were employed in the treatment of all patients with ATFL rupture during the study to improve impaired proprioceptive function. The mean post-traumatic vibration time on the ruptured side was 5.72±1.06 seconds, while the mean vibration time at the 12-week follow-up was 7.65±1.28 seconds. The mean

increase of 1.93±1.00 units in vibration time at the 12th week post-trauma was statistically significant compared to the time of trauma (p=0.001; p<0.01). It can be postulated that proprioceptive sensation improved with the proprioceptive exercises, thereby enhancing vibration sensation.

CONCLUSION

Our study observed significant differences in vibration measurements between intact and ruptured ATFL ligaments using a tuning fork. We found that impaired proprioception following acute ATFL rupture also affected patients' vibration sensation, with a decrease in vibration duration in the damaged ligaments. After three months of conservative treatment, including proprioceptive exercises and splinting, the difference in vibration duration between both ankles decreased to levels comparable to those observed in healthy individuals. Based on the quantitative data obtained in our study of acute ATFL rupture cases, we propose that the comparative tuning fork-assisted vibration measurement method can be used as a proprioception assessment tool and for monitoring sensory recovery. Furthermore, this method could facilitate the rapid diagnosis of ligament ruptures.

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Ethics Committee Approval: This study was approved by the Bakirköy Dr.Sadi Konuk Training and Research Hospital Ethics Committee (Date: 01.08.2022, Decision No: 2022/250).

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Conflict of Interest: None of the authors involved in our study has any conflict of interest to declare.

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ORİJİNAL ÇALIŞMA - *ÖZ*

Akut anterior talofibular ligament rüptürü olgularında diapozon yardımlı vibrasyon duyusunun proprioseptif ölçüm yöntemi olarak kullanılabilirliği: Tek merkezli çalışma

AMAÇ: Bu çalışmanın amacı, akut ayak bileği burkulmasını takiben anterior talofibular ligament (ATFL) rüptürü olan hastalarda vibrasyon hissindeki değişiklikleri araştırmak ve bunun bir propriyoseptif değerlendirme aracı olarak potansiyel kullanımını değerlendirmektir.
GEREÇ VE YÖNTEM: Ayak bileği inversiyon ve plantar fleksiyonda iken ultrason ile yırtık olarak tanımlanan ATFL bölgesine 128 Hz'lik bir diapozon uygulandı. Titreşim süresi bir kronometre kullanılarak ölçüldü. Veriler sağlıklı bir popülasyondan ve yırtık olmaksızın akut burkulma sonrası lateral ayak bileği ödemi olan hastalardan elde edilen verilerle karşılaştırıldı. Çalışma prospektif olarak tasarlanmıştır.
BULGULAR: Ortalama yaşı 29.19 olan toplam 81 hasta (48 erkek, 33 kadın) çalışmaya dahil edildi. ATFL rüptürü olan 27 hastanın 9'unda ek kalkaneofibüler ligament (CFL) yaralanması ve 5'inde ek posterior talofibüler ligament (PTFL) yaralanması vardı (Grade 2-3). ATFL rüptürü olan hastalarda ortalama titreşim süresi yaralı tarafta 5.72 saniye, yaralanmamış tarafta ise 7.87 saniye olup istatistiksel olarak anlamlı bir fark göstermiştir (p=0.001). 12 haftalık takipte, ortalama titreşim süresi 7.65 saniyeye yükselmiştir ve bu da istatistiksel olarak anlamlıdır (p=0.001).
SONUÇ: Akut ATFL rüptürüne bağlı proprioseptif bozukluk, rüptür bölgesinde vibrasyon hissinin azalmasıyla ilişkilendirilmiştir. Propriosepsiyon iyileştikçe vibrasyon hissi de düzelmiştir. Bu nedenle, diapazon kullanılarak yapılan vibrasyon ölçümü pratik bir propriyoseptif değerlendirme aracı ve yardımcı bir tanı yöntemi olarak hizmet edebilir.

Anahtar sözcükler: ATFL; diapozon; propriosepsiyon; vibrasyon.

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ORIGINAL ARTICLE

Assessing the impact of radiological measurement methods on forensic medical reports in traumatic vertebral compression fractures

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ABSTRACT

BACKGROUND: Vertebral compression fractures of varying severity and morphology may result from trauma and often require the preparation of a forensic medical report. Given the legal implications, accurate measurement of the compression ratio is critical. This study aims to evaluate whether four literature-defined methods for determining compression ratios are consistent with one another and with radiology reports, and to examine whether the choice of method alters the conclusions of forensic medical reports.

METHODS: A retrospective review was conducted of forensic reports issued by our Department of Forensic Medicine between June 1, 2014 and June 1, 2024. Forty-two cases met the predefined inclusion criteria. For each vertebral fracture, the compression ratio was calculated using four established methods. Consistency was assessed both among these methods and between each method and the compression ratio documented in the corresponding radiology report. Finally, it was evaluated whether measurement discrepancies would alter the forensic conclusions regarding (1) the effect of the fracture on life functions, (2) permanent weakness or loss of function of one of the senses or organs, and (3) degree of disability.

RESULTS: Agreement among the four measurement methods was weak to moderate, with inconsistency rates of 14.8% to 66.7% compared to radiology reports. Forensic report conclusions varied according to the measurement method.

CONCLUSION: Method selection significantly influences both calculated compression ratios and the resulting conclusions of forensic reports in vertebral compression fractures. A standardized, universally accepted measurement protocol is therefore required in forensic practice to support fair and consistent legal decisions.

Keywords: Vertebral compression fracture; compression ratio; disability; forensic report.

INTRODUCTION

Trauma-related vertebral fractures constitute a major cause of global mortality and morbidity. In the United States, treatment and rehabilitation costs for spinal and spinal cord injuries rank second only to those for neonatal respiratory distress syndrome.[1,2]

The reported incidence of vertebral injuries among trauma patients ranges from 5.8% to 23.2%.[3,4] Mechanistically, these fractures are classified into four main categories: compression fractures, burst fractures, flexion–distraction (Chance) fractures, and fracture–dislocations.[5,6] Compression fractures are the most prevalent in the thoracic, lumbar, and subaxial cervical regions, accounting for 50%-70% of thoracolumbar vertebral fractures.[6,7]

Traffic accidents, falls, violence, and sports/recreational injuries represent the leading etiologies. The incidence of traumatic spinal fractures is estimated at 136.9 per million in un-

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derdeveloped countries versus 87.2 per million in developed countries, with the highest rates observed among males aged 20–40 years.[2,8,9]

Forensic Medical Significance of Vertebral Fractures

These injuries frequently arise from criminal incidents and require forensic evaluation. Under the Turkish Penal Code (TPC), prosecutorial authorities or criminal courts request definitive forensic medical reports. In civil cases and insurance claims, courts and insurers request assessments of causality and injury-specific disability to support compensation decisions. Therefore, clear, standardized guidelines for defining and reporting these injuries are crucial for accurate determination of criminal penalties and civil compensation.

The TPC, in force since 2005, specifies that a bone fracture increases the applicable penalty according to the "effect of the fracture on life functions" (EFLF). To standardize implementation, a guideline was issued by forensic medicine experts, defining a range of fracture types and assigning severity grades from 1 to 6 [10]. Under this guideline, vertebral compression fractures with a compression ratio (CR) below one-third are graded as 3 (moderate), whereas those exceeding one-third are graded as 4 (severe) (Table 1).

The TPC also provides for increased penalties when an injury causes permanent weakness or loss of function of a sense or organ (PWFO). The accompanying guideline defines this as follows: "If the anatomical loss and/or functional impairment of the organ or extremity corresponds to 10-50% of the organ's or extremity's own anatomical structure and/or function, it should be considered 'permanent impairment of function'; if it exceeds 50%, it should be regarded as 'loss of function'."[10] Completion of the prescribed healing period is required for assessment: six months for conservatively treated adult vertebral corpus fractures and nine months if stabilization procedures have been performed (Table 1).[11]

Disability is defined as the residual impairments that persist after completion of all treatment and rehabilitation. The quantification of these impairments using standardized tables, based on specific clinical parameters, is referred to as the "degree of disability."[12] Assessment of degree of disability also requires completion of the prescribed fracture healing period.[11] In Türkiye, multiple medicolegal/legal regulations have been enacted over time, and the degree of disability is calculated according to the regulation in force at the time of injury (Table 1).[13]

Forensic medical guidelines and tables for vertebral compression fractures—used in both definitive and disability reports—emphasize the vertebral body CR as a key determinant of report outcomes.[10,14-16] However, no universally accepted standard method exists for measuring this ratio.[17,18]

Various methods have been described for calculating the vertebral CR.[17-20] The four most commonly used are:

Method 1: Ratio of the anterior to posterior height of the fractured vertebral body.[17-20]

Method 2: Ratio of the anterior height of the fractured ver-

Table 1. Medicolegal evaluation in vertebral compression fractures

	Vertebral body compression ratio				
	<1/3	**>1/3**	**<25%**	**25-50%**	**>50%**
Definitive report					
Criminal case					
EFLF	3	4			
PWFO	If fusion surgery has been performed, permanent weakness is considered. In other cases, calculation according to the disability tables is recommended.				
Disability report					
Civil case					
Disability Table	15	22[and]			
Impairment Table					
Injury model			8	13/18*	28/23*
ROM model			4/2/5*	6/3/7*	10/5/12*
Disability Guide					
Injury model			8	13/18*	28/23*
ROM model			4/2/5*	6/3/7*	10/5/12*

EFLF: Effect of fracture on life functions; PWFO: Permanent weakness or loss of function of one of the senses or organs. [and]If the compression ratio is greater than ½. *According to the cervical/thoracic/lumbar vertebral segment.

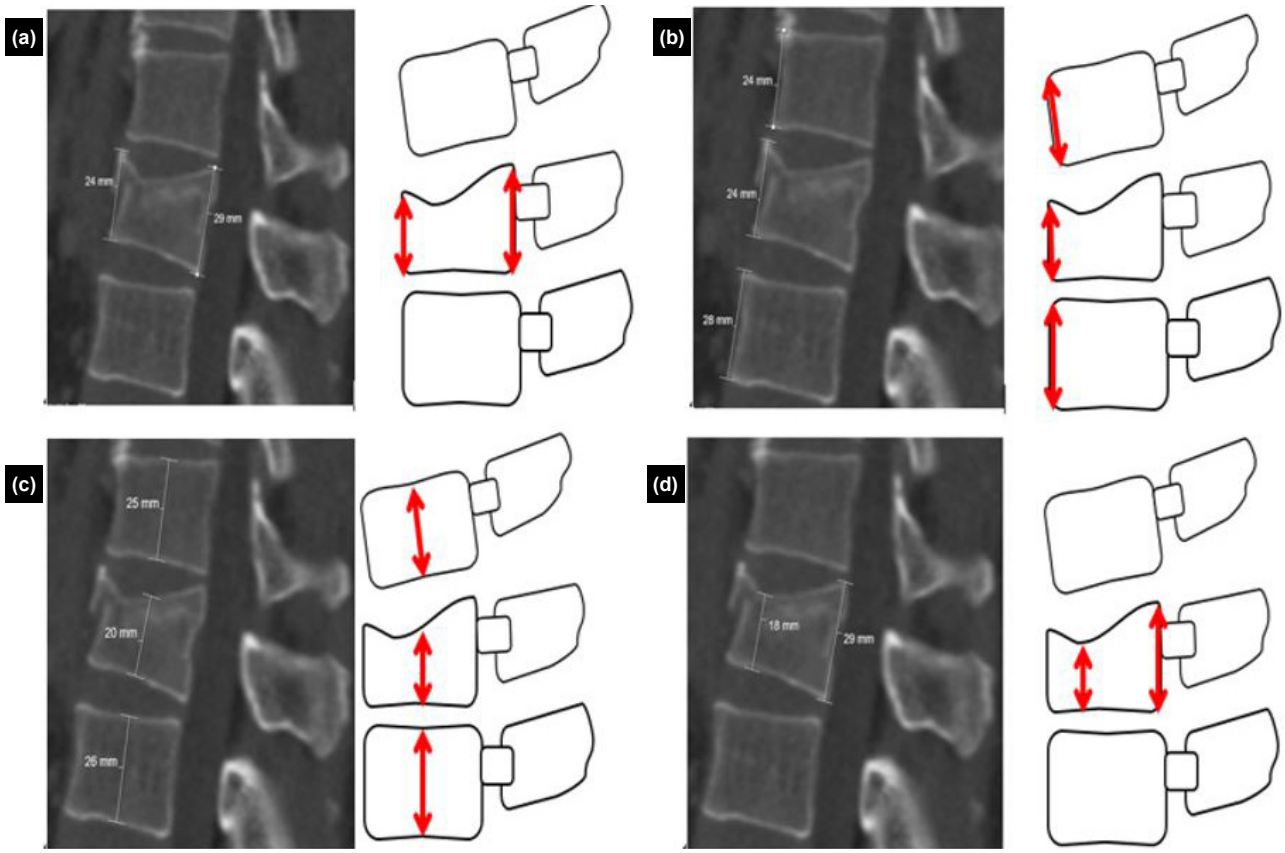

Figure 1. Methods for measuring the compression ratio (CR). **(a)** Method 1; **(b)** Method 2; **(c)** Method 3; **(d)** Method 4. *For example, if the anterior height of the fractured vertebra is 24 mm and the posterior height is 29 mm, the compression rate calculated using Method 1 is: (1-24/29)*100=17.2%.*

tebral body to the mean anterior heights of the adjacent vertebrae.[17-20]

Method 3: Ratio of the mid-vertebral (middle) height of the fractured body to the mean mid-vertebral heights of the adjacent vertebrae.[19]

Method 4: Ratio of the minimal (deepest collapsed) height of the fractured vertebral body to its posterior height (Fig. 1).[17]

A 2016 international survey of experts showed that 51.4%-54.6% of respondents used Method 1, while 34.6%-38.3% used Method 2.[18] Data on the usage frequencies of the other methods are not available.

Although CR is a key determinant in both definitive and disability forensic reports, no standardized measurement method exists. This study aimed to evaluate whether variation in measurement methods for vertebral compression fractures—and therefore the absence of a standardized approach—significantly impacts forensic report outcomes, which play a critical role in both criminal and civil proceedings.

MATERIALS AND METHODS

Ethical Approval of the Study Protocol

This study was conducted with the approval of the Düzce University Clinical Research Ethics Committee (date: 02.09.2024, approval number: 2024/169) and adhered to the principles of the Declaration of Helsinki.

Formation of the Data Group

Case files of definitive and permanent disability reports issued between June 1, 2014 and June 1, 2024, by the Düzce University Department of Forensic Medicine were reviewed retrospectively. Inclusion criteria were vertebral fractures with measurable height loss, accessible radiological images, and a confirmed causal relationship with trauma. Exclusion criteria comprised inadequate image quality, consecutive fractures in the same vertebral region, or unavailable imaging. Each image obtained at a different time and each fracture affecting a distinct vertebra were accepted as separate cases. A total of 42 cases met these criteria. Among them, 27 radiology reports included defined CRs, and 56 forensic reports were analyzed—27 on EFLF, 14 on PWFO, and 15 on degree of disability.

Data Collection and Processing Procedure

Radiological images (computed tomography [CT] or magnetic resonance imaging [MRI]) obtained on the day of injury were used to assess EFLF, whereas images acquired after completion of the defined healing period were used for PWFO and

Table 2. Comparison of cases by age and gender

Gender	Count (n)	Mean Age	Minimum	Maximum	Standard Deviation
Male	32	44.94	17	81	17.71
Female	10	43.00	21	78	20.53
Total	42	44.48	17	81	18.18

Table 3. Correlation between measurement methods [ICC (95% CI)]

	Method 1	Method 2	Method 3	Method 4
Method 2	ICC=0.8538 (0.7441 to 0.9187)			
Method 3	ICC=0.3938 (0.1055 to 0.6211)	ICC=0.5733 (0.3293 to 0.7455)		
Method 4	ICC=0.6357 (0.4141 to 0.7862)	ICC=0.6302 (0.4064 to 0.7826)	ICC=0.7628 (0.5995 to 0.8651)	

disability evaluations. CRs for each vertebral fracture were measured on PACS (Picture Archiving and Communication Systems) using the four methods described above. Radiology reports were reviewed for documented CR; when present, those values were recorded. Each method's CRs were compared pairwise and, where available, against the ratio documented in the radiology report. Furthermore, it was assessed whether variations in these CRs influenced the conclusions of the forensic reports. To assess reliability, all measurements were repeated by the same researcher after a three-week interval, and independently by a second researcher. Intraclass correlation coefficients were calculated for intra- and interobserver agreement.

Statistical Analysis

All analyses were carried out in the SPSS software (IBM Statistical Package for the Social Sciences, v22, Armonk, New York,). Categorical variables were summarized as frequency and percentage; continuous variables as mean±standard deviation, median, and minimum–maximum values. Inter-rater reliability was evaluated using kappa for categorical measures and the intraclass correlation coefficient (ICC) for continuous measures.[21,22]

RESULTS

Descriptive Findings

Of the 42 cases, 76.2% (n=32) were male and 23.8% (n=10) were female. Ages ranged from 17 to 81 years (mean±SD: 44.48±18.18) (Table 2).

A total of 56 forensic reports were generated for these cases: 27 on EFLF, 14 on PWFO, and 15 on degree of disability. Of the 15 cases evaluated for disability, six were assessed using the Disability Guide, four using the Impairment Table, and five using the Disability Table (Fig. 2).

In this study, in-vehicle traffic accidents were the leading cause of vertebral compression fractures (54.8%, n=23), followed by pedestrian injuries (26.2%, n=11). The least common etiology was impact from a falling heavy object (2.4%, n=1) (Fig. 3). Fractures were most frequent at L1 (21.4%, n=9), followed by L4 (14.3%, n=6), L2 (11.9%, n=5), and T12 (9.5%, n=4) (Fig. 4).

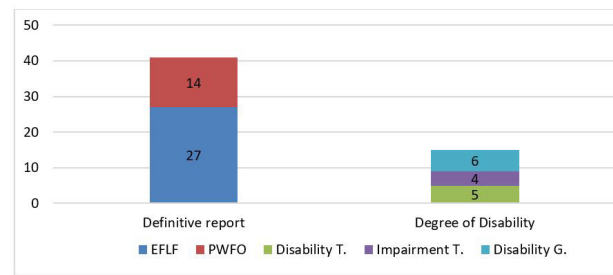

Figure 2. Distribution of cases according to the type of forensic report issued.

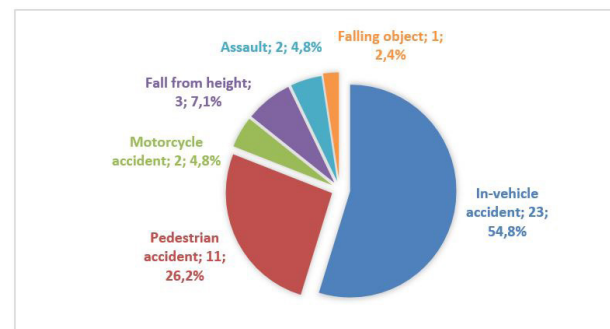

Figure 3. Percentage distribution of cases by type of incident.

Table 4. Comparison of radiology reports and measurement methods

	Radiology Reports (n)	%
Method 1		
Compatible	18	66.7
Incompatible	9	33.3
No data	15	-
Method 2		
Compatible	23	85.2
Incompatible	4	14.8
No data	15	-
Method 3		
Compatible	19	70.4
Incompatible	8	29.6
No data	15	-
Method 4		
Compatible	9	33.3
Incompatible	18	66.7
No data	15	-
Total	42	100%

Correlation Between Radiological Measurement Methods

Comparison of CRs across the four methods revealed the highest agreement between Method 1 and Method 2 (ICC=0.8538) and between Method 3 and Method 4 (ICC=0.7628). The lowest agreement was observed between Method 1 and Method 3 (ICC=0.3958) (Table 3).

Comparison of Radiological Measurement Methods with Radiology Report Results

Of the 42 imaging studies, each had an accompanying radiology report, but 15 of these did not specify a CR. Among the 27 reports with available ratios, the rates of discrepancy between the radiologist-reported value and each measurement method were: 14.8% (n=4) for Method 2, 29.6% (n=8) for Method 3, 33.3% (n=9) for Method 1, and 66.7% (n=18) for Method 4 (Table 4).

Comparison of Radiological Measurement Methods with Issued Forensic Report Results

For the assessment of EFLF, CRs derived from all four radiological measurement methods were inconsistent with the corresponding forensic report conclusions. Pairwise comparisons among the four radiological methods revealed good agreement between Method 1 and Method 2 (κ=0.630; 95% CI, 0.172–1.000), moderate agreement between Method 3 and Method 4 (κ=0.497; 95% CI, 0.190–0.804), and poor agreement between Method 2 and Method 4 (κ=0.404; 95% CI, 0.099–0.709). All other method pairs showed poor agreement (Table 5).

In comparison with the PWFO conclusions, Method 3 demonstrated good agreement (κ=0.755, 95% CI, 0.307–1.000) and Method 2 showed moderate agreement (κ=0.567, 95% CI, 0.032–1.000), whereas Method 1 (κ=–0.418, 95% CI, –0.124–0.960) and Method 4 (κ=0.235, 95% CI, –0.054–0.525) were inconsistent. Pairwise comparisons among the four methods showed that Method 1 and Method 2 agreed well (κ=0.806, 95% CI, 0.448–1.000), Method 2 and Method 3 also showed good agreement (κ=0.755, 95% CI, 0.307–1.000), and Method 1 and Method 3 exhibited moderate agreement (κ=0.581, 95% CI, 0.0953–1.000), while Method 4 remained inconsistent with all others (Table 6).

Comparing the conclusions of the 15 disability reports with the results from each radiological measurement method revealed discrepancies in 20% (n=3) of cases for Method 1, 33.3% (n=5) for Method 2, 13.3% (n=2) for Method 3, and 40% (n=6) for Method 4 (Table 7).

Assessment of Measurement Consistency

Intra- and interobserver reliability was assessed by having the primary researcher repeat all measurements three weeks af-

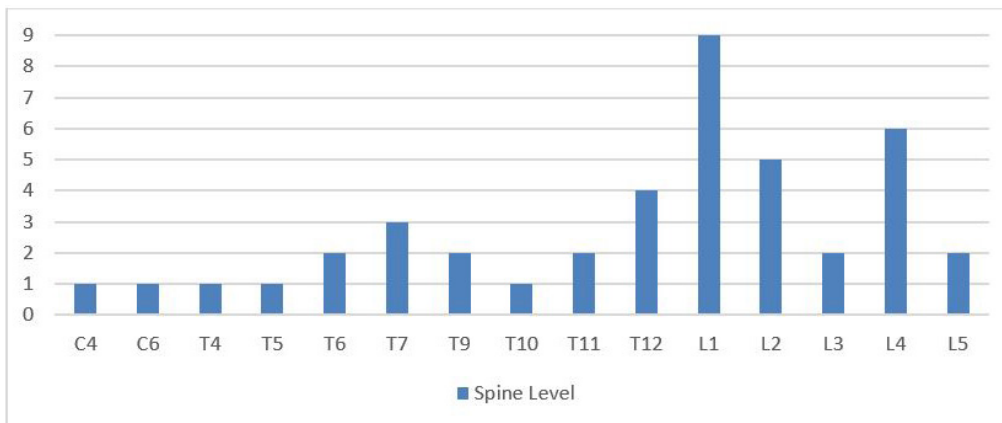

Figure 4. Distribution of vertebral fractures by spinal level.

Table 5. Comparison between forensic report values and measurement-based values for the severity grade of EFLF (effect of the fracture on life functions)

n=27	Forensic Report Value			Method 1			Method 2			Method 3		
	3	4	κ (95% CI)	3	4	κ (95% CI)	3	4	κ (95% CI)	3	4	κ (95% CI)
M1												
3	18	7	κ= -0.130									
4	2	0	(-0.281 to 0.0204)									
M2												
3	18	5	κ=0.216	23	0	κ=0.630						
4	2	2		2	2	(-0.190 to 0.621)			(0.172 to 1.000)			
M3												
3	18	4	κ=0.362	20	2	κ=-0.118	20	2	κ=0.335			
4	2	3	(-0.0438 to 0.768)	5	0	(-0.244 to 0.00724)	3	2	(-0.121 to 0.791)			
M4 3	13	3	κ=0.187	16	0	κ=0.208	16	0	κ=0.404	16	0	κ=0.497
4	7	4	(-0.174 to 0.548)	9	2	(-0.0496 to 0.467)	7	4	(0.0986 to 0.709)	6	5	(0.190 to 0.804)

M1: Method 1; M2: Method 2; M3: Method 3; M4: Method 4. EFLF: Effect of fracture on life functions.

Table 6. Comparison between forensic report decisions and measurement-based decisions for PWFO (permanent weakness or loss of function of one of the senses or organs)

n=13	Forensic Report Value			Method 1			Method 2			Method 3		
	N	W	κ (95% CI)	N	W	κ (95% CI)	N	W	κ (95% CI)	N	W	κ (95% CI)
M1												
N	8	1	κ= -0.418									
W	2	2	(-0.124 to 0.960)									
M2												
N	9	1	κ=0.567	9	1	κ=0.806						
W	1	2		0	3	(0.448 to 1.000)						
M3												
N	10	1	κ=0.755	9	2	κ=0.581	10	1	κ=0.755			
W	0	2	(0.307 to 1.000)	0	2	(0.0953 to 1.000)	0	2	(0.307 to 1.000)			
M4 N	4	0	κ=0.235	4	0	κ=0.330	4	0	κ=0.235	4	0	κ=0.150
W	6	3	(-0.0540 to 0.525)	5	4	(-0.0121 to 0.672)	6	3	(-0.0540 to 0.525)	7	2	(-0.0756 to 0.375)

M1: Method 1; M2: Method 2; M3: Method 3; M4: Method 4. PWFO: Permanent weakness or loss of function of one of the senses or organs. N: Normal; W: Weakness.

ter the initial evaluation, and a second researcher independently measure each case using each method. Intraclass correlation analysis demonstrated excellent consistency for all methods (Table 8).

DISCUSSION

This study analyzed 42 cases of trauma-related vertebral compression fractures reported by our Department of Forensic Medicine. Of these, 76.2% (n=32) were male and 23.8% (n=10) female, with mean ages of 44.94±17.71 years for males and 43.00±20.53 years for females. Incident etiology included in-vehicle traffic accidents in 54.8% (n=23), pedestrian injuries in 26.2% (n=11), and falls from height in 7.1% (n=3). Although epidemiological data vary according to country development level, incident type, and study year, most literature reports a predominance of males aged 31.7–50.9 years, with traffic accidents as the leading cause and falls from height as the second most common mechanism.[2-4,7,8,23] Therefore, our cohort is consistent with the literature in terms of gender distribution, age, and etiology.

Table 7. Comparison between forensic report and measurement-based values for disability ratios

n=15	Forensic Report Value	Method 1	Method 2	Method 3	Method 4
Case 3	8	13	13	8	13
Case 7	29	21.2	21.2	29	29
Case 8	4	4	4	4	4
Case 9	4	4	4	4	5
Case 12	15	15	0	0	15
Case 13	17	17	17	17	17
Case 16	32	32	32	32	32
Case 20	8	8	8	8	13
Case 22	23.5	23.5	23.5	23.5	23.5
Case 23	37	37	37	37	37
Case 27	26.2	26.2	26.2	26.2	26.2
Case 29	18	18	8	18	23
Case 32	8	8	0	8	18
Case 35	8	13	13	8	13
Case 36	13	13	13	8	13
Rate of differing results (n,%)		**3 (20%)**	**5 (33.3%)**	**2 (13.3%)**	**6 (40%)**

Table 8. Interobserver correlation

	1st researcher (1st and 2nd measurements)		1st researcher and 2nd researcher	
	ICC	95% CI	ICC	95% CI
Method 1	0.9579	0.9232-0.9772	0.9274	0.8690-0.9603
Method 2	0.9901	0.9817-0.9947	0.9703	0.9454-0.9839
Method 3	0.9729	0.9502-0.9854	0.9695	0.9440-0.9835
Method 4	0.9516	0.9118-0.9737	0.9433	0.8970-0.9691

In our cohort, transportation-related incidents (in-vehicle, motorcycle, and pedestrian accidents) comprised 85.3% of cases—markedly higher than rates reported in previous studies.[2-4] This likely reflects our exclusive inclusion of vertebral injuries undergoing forensic evaluation, as self-inflicted or non-forensically referred events (e.g., simple falls, heavy-object impacts, sports injuries) often bypass forensic assessment.

As emphasized in the literature, the thoracolumbar junction (T10–L2) accounts for over half of all spinal fractures, a vulnerability attributed to its transitional anatomy between kyphosis and lordosis, high mobility, exposure to diverse mechanical forces, and relatively weak muscular support. In our series, fractures most commonly involved L1 (n=8), L4 (n=6), L2 (n=5), and T12 (n=4), with 47.6% (n=20) of cases affecting the thoracolumbar junction, consistent with previous reports.[5,24,25]

From a clinical standpoint, multiple classification systems have been proposed to guide the choice between conservative and surgical management of vertebral compression fractures.[26,27] Although contemporary schemes incorporate a range of radiological and clinical parameters, assessment of vertebral height loss remains a cornerstone of the most widely used practical classifications.[28]

Despite its recognized importance, no single classification has achieved universal acceptance, nor has any standardized protocol for measuring vertebral height loss been established.[17,18] This lack of consensus undermines the validity and consistency of treatment decisions. In their 2006 review, the Spine Trauma Study Group evaluated several measurement techniques—detailing each method's strengths and limitations—and ultimately recommended Method 2 for routine clinical practice.[17]

In a 2016 global survey of neurosurgeons, orthopedic surgeons, and trauma surgeons, practitioners were asked which

method they employ to assess vertebral height loss. Depending on the vertebral segment and geographic region, 51.4% to 54.6% of respondents favored Method 1, whereas 34.6% to 38.3% preferred Method 2. This study not only highlights the absence of consensus in clinical practice but also challenges the earlier endorsement of Method 2, arguing that such recommendations should await further reliability investigations.[18]

Method 1 quantifies vertebral compression by calculating the ratio of the anterior to posterior height of the fractured vertebral body. This straightforward and rapid approach evaluates the structural integrity of the anterior and middle columns. However, in burst fractures the posterior wall may also collapse, leading to underestimation of the true degree of compression.[19,20] In our series, CRs derived using this method differed by more than one-third from those reported by the radiology specialist and were discordant with both the EFLF and PWFO determinations in the forensic reports. Moreover, application of Method 1 would have altered the disability rating in 20% of the disability reports.

Method 2 defines vertebral compression as the ratio of the anterior height of the injured vertebra to the mean anterior heights of the adjacent vertebrae. By anchoring measurements to intact vertebrae, this approach remains valid even when collapse affects the entire vertebral body. Comparative analyses have shown that Method 1 underestimates compression relative to Method 2, and Method 2 has been specifically recommended for burst fractures.[19,20] In our cohort, CRs calculated using Method 2 diverged from the radiology specialist's values in 14.8% of cases. Poor correlation was observed with EFLF determinations, while moderate agreement was found with PWFO assessments. Moreover, applying Method 2 would have altered the disability rating in one-third of the forensic disability reports.

Method 3 quantifies vertebral compression by comparing the mid-vertebral height of the injured vertebra to the mean mid-vertebral heights of the adjacent cephalad and caudad segments. Limited radiographic evidence suggests that other techniques may underdiagnose fractures with prominent central column collapse, particularly in osteoporotic spines where mid-body weakness predisposes to instability.[14] In our series, CRs calculated by Method 3 differed from the radiology specialist's measurements in 29.6% of cases. This method exhibited poor agreement with EFLF determinations but good agreement with PWFO assessments, and it would have altered the disability rating in 13.3% of the forensic disability reports.

Method 4 defines vertebral compression as the ratio of the point of maximal collapse to the posterior height of the fractured vertebra. Although this approach lacks robust validation, it is argued to better capture focal deformities than fixed-wall techniques.[19] In our series, CRs derived by Method 4 diverged from the radiologist's measurements in 66.7% of cases and showed poor agreement with both EFLF and PWFO determinations. Moreover, applying this method would have altered the disability rating in 40% of forensic reports. Despite its theoretical advantage—since trauma can produce collapse in varying vertebral regions—Method 4 proved the least consistent with expert assessments and yielded the highest rate of discrepancies in disability evaluations.

Pairwise comparisons among the four measurement methods revealed that none demonstrated perfect consistency. The strongest agreement occurred between Methods 1 and 2 (ICC=0.8538), which may reflect their shared reliance on anterior vertebral height. Yet, the robust correlation between Methods 3 and 4 (ICC=0.7628), despite no common measurement parameter, and the moderate agreement between Methods 1 and 4 (ICC=0.6357), both of which employ posterior vertebral height, call this assumption into question. All remaining intermethod comparisons yielded only weak to moderate consistency.

Articles 87 and 95 of the Turkish Penal Code define "aggravated injury resulting in consequences" and "aggravated torture resulting in consequences," respectively, prescribing enhanced penalties when a bone fracture is demonstrated. Because vertebral fracture CRs are calculated using various non-standardized formulas, forensic reports may assign disparate EFLF ratings (and thus different sentences) for identical fracture patterns. In our study, none of the four measurement methods demonstrated consistency with the EFLF determinations recorded in forensic reports. This inconsistency underscores the urgent need for forensic experts and injury assessment authorities to adopt a single, validated protocol for quantifying vertebral compression fractures.[10]

Articles 87, 89, and 95 of the Turkish Penal Code designate permanent weakening of function as an aggravating factor in sentencing. The accompanying guideline lists commonly encountered conditions and specifies only spinal injuries treated with fusion surgery as PWFO. Although vertebral fractures are both frequent and highly morbid, no additional fracture patterns are defined; for unlisted conditions, the guideline refers to general disability–impairment tables. In our study, we compared each radiological measurement method's results with the PWFO determinations recorded in the forensic reports. Methods 1 and 4 showed poor agreement with the issued PWFO decisions, whereas Methods 2 and 3 demonstrated moderate agreement.

When we compared measurement methods against 15 issued disability reports, we found inconsistencies in 20% of cases for Method 1, 33.3% for Method 2, 13.3% for Method 3, and 40% for Method 4. Such discrepancies between expert reports may raise doubts among decision-makers regarding their reliability. Our data indicate that these inconsistencies stem not only from differences in expert opinions but also from measurement techniques. This situation underscores the urgent need for standardization of vertebral compression assessment in forensic medicine practices.

Another critical concern involves the imaging reports issued

by radiology specialists. In our series, approximately one-third of these reports noted only the presence of a fracture and omitted any quantification of vertebral compression. Among the reports that did include a CR, none specified the measurement method employed.

From a clinical standpoint, treatment decisions integrate multiple parameters defined by fracture classification systems—fracture morphology, neurological status, and comorbidities—and spine surgeons typically review imaging studies directly. In forensic practice, however, the reported CR profoundly influences expert conclusions, even when no other abnormalities are present, and forensic physicians customarily base their evaluations on the radiologist's report.

In practice, forensic authorities sometimes must issue reports based solely on medical documentation—without direct patient examination—or may lack access to the underlying imaging studies. In our series of 27 cases in which radiology reports specified a CR, the proportions of measurements that diverged from the radiologist's value were 33.3% for Method 1, 14.8% for Method 2, 29.6% for Method 3, and 66.7% for Method 4.

Although our investigation was limited to a single center, the ten-year inclusion period and the outsourcing of emergency imaging to external radiology services resulted in fracture reports prepared by a wide array of radiologists. The pronounced discrepancies between radiologists' documented CRs and those derived from our standardized measurement methods imply an underlying lack of consistency in vertebral height assessment protocols.

A single-point variation in EFLF severity grading or a determination of PWFO can markedly increase criminal penalties, and even a 1% discrepancy in measured compression may alter civil compensation. Such variability—rooted in non-standardized measurement techniques—is therefore unacceptable. Expert witnesses must base their reports on rigorous scientific and technical methods before submitting them to judicial authorities.[29] Yet forensic evaluations often depend on radiology reports that either omit the CR altogether or fail to specify the measurement method used. In our series, none of the four methods we assessed fully corresponded to the CRs documented by radiologists.

Limitations

The main limitation of this study was the modest sample size. Factors contributing to this include the relatively small population of our province, the fact that forensic medical reports are also prepared by the Forensic Medicine Branch Directorate and state hospital outside our department, the poor image quality in some cases, and our inability to obtain radiographs taken at external centers.

CONCLUSION

Multiple techniques are available for quantifying vertebral compression in fracture cases, yet no universally accepted standard method exists. The vast majority of studies address measurement from a clinical standpoint and—to our knowledge—none have explored its medicolegal implications.

Omitting the measurement protocol in both radiological and forensic reports leads to inconsistent evaluations and threatens procedural fairness. To prevent such disparities and uphold judicial integrity, forensic assessments must adopt a single, validated measurement procedure that aligns with legal criteria. Expert opinions should meet the highest scientific and technical standards, integrating vertebral compression quantification into disability and impairment frameworks as well as forensic medical practice.

We recommend conducting multicenter studies with larger cohorts to identify the most reliable measurement method and establish consensus guidelines for vertebral compression assessment.

Ethics Committee Approval: This study was approved by the Düzce University Clinical Research Ethics Committee Ethics Committee (Date: 02.09.2024, Decision No: 2024/169).

Peer-review: Externally peer-reviewed.

Authorship Contributions: Concept: A.S., B.B.; Design: A.S., B.B., M.A.S.; Supervision: A.S., B.B.; Materials: A.S., S.A.; Data collection and/or processing: A.S., S.A.; Analysis and/or interpretation: M.A.S., A.S.; Literature review: A.S., So.A.; Writing: A.S., So.A.; Critical review: A.S., B.B., M.A.S., S.A., So.A.

Conflict of Interest: None declared.

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ORİJİNAL ÇALIŞMA - *ÖZ*

Travmatik vertebra kompresyon kırıklarında radyolojik ölçüm yöntemlerinin adli tıbbi raporlar üzerindeki etkisinin değerlendirilmesi

AMAÇ: Travma sonucunda farklı şiddet ve morfolojide vertebra kompresyon kırıkları oluşabilmekte ve çoğu zaman adli tıbbi rapor hazırlanması gerekmektedir. Hukuki sonuçları göz önüne alındığında, kompresyon oranının doğru ölçülmesi kritik öneme sahiptir. Bu çalışma, literatürde tanımlanmış dört farklı ölçüm yönteminin kompresyon oranını belirlemede birbirleriyle ve radyoloji raporlarıyla uyumlu olup olmadığını değerlendirmeyi ve yöntem seçiminin adli tıbbi rapor sonuçlarını değiştirip değiştirmediğini incelemeyi amaçlamaktadır.
GEREÇ VE YÖNTEM: 1 Haziran 2014 ile 1 Haziran 2024 tarihleri arasında Adli Tıp Anabilim Dalı tarafından düzenlenmiş adli raporlar retrospektif olarak incelenmiştir. Önceden belirlenmiş dahil etme kriterlerini karşılayan 42 olgu çalışmaya dahil edilmiştir. Her bir vertebra kırığı için kompresyon oranı, literatürde tanımlanmış dört farklı yöntemle hesaplanmıştır. Tutarlılık hem bu yöntemler arasında hem de her bir yöntem ile ilgili radyoloji raporunda belgelenen kompresyon oranı ile karşılaştırılarak değerlendirilmiştir. Son olarak, ölçüm farklılıklarının adli tıbbi raporlardaki şu üç konuda sonucu değiştirip değiştirmediği incelenmiştir: (1) Kırığın hayat fonksiyonlarına etkisi, (2) duyu veya organlardan birinin işlevinde sürekli zayıflama ya da kayıp, (3) engellilik oranı.
BULGULAR: Dört ölçüm yöntemi arasındaki uyum zayıf ile orta düzeyde bulunmuş olup, radyoloji raporlarıyla karşılaştırıldığında tutarsızlık oranları %14.8 ile %66.7 arasında değişmiştir. Adli tıbbi rapor sonuçları, kullanılan ölçüm yöntemine göre farklılık göstermiştir.
SONUÇ: Yöntem seçimi, hem hesaplanan kompresyon oranlarını hem de vertebra kompresyon kırıklarına ilişkin adli tıbbi raporların sonuçlarını önemli ölçüde etkilemektedir. Bu nedenle, adli uygulamalarda adil ve tutarlı hukuki kararları desteklemek amacıyla standart ve evrensel olarak kabul edilmiş bir ölçüm protokolüne ihtiyaç vardır.

Anahtar sözcükler: Adli tıbbi rapor; engellilik; kompresyon oranı; vertebra kompresyon kırığı.

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ORIGINAL ARTICLE

Functional outcomes of tibial medullary cancellous bone graft combined with allograft in medial open-wedge high tibial osteotomy: A retrospective cohort study

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ABSTRACT

BACKGROUND: We evaluated the long-term outcomes of bone autograft versus tibial medullary cancellous bone graft combined with allograft as therapeutic interventions for medial compartment osteoarthritis associated with genu varum deformity.

METHODS: This retrospective cohort study included patients with knee osteoarthritis who underwent medial open-wedge high tibial osteotomy (MOWHTO), receiving either an autogenous bone graft or a tibial medullary cancellous bone graft combined with an allograft. Clinical status was assessed using the Visual Analog Scale (VAS) and the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC). Radiological parameters, including the hip-knee-ankle angle (HKA), medial proximal tibial angle (MPTA), and femorotibial angle (FTA), were measured preoperatively and at the 6-month follow-up.

RESULTS: In total, 157 patients were included: 81 in Group A (autograft) and 76 in Group B (tibial medullary cancellous bone graft combined with allograft). No significant differences were observed between the groups in postoperative HKA, MPTA, and FTA values. However, VAS and WOMAC scores were significantly lower in the combined graft group.

CONCLUSION: The use of a combined tibial medullary cancellous bone graft with allograft in MOWHTO is associated with improved functional outcomes at the 6-month follow-up, as evidenced by statistically significantly reduced VAS and WOMAC scores.

Keywords: Medial opening wedge high tibial osteotomy; cancellous bone allograft; function; outcome; allograft; autograft.

INTRODUCTION

Degenerative joint diseases have become increasingly significant public health concerns, largely due to the growing prevalence of the aging population worldwide.[1-4] Of these, knee osteoarthritis (KOA) is one of the most prevalent and debilitating conditions. KOA is characterized by progressive degeneration of articular cartilage, subchondral bone remodeling, and synovial inflammation. These pathological changes lead to pain, stiffness, and reduced mobility, ultimately impairing joint function. As a leading cause of disability, KOA imposes substantial social and economic burdens globally.[2,3,5]

Medial opening wedge high tibial osteotomy (MOWHTO) is a widely used surgical intervention for patients with medial compartment knee osteoarthritis. By strategically inserting a medially based wedge into the proximal tibia, the procedure facilitates realignment of the mechanical axis of the lower limb. This realignment reduces the load on the medial compartment and promotes a more balanced distribution of joint forces. Consequently, MOWHTO improves functional capacity and alleviates pain.[1,6]

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The choice of material to fill the osteotomy gap created during MOWHTO remains uncertain.[3-6] Autologous bone grafts harvested from the iliac crest have long been considered the gold standard due to their osteogenic, osteoinductive, and osteoconductive properties.[4,7,8] However, their use is associated with several drawbacks, including prolonged operative time, donor site morbidity, and significant postoperative pain.[9,10] To overcome these limitations, various alternatives have been proposed, such as the use of allogenic bone grafts, leaving the osteotomy site unfilled, or using synthetic bone substitutes as viable replacements for autologous grafts.[6,11,12]

Concurrently, an intramedullary cancellous autograft harvested from the osteotomy site itself may be used to fill the osteotomy gap.[4] However, the quantity of autograft obtained from this site is sometimes insufficient for complete defect filling.[4] Therefore, a composite graft comprising intramedullary autograft and allograft can serve as an effective alternative to augment the osteotomy site. Each grafting option presents distinct advantages and limitations, and the choice of material should be individualized based on the patient's clinical context, anatomical considerations, and surgical objectives.[4,13,14]

The primary objective of our study was to evaluate the long-term outcomes of using bone autograft alone or a combination of tibial intramedullary cancellous bone graft and allograft in the treatment of medial compartment osteoarthritis associated with genu varum deformity. The secondary objective was to compare radiological outcomes between the autograft group and the combined graft group.

MATERIALS AND METHODS

The Ethics Committee of Haydarpaşa Numune Training and Research Hospital, Health Sciences University, approved the study protocol (approval number: HNEAH-GOAEK2024-109). The study was performed in accordance with the Declaration of Helsinki. This retrospective cohort study included patients with KOA who underwent MOWHTO and received either an autogenous bone graft or a combination of tibial medullary cancellous bone graft and allograft.

Sample sizes were determined using G*Power (version 3.1.9.7, University of Düsseldorf, Düsseldorf, Germany) for a power analysis. The analysis indicated that 81 patients in Group A and 76 patients in Group B were required to achieve 87.5% power to detect a medium effect size (Cohen's d = 0.5) using an independent-samples t-test with a two-tailed alpha level of 0.05. Inclusion criteria comprised patients who underwent MOWHTO between January 1, 2018, and January 1, 2023, with a minimum knee range of motion of 100°, a maximum flexion contracture of 10°, and no significant cartilage damage in the lateral compartment or patellofemoral joint.

Patients were excluded if they had secondary osteoarthritis; underwent open-wedge high tibial osteotomy (OWHTO) in combination with ligament reconstruction, revision OWHTO, double osteotomy, or bilateral OWHTO; required arthroscopic or bone tumor procedures; had an osteotomy gap width of <10 mm; a follow-up duration of <12 months; or had incomplete medical records.

Preoperative and postoperative assessments were conducted using full-length, standing anteroposterior radiographs of the lower extremity. Radiographic parameters included the hip-knee-ankle angle (HKAA), medial proximal tibial angle (MPTA), and femorotibial angle (FTA). These measurements were obtained preoperatively and at the 6-month postoperative follow-up. Delayed union was defined as persistent pain at the osteotomy site on physical examination and the absence of radiographic evidence of bone union at 3 months postoperatively. Nonunion was defined as the continuation of these clinical and radiological findings at 6 months postoperatively. Bone healing was assessed based on osteoconductivity and absorbability. Osteoconductivity was evaluated using a modified Van Hemert scoring system, wherein patients assigned to Group 3 or higher were considered to have achieved adequate bone union. The clinical status of the knee was assessed using the Visual Analog Scale (VAS) for pain and the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC). VAS and WOMAC scores were recorded for each patient during the follow-up period after MOWHTO surgery at our institution.

Surgical Technique

Under fluoroscopic guidance, a 2.0 mm Kirschner wire (K-wire) was used to delineate the joint line, ensuring accurate parallel alignment. Subsequently, a 2.5 mm K-wire was placed to mark the osteotomy trajectory in the frontal plane, defining the optimal orientation of the cut. The osteotomy was performed starting at the superior border of the pes anserinus and extending medially to within 1 cm of the lateral cortical margin, while maintaining a safe distance of 20–25 mm from the proximal tibial articular surface. Controlled and gradual distraction of the osteotomy site was achieved using a spreading clamp, with careful elevation of the distal fragment in both the anterior and posterior directions to ensure uniform opening while preserving the integrity of the lateral cortex. A curette was used to harvest cancellous bone from the adjacent osteotomy surfaces. The harvested bone was morselized and used to augment the osteotomy site beneath the fixation plate.

Stabilization was achieved using a high tibial open wedge osteotomy plate (Deva Orthopaedic Implants, Istanbul, Türkiye), positioned anterior to the posterior tibial cortex to ensure optimal mechanical support and alignment. The harvested cancellous autograft was inserted into the osteotomy site, filling anterior and posterior gaps, and compressed between the bony cortex and periosteum to ensure a secure and stable construct. In cases where the volume of autologous graft was insufficient, an allogenic cancellous bone graft (crushed/chip form; Alamo Biologics, San Antonio, TX, USA) was used to supplement the osteotomy gap, enhancing structural integrity

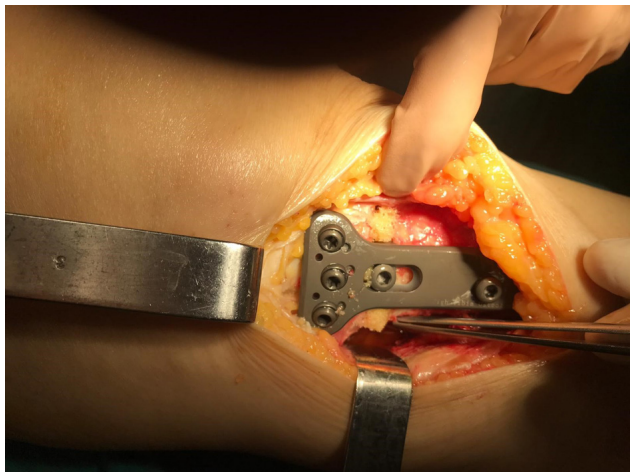

Figure 1. Image of the surgical procedure.

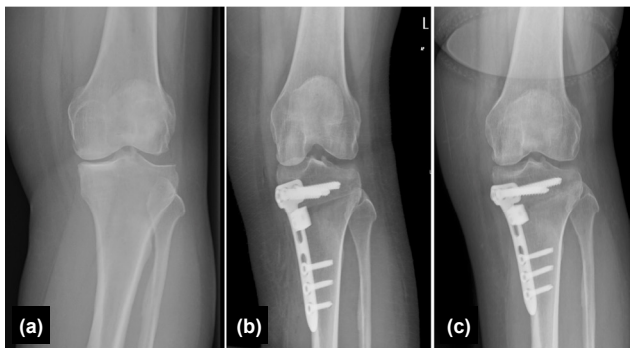

Figure 2. Anteroposterior (AP) radiograph of a patient with autograft. **a)** Preoperative AP radiograph; **b)** Early postoperative AP radiograph with autograft only; **c)** Late postoperative AP radiograph with autograft only.

and promoting durable bone healing. Appropriate gap filling with allograft was achieved in all cases. On average, 12.7±3 cc of allograft was used. The surgical procedure is demonstrated in Figure 1. Preoperative and postoperative early and late anteroposterior (AP) radiographs of the groups are shown in Figures 2 and 3.

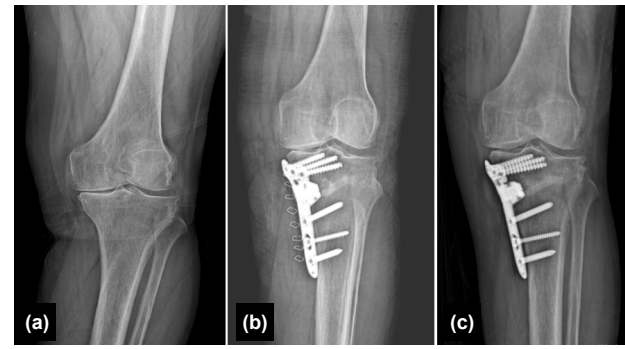

Figure 3. Anteroposterior (AP) radiographs of a patient with combined autograft and allograft. **a)** Preoperative AP radiograph; **b)** Early postoperative AP radiograph with autograft+allograft; **c)** Late postoperative AP radiograph with autograft+allograft.

Statistical Analyses

Statistical analyses were performed using SPSS (version 22.0; IBM Corp., Armonk, NY, USA). Categorical variables are expressed as frequencies and percentages, whereas continuous variables are presented as mean±standard deviation. The Kolmogorov–Smirnov test was used to assess the normality of the distribution. Comparisons of categorical variables between groups were conducted using Fisher's exact test or Pearson's chi-square test, as appropriate. Continuous variables were compared between groups using the independent samples t-test for normally distributed data and the Mann–Whitney U test for non-normally distributed data. For within-group pre- and postoperative comparisons of normally distributed variables, the paired samples t-test was used. Radiographs were independently reviewed by two orthopedic surgeons specializing in knee surgery. Intra- and inter-observer reliabilities were evaluated using the intraclass correlation coefficient. P-values <0.05 were considered statistically significant.

RESULTS

In total, 157 patients were included in the study: 81 patients in

Table 1. Pearson's chi-square test results for postoperative complications – comparison between autograft group and combined allograft and autograft group

Complication	Autograft Group, n (%)	Combined Allograft and Autograft Group, n (%)	p-value
Fracture extending to tibial plateau	7 (8.6)	5 (6.6)	0.767
Modified Hemert Score 3–5	80 (98.7)	73 (96.1)	0.355
Delayed union	1 (1.2)	3 (3.9)	0.355
Lateral cortex disruption	5 (6.2)	2 (2.6)	0.444
Local superficial infection	1 (1.2)	0	
Hyposensitivity in area of cutaneous branch of saphenous nerve	7 (8.6)	0	0.014
Lateral cortex fracture	9 (11.1)	2 (2.6)	0.058

Table 2. Paired samples t-test results for the autograft group

Variable	Mean±SD	p-value
Preoperative MPTA (°)	84.74±0.14	<0.001
Postoperative MPTA (°)	94.75±0.22	
Preoperative FTA (°)	180.22±0.185	<0.001
Postoperative FTA (°)	170.66±0.17	
Preoperative VAS	34.02±0.28	<0.001
Postoperative VAS	17.87±0.20	
Preoperative WOMAC (Total)	44.37±0.33	<0.001
Postoperative WOMAC (Total)	25.37±0.39	
Preoperative WOMAC (Pain)	9.88±0.16	<0.001
Postoperative WOMAC (Pain)	4.66±0.15	
Preoperative WOMAC (Stiffness)	3.83±0.13	0.010
Postoperative WOMAC (Stiffness)	3.72±0.13	
Preoperative WOMAC (Function)	30.66±0.26	<0.001
Postoperative WOMAC (Function)	16.98±0.30	
Preoperative HKA Angle (°)	10.74±0.10	<0.001
Postoperative HKA Angle (°)	8.64±0.12	

FTA: Femorotibial angle; HKA: Hip-knee-ankle angle; MPTA: Medial proximal tibial angle; VAS: Visual Analog Scale; WOMAC: Western Ontario and McMaster Universities Osteoarthritis Index.

Table 3. Paired samples t-test results for the tibial medullary cancellous bone graft combined with allograft group

Variable	Mean±SD	p-value
Preoperative MPTA (°)	84.66±1.17	<0.001
Postoperative MPTA (°)	94.35±2.26	
Preoperative FTA (°)	180.15±1.88	<0.001
Postoperative FTA (°)	171.09±1.42	
Preoperative VAS	33.85±2.35	<0.001
Postoperative VAS	17.23±1.33	
Preoperative WOMAC (Total)	43.65±3.11	<0.001
Postoperative WOMAC (Total)	24.04±2.88	
Preoperative WOMAC (Pain)	9.80±1.55	<0.001
Postoperative WOMAC (Pain)	4.31±1.10	
Preoperative WOMAC (Stiffness)	3.75±1.20	0.019
Postoperative WOMAC (Stiffness)	3.66±1.14	
Preoperative WOMAC (Function)	30.10±2.20	<0.001
Postoperative WOMAC (Function)	16.06±2.12	
Preoperative HKA Angle (°)	11.13±2.19	<0.001
Postoperative HKA Angle (°)	8.74±2.25	

FTA: Femorotibial angle; HKA: Hip-knee-ankle angle; MPTA: Medial proximal tibial angle; VAS: Visual Analog Scale; WOMAC: Western Ontario and McMaster Universities Osteoarthritis Index.

Group A (autograft) and 76 patients in Group B (tibial medullary cancellous bone graft combined with allograft). In Group A, 73 patients (90.1%) were female and 8 (9.9%) were male. In Group B, 60 patients (78.9%) were female and 16 (21.1%) were male. No statistically significant differences were observed in sex distribution between the groups (p=0.075). The mean age in the autograft group was 53.21±6.60 years, whereas the mean age in the combined graft group was 55.23±6.49 years, with no statistically significant difference between groups (p=0.053). Similarly, body mass index did not differ significantly between the two groups.

Table 1 presents complications within each subgroup. In the autograft group, significant differences were observed between preoperative and postoperative values of MPTA, hip-knee-ankle angle (HKA), and FTA (Table 2). Similarly, the tibial medullary cancellous bone graft combined with the allograft group exhibited significant pre-to-postoperative changes in MPTA, HKA, and FTA (Table 3). However, no significant differences were observed between the two groups in postoperative MPTA, HKA, and FTA. In contrast, VAS and WOMAC scores differed significantly between the autograft group and the combined graft group (Table 4).

DISCUSSION

OWHTO is a widely used surgical technique for patients with varus deformity and medial compartment osteoarthritis; it is aimed at relieving symptoms by shifting the weight-bearing axis from the degenerated medial compartment to a more neutral or lateral position, thereby delaying the need for total knee arthroplasty.[1,15,16] However, the optimal graft material and surgical approach remain uncertain. The iliac crest autograft has traditionally been considered the gold standard for bone grafting in OWHTO.[17,18] Despite its osteogenic potential, autologous bone harvesting from the iliac crest carries significant morbidity. Complications at the donor site include chronic pain, infection, sensory disturbances, and vascular or neurological injuries such as gluteal artery damage, deep wound infection, sciatic nerve injury, and iliac bone fracture.[19-22] Similarly, harvesting autografts from the distal tibial fragment presents its own challenges, most notably an elevated risk of donor site fracture, which may adversely affect overall patient outcomes.[4,23,24]

Our study demonstrated comparable long-term radiographic outcomes between patients who underwent autograft procedures and those who received a combination of tibial medullary cancellous bone graft and allograft. Postoperative HKAA, FTA, and MPTA values did not differ significantly between the groups (p>0.05), likely reflecting the similarity in surgical technique used across cohorts.[3,4,24-28] These findings indicate that both grafting approaches are effective in achieving satisfactory alignment and maintaining mechanical stability, supporting their use as viable options in OWHTO.

The clinical status of the knee was evaluated using VAS and WOMAC scores. Postoperative analysis demonstrated sig-

Table 4. Comparison of clinical and radiological outcomes between the autograft group and the combined allograft and autograft group

Complication	Autograft Group, (Mean±SD)	Combined Allograft and Autograft Group, (Mean±SD)	p-value
Age (years)	53.21±6.60	55.25±6.49	0.053
Preoperative MPTA (°)	84.77±1.24	84.63±1.18	0.492
Postoperative MPTA (°)	94.77±1.97	94.32±2.28	0.191
Preoperative FTA (°)	180.28±1.63	180.08±1.88	0.468
Postoperative FTA (°)	170.67±1.45	171.11±1.45	0.061
Preoperative VAS	34.07±2.43	33.79±2.39	0.462
Postoperative VAS	17.86±1.75	17.20±1.35	0.008
Preoperative WOMAC (Total)	44.42±2.90	43.57±3.16	0.081
Postoperative WOMAC (Total)	25.37±3.44	23.97±2.90	0.007
Preoperative WOMAC (Pain)	9.93±1.43	9.75±1.53	0.460
Postoperative WOMAC (Pain)	4.69±1.35	4.26±1.14	0.031
Preoperative WOMAC (Stiffness)	3.81±1.16	3.76±1.22	0.787
Postoperative WOMAC (Stiffness)	3.72±1.15	3.67±1.15	0.808
Preoperative WOMAC (Function)	30.68±2.32	30.05±2.20	0.085
Postoperative WOMAC (Function)	16.96±2.65	16.04±2.15	0.018
Osteotomy Angle (°)	15.26±3.12	14.53±2.47	0.112
Body Mass Index (BMI) (kg/m²)	26.32±1.75	26.21±1.70	0.690
Preoperative HKA Angle (°)	10.83±2.08	11.06±1.20	0.408
Postoperative HKA Angle (°)	8.74±2.10	8.63±1.38	0.713
Follow-up Duration (months)	26.98±10.73	23.96±7.69	0.044

FTA: Femorotibial angle; HKA: Hip-knee-ankle angle; MPTA: Medial proximal tibial angle; VAS: Visual Analog Scale; WOMAC: Western Ontario and McMaster Universities Osteoarthritis Index.

nificantly reduced VAS pain scores and improved WOMAC scores in patients who underwent the combined tibial medullary cancellous bone graft and allograft procedure. These findings suggest a potential clinical benefit of the combined approach. In addition, the autograft technique was associated with significant donor site morbidity, whereas the combined graft technique demonstrated a low incidence of surgical site complications, indicating a further benefit of the combined technique.

Limitations

Our study has several limitations. First, its retrospective design inherently introduces potential biases, including reliance on existing records, which may be incomplete or inaccurate, thereby affecting the validity and generalizability of the findings. In addition, due to this design, the influence of surgical experience on complication rates could not be clearly assessed. Our study included patients who received either an autograft or a tibial medullary cancellous bone graft combined with an allograft; patients treated with an allograft alone or without any graft were not part of the analysis. Furthermore, the assessment of gap filling was based solely on standard radiographs. Although intra- and interobserver agreement for bone union exceeded 0.8, this evaluation remains challenging and susceptible to observer bias.

CONCLUSION

The use of a combined tibial medullary cancellous bone graft with allograft in MOWHTO is associated with improved functional outcomes at 6-month follow-up, as evidenced by significantly reduced VAS and WOMAC scores.

Ethics Committee Approval: This study was approved by the Haydarpaşa Numune Training and Research Hospital of Health Sciences University Ethics Committee (Date: 03.09.2024, Decision No: HNEAH-GOAEK2024-109).

Peer-review: Externally peer-reviewed.

Authorship Contributions: Concept: O.Y., C.H.K., K.G.; Design: O.Y., C.H.K., K.G.; Supervision: O.Y.; Resource: O.Y., C.H.K., K.G.; Materials: O.Y., C.H.K., K.G.; Data collection and/or processing: O.Y., C.H.K., K.G.; Analysis and/or interpretation: O.Y., C.H.K.; Literature review: O.Y., C.H.K., K.G.; Writing: O.Y., C.H.K., K.G.; Critical review: O.Y.

Conflict of Interest: None declared.

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ORİJİNAL ÇALIŞMA - *ÖZ*

Medial kama yüksek tibial osteotomi için tibial medüller kansellöz kemik grefti ile allogreft kombinasyonunun fonksiyonel sonuçları: Retrospektif kohort çalışma

AMAÇ: Bu çalışmanın amacı, genu varum deformitesi ile ilişkili medial kompartman osteoartritinin tedavisinde uygulanan kemik otogrefti ile tibial medüller kansellöz kemik greftinin allogreft ile kombinasyonunun uzun dönem sonuçlarını değerlendirmektir.

GEREÇ VE YÖNTEM: Bu retrospektif kohort çalışmaya, medial kama yüksek tibial osteotomi (MKYTO) ameliyatı geçirmiş ve otolog kemik grefti ya da tibial medüller kansellöz kemik grefti ile allogreft kombinasyonu uygulanmış diz osteoartritli hastalar dahil edilmiştir. Hastaların klinik durumları Visual Analog Skala (VAS) ve Western Ontario ve McMaster Üniversitesi Osteoartrit İndeksi (WOMAİ) kullanılarak değerlendirilmiştir. Ayrıca kalça-diz-ayak bileği açısı (HKA), medial proksimal tibial açı (MPTA) ve femorotibial açı (FTA) ölçülmüştür. Radyolojik değerlendirmeler ameliyat öncesinde ve 6 aylık takipte yapılmıştır.

BULGULAR: Çalışmaya toplam 157 hasta dahil edilmiştir: Grup A'da (otogreft) 81 hasta, Grup B'de (tibial medüller kansellöz kemik grefti ile allogreft kombinasyonu) 76 hasta yer almıştır. Postoperatif HKA, MPTA ve FTA değerleri açısından gruplar arasında anlamlı bir fark bulunmamıştır. VAS ve WOMAİ skorları medüller kansellöz kemik grefti ile allogreft kombinasyonu uygulanan grupta anlamlı düzeyde daha düşük bulunmuştur.

SONUÇ: MOWHTO tedavisinde, tibial medüller kansellöz kemik grefti ile allogreft kombinasyonu kullanımı, anlamlı olarak düşük VAS ve WOMAİ skorları göstermiş olup, 6 aylık takip süresi sonunda iyileşen fonksiyonel sonuçlarla ilişkilidir.

Anahtar sözcükler: Medial açılı kama yüksek tibial osteotomi; kansellöz kemik allogrefti; fonksiyon; klinik sonuç; allogreft; otogreft.

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ORIGINAL ARTICLE

A novel technique in displaced distal radius fractures not reduced via closed reduction in pediatric patients: reduction after stepwise injection of physiological saline – a case series

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ABSTRACT

BACKGROUND: The purpose of this study was to present a new method for managing displaced metaphyseal fractures of the distal radius in pediatric patients that could not be reduced by closed reduction, and to evaluate the clinical and radiological outcomes of reduction after the stepwise injection of physiological saline.

METHODS: A total of 24 pediatric patients who underwent closed reduction of displaced metaphyseal distal radius fractures using the stepwise injection of physiological saline in our clinic between May 2018 and May 2020 were retrospectively examined. Follow-up visits were scheduled for all patients at three, six, and 12 months. Radiological and functional outcomes were evaluated. The Mayo Wrist Score was used in the clinical assessments, and union and deformity were assessed radiologically.

RESULTS: Sixteen patients were boys and eight were girls, with a mean age of 9.38±2.123 years. Among the etiologies of injury, falling off a bike accounted for six cases, skating injuries for five, scooter-related falls for four, falls at school for four, falls at home for three, and falls from stairs for two cases. Fourteen patients had right-sided fractures and ten had left-sided fractures. The mean number of pins used during surgery was 2.79±0.588. The mean amount of physiological saline used during surgery was 16.25±4.72 mL. The patients stayed in the hospital for a mean duration of 2±0.590 days after surgery, and their mean follow-up duration was 80.54±24.775 days. The mean time for pin removal was 4.46±0.658 weeks. Four patients had good Mayo Wrist Scores, and 20 patients had excellent scores. During follow-up, only two patients developed pin site infections.

CONCLUSION: Closed reduction and percutaneous pinning using the stepwise injection of physiological saline appears to be an effective and safe treatment technique for displaced distal radius fractures that cannot be reduced by closed reduction in pediatric patients.

Keywords: Physiological saline; pediatric cases; displaced fracture; distal radius.

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INTRODUCTION

Fractures of the forearm are the most prevalent long bone fractures during childhood, and the most frequently encountered among these are metaphyseal fractures of the distal radius.[1,2] Although boys have a higher rate of experiencing these fractures, young girls engaging in sports are also prone to forearm fractures. Such fractures usually occur due to falling onto an outstretched arm and, more rarely, from high-energy trauma such as falls from height or road accidents.[3] Forearm fractures may be accompanied by injuries involving the elbow, carpal bones, or ulna.[4,5] Metaphyseal fractures of the distal radius mainly include three patterns: torus, greenstick, and complete fractures (with intact bone length or bayonet deformity). Treatment methods include immobilization alone, closed reduction and plastering, closed reduction with percutaneous pinning, and open reduction. The choice of treatment varies based on the fracture pattern, the degree of instability, the presence of concomitant injuries, and the age of the patient. Torus fractures are usually treated with immobilization alone.[6,7] Greenstick fractures are primarily treated by immobilization, while those with deformity require closed reduction and plastering.[8,9] Displaced radius fractures are unstable fractures, and their treatment includes closed reduction and plastering, closed reduction in addition to percutaneous pinning, and open reduction.[10-12] Pediatric distal radius fractures may include open fractures, irreducible fractures, fractures with compartment syndrome or carpal tunnel syndrome, fractures with severe swelling, fractures requiring stabilization on the same side, and fractures that require re-manipulation due to loss of reduction.[13] It is known that fracture hematoma and the thicker periosteum in children can prevent reduction in displaced fractures where the deformity is severe. For this reason, the hematoma and periosteum must be moved away from the fracture gap. In the cases in this study, physiological saline (PS) was injected into the fracture gap to meet these needs.
The purpose of this study was, for the first time, to present a novel method for displaced metaphyseal fractures of the distal radius that could not be reduced by closed reduction in pediatric patients, and to evaluate the clinical and radiological outcomes of reduction after stepwise injection of physiological saline.

MATERIALS AND METHODS

Design and Participants

This retrospective single-center study was performed at the Department of Orthopedics and Traumatology of Kocaeli Derince Training and Research Hospital, a tertiary health institution, from May 2018 to May 2020.Written informed consent was obtained from the parents and/or legal guardians of the patients. Approval for the study protocol was granted by the Institutional Ethics Committee (No: 2020/86, Date: 25/06/2020). All procedures were conducted in accordance with the principles of the Declaration of Helsinki.

Figure 1. Lateral view of distal radius fracture.

All patients who underwent surgery for displaced metaphyseal fractures of the distal radius (Fig. 1) in our clinic were retrospectively analyzed. In our clinical practice, these fractures are initially treated with closed reduction and plastering in the emergency department (Fig. 2a, 2b). In cases of reduction failure during follow-up (after approximately 7-10 days), closed reduction and plastering combined with percutaneous pinning are performed in the operating room under general anesthesia. If reduction fails under general anesthesia or in case of instability, closed reduction and percutaneous pinning into the fracture line are performed using PS (Fig. 3). Translation of more than half of the bone radius, rotational deformity, angulation greater than 15° in children younger than 10 years, and angulation greater than 10° in children older than 10 years old were considered criteria indicating contraindication for reduction. In this study, a total of 24 pediatric patients who underwent closed reduction for displaced metaphyseal fractures of the distal radius using the stepwise injection of PS were included. The clinical and radiological results of the patients were evaluated in the outpatient clinic by the clinician. At the last follow-up, the Mayo Wrist Score was used to assess wrist function. The presence of union and deformity was evaluated radiologically. The exclusion criteria were as follows: patients who underwent closed reduction in the emergency setting, those who underwent closed reduction in the operating room under general anesthesia without PS, and those with missing data.

Surgical Technique

The operations for all patients were performed under general anesthesia by the same surgical team using the same technique. Closed reduction with appropriate traction and manipulation was performed on a radiolucent table. None of the patients achieved adequate reduction based on anteroposterior and lateral fluoroscopic images. Initially, 10 cc of PS

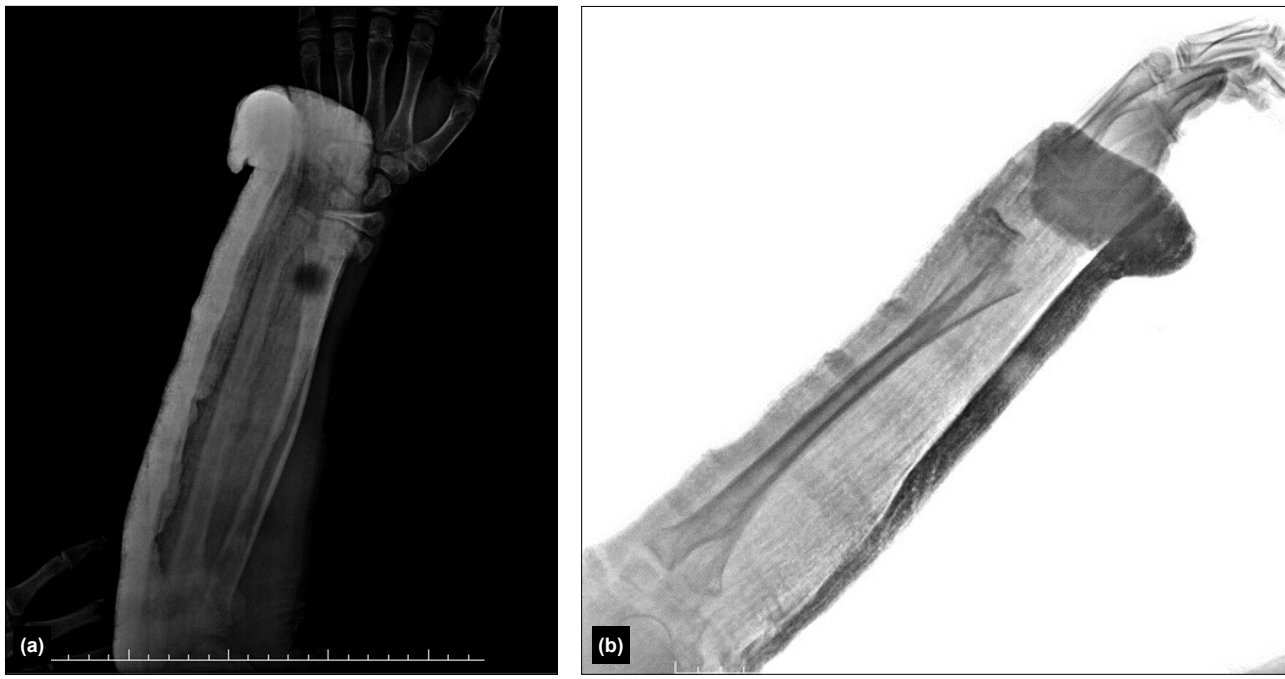

Figure 2. (a,b) Control anteroposterior (AP) and lateral views taken after closed reduction in the emergency department.

was injected from the dorsal surface into the fracture line, and closed reduction was performed. PS was injected into the fracture gap under fluoroscopic guidance. In each instance of reduction failure, an additional 5 cc of PS was injected, and closed reduction was repeated. The hematoma in the fracture area was not drained during the injection; however, after the injection, with manipulation, some hematoma was allowed to drain from the needle entry point (Video 1). Once reduction was achieved, cross pinning was applied using two or three 1.6-mm Kirschner wires (K-wires) for younger patients and 1.8-2-mm K-wires for older patients. In the presence of displaced ulnar fractures, osteosynthesis was performed using a K-wire after ulnar reduction. The wire length was adjusted, and a short arm splint was applied.

Postoperative Care and Rehabilitation

Postoperatively, elevation of the fracture site above heart level and cold compression were performed. Finger mobilization was initiated, and circulation was monitored. Patients with regressed edema were discharged. At weeks 2 and 4, all patients underwent X-ray imaging. At week 4, short arm casts were removed. According to the status of union findings

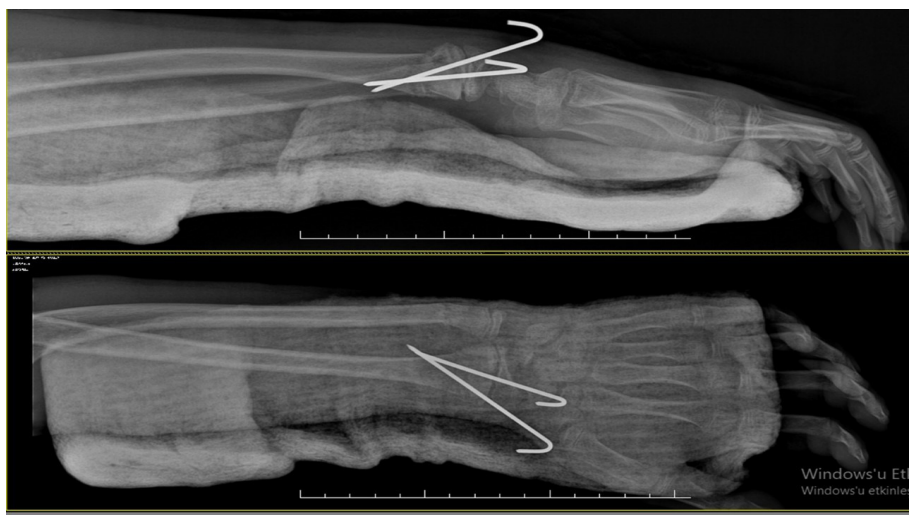

Figure 3. Postoperative anteroposterior (AP) and lateral views.

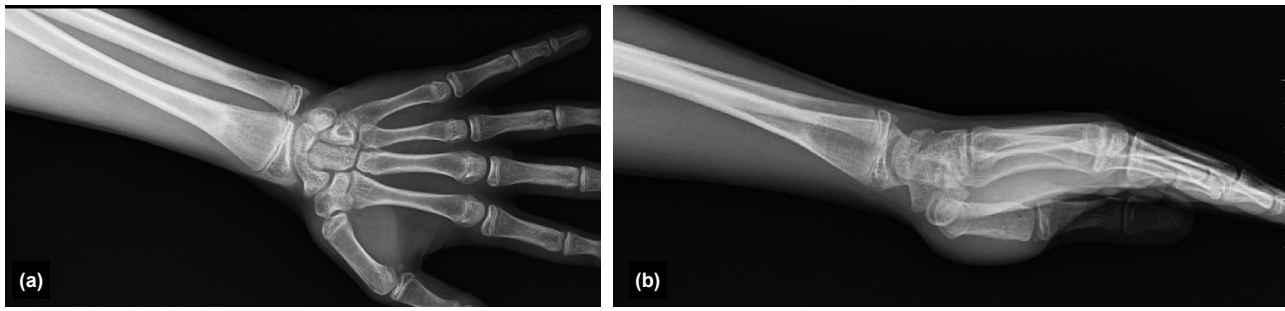

Figure 4. (a,b) X-ray images at final follow-up.

Table 1. Baseline data of patients

Variable	n (%)
Sex	
Female	8 (33.3)
Male	16 (66.7)
Age, year s	
Mean±SD	9.38±2.123
Median [Q1-Q3]	9.00 [8.00-11.00]
Range (min-max)	6.00-13.00
Etiology	
Fall off bike	6 (25.0)
Skating injury	5 (20.8)
Fall from scooter	4 (16.7)
Fall at school	4 (16.7)
Fall at home	3 (12.5)
Fall from stairs	2 (8.3)
Affected side	
Right	14 (58.3)
Left	10 (41.7)
Deformity	
Bayonet	24 (100.0)
Total	24 (100.0)

(i.e., callus formation), K-wires were removed at postoperative weeks 4 to 6. An exercise protocol was then initiated. Follow-ups were scheduled for all patients at three, six, and 12 months.

Statistical Analysis

Statistical analyses were performed using SPSS version 20.0 for Windows (IBM Corp., Armonk, NY, USA). Descriptive statistics, including mean ± standard deviation (SD), median (min-max), and frequency and percentage values, were calculated. The Shapiro-Wilk test was used to assess the normality of data distribution. A p-value of <0.05 was considered significant.

RESULTS

The study sample included 24 patients in total. All patients also had distal ulna fractures. Of the patients, 16 (66.7%) were boys and eight (33.3%) were girls. The mean age of the patients was 9.38±2.123 (range, 6-13 years). Among the etiologies of injury, falling off a bike accounted for six (25.0%) cases, skating injuries for five (20.8%), scooter-related falls for four (16.7%), falls at school for four (16.7%), falls at home for three (12.5%), and falls from stairs for two (8.3%) cases. Fourteen (58.3%) patients had right-sided fractures, and 10 (41.7%) had left-sided fractures. Initial X-ray images revealed bayonet deformities in all patients (Table 1).

The mean number of pins used during surgery was 2.79±0.588 (range, 2-4). The mean amount of PS used during surgery was 16.25±4.72 mL (range, 10-25). The patients stayed in the hospital for a mean duration of 2±0.590 days (range, 1-3) after surgery. The mean follow-up duration was 80.54±24.775 days (range, 37-130). The mean time before pin removal was 4.46±0.658 weeks (range, 4-6). At the final follow-up, the mean Mayo Wrist Score was 93.33±6.019 (range, 80-100). Four (16.7%) patients had good Mayo Wrist Scores, while 20 (83.3%) had excellent scores. During follow-up, only two (8.3%) patients developed pin site infections (Table 2). No nonunion or angular deformity was observed on the final radiological evaluations (Fig. 4a, 4b).

DISCUSSION

Fractures of the distal forearm are more prevalent among boys during childhood, although their incidence increases between 9 and 13 years of age in both sexes.[14-16] This may be attributed to the increasing frequency and diversity of sports activities with age. The number of male patients in our study was higher than the number of female patients, consistent with the literature. Rennie et al.[16] reported that distal forearm fractures most commonly occurred due to accidental events at home, such as falling from stairs or bed, as well as sports injuries. In this study, the most common cause was also sports-related injuries.

In this study, the fracture sites demonstrated a bayonet appearance, described as fracture fragments lying in side-by-

Table 2. Operative and postoperative data of patients

Variable	
Number of pins	
Mean±SD	2.79±0.588
Median [Q1-Q3]	3.00 [2.00-3.00]
Range (min-max)	2.00-4.00
Amount of physiological saline, mL	
Mean±SD	16.25±4.72
Median [Q1-Q3]	15.00 [11.25-20.00]
Range (min-max)	10.00-25.00
Length of hospital stay, days	
Mean±SD	2.00±0.590
Median [Q1-Q3]	2.00 [2.00-2.00]
Range (min-max)	1.00-3.00
Follow-up, days	
Mean±SD	80.54±24.775
Median [Q1-Q3]	82.50 [63.00-95.50]
Range (min-max)	37.00-130.00
Time to pin removal, weeks	
Mean±SD	4.46±0.658
Median [Q1-Q3]	4.00 [4.00-5.00]
Range (min-max)	4.00-6.00
Mayo Wrist Score	
Mean±SD	93.33±6.019
Median [Q1-Q3]	95.00 [90.00-100.00]
Range (min-max)	80.00-100.00
Mayo Wrist Score classification	
Good	4 (16.7)
Excellent	20 (83.3)
Complications, n (%)	
Yes (pin site infection)	2 (8.3)
No	22 (91.7)

side contact. Such fractures exhibit the greatest degree of deformity and are difficult to reduce and remodel. Loss of reduction is common.[17] Despite this, some studies in the literature have reported that remodeling may be possible. Wilkins et al.[18] reported that bayonet apposition could be remodeled in patients up to 12 years of age, provided that the linear alignment was nearly anatomical.

The treatment modalities for completely displaced distal radius fractures in the pediatric population include closed reduction and plastering, closed reduction and pinning under general anesthesia, and open reduction and pinning. In most cases, closed reduction and plastering are effective; however, complications such as angulation, loss of reduction, and malunion may occur, resulting in prolonged treatment duration, increased treatment costs, and undesirable aesthetic and functional outcomes. Therefore, maintaining alignment is as critical as achieving the reduction itself. Factors such as excessive swelling, improper molding of the cast, delayed treatment, and patient non-compliance with treatment can adversely affect alignment and lead to malalignment. If closed reduction and plastering fail, closed reduction and pinning or open reduction and pinning can be performed under general anesthesia. In their prospective randomized controlled study, McLauchlan et al.[12] compared outcomes in children with completely displaced metaphyseal fractures of the distal radius treated with manipulation and above-elbow casting alone versus those treated with the addition of percutaneous K-wire insertion. They reported that the use of a percutaneous K-wire was a safe method of maintaining fracture alignment.

Percutaneous pinning is also effective in preventing plaster-related complications. In cases of difficult manipulation or reduction failure, certain techniques such as Kapandji pinning can be used.[19,20] Although closed reduction generally yields successful outcomes, open reduction may be required in severely displaced fractures due to fracture hematoma and periosteal intrusion in the fracture gap. In our study, we used a novel technique for patients in whom closed reduction with manipulation had failed. During the stepwise injection of PS from the dorsal surface into the fracture line, we believe that two mechanisms are involved in facilitating reduction. First, this technique eliminates hematomas that prevent reduction by creating high pressure in the fracture gap. Because children have a thicker periosteum compared to adults, post-traumatic injuries and disruption of its integrity are less likely. Second, the periosteum, which is wedged between the fracture ends, recovers with the increased pressure (similar to a wrinkled, deflated balloon when air is supplied) and returns to its normal alignment as it separates from the compressed area, thereby facilitating fracture reduction. In our study, nearly anatomical closed reduction was achieved with this method in all patients. In other words, this method eliminates the need for open reduction. This result demonstrates the effectiveness of the method.

The stepwise application of PS is also important for administering the lowest sufficient dose and preventing complications such as compartment syndrome. None of the patients in our study experienced compartment syndrome or severe edema. The possible reasons for the absence of compartment syndrome include the distal location of the fracture, the distribution of PS pressure to both the dorsal and volar compartments, and the use of an amount of PS small enough to avoid increasing compartment pressure. To the best of our knowledge, the literature does not specify how much fluid can cause compartment syndrome in the pediatric forearm. The amount of PS given to the patient is distributed by applying equal pressure to the dorsal, deep volar, and mobile wad compartments around the fractured radius, causing the pressure to drop and reducing the risk of compartment syn-

drome. However, some risk of compartment syndrome always exists with this method. A limitation of this technique is the lack of a tool for measuring compartment pressures. Nevertheless, it is known that the diagnosis of compartment syndrome can also be made clinically.

This technique was applied to a group with a wide age range (6-13 years). A 6-year-old patient and a 13-year-old patient have different criteria for acceptable reduction. However, the main problem here is that the bayonet deformity cannot be corrected by closed reduction. This may be caused by the presence of soft tissue in the fracture space. The most definite indication for this technique is an unreduced bayonet deformity. Therefore, age is not a determining factor for the indication of this technique. On the other hand, a crucial cutoff point for pediatric distal radius fractures is ten years of age. Since the reduction criteria differ below and above the age of ten, the need for PS injection may vary depending on age. The results of this study are not sufficient to demonstrate this distinction.

Although the length of hospital stay, the duration of immobilization, and the time of pin removal varied, all results were consistent with reports in the relevant literature. Two patients in this study developed pin site infections, which were treated with oral antibiotics and wound dressing with rifampicin. No pin migration, loss of reduction, or neurovascular injury was observed. Delayed fracture healing and nonunion did not occur in any patient. At the final follow-up, all patients were evaluated for functional and radiological outcomes. The results were good in four patients and excellent in 20 patients.

The primary limitations of this study were its single-center, retrospective design and its relatively small sample size. The main strength of this study is that this technique is being applied for the first time, and in this technique, there is no need for open reduction.

CONCLUSION

In conclusion, closed reduction and percutaneous pinning using the stepwise injection of PS appears to be an effective and safe treatment technique for displaced distal radius fractures that cannot be reduced by closed reduction in pediatric cases. However, additional multi-center, large-scale, prospective studies are needed to obtain more reliable results on this topic.

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ORİJİNAL ÇALIŞMA - *ÖZ*

Kapalı redükte edilemeyen pediatrik deplase distal radius kırıklarında yeni bir teknik: Fizyolojik salinin kademeli enjeksiyonu sonrası redüksiyon – Olgu serisi

AMAÇ: Bu çalışmanın amacı, pediatrik olgularda kapalı redükte olmayan deplase distal radius metafiz kırıklarında, fizyolojik salinin kademeli enjeksiyonu ile redüksiyonu içeren yeni bir yöntemi sunmak ve bu yöntemin klinik ve radyolojik sonuçlarını değerlendirmektir.
GEREÇ VE YÖNTEM: Kliniğimizde Mayıs 2018–Mayıs 2020 tarihleri arasında, deplase distal radius metafiz kırığı nedeniyle fizyolojik salinin kademeli enjeksiyonu uygulanarak kapalı redüksiyon yapılan toplam 24 pediatrik hasta retrospektif olarak incelendi. Tüm hastalar 3., 6. ve 12. aylarda takip edildi. Radyolojik ve fonksiyonel sonuçlar değerlendirildi. Klinik değerlendirmede Mayo El Bileği Skoru kullanıldı. Radyolojik olarak kaynama ve deformite varlığı değerlendirildi.
BULGULAR: Hastaların 16'sı erkek, 8'i kız olup, ortalama yaş 9.38±2.123 yıldı. Yaralanma etiyolojileri arasında bisikletten düşme 6, paten yaralanması 5, skuter düşmesi 4, okulda düşme 4, evde düşme 3 ve merdivenden düşme 2 olgu ile temsil edildi. On dört hastada sağ, 10 hastada sol taraf kırığı mevcuttu. Ameliyatta kullanılan pin sayısı ortalama 2.79±0.588 idi. Ameliyat sırasında kullanılan fizyolojik salin miktarı ortalama 16.25±4.72 mL olarak kaydedildi. Hastaların ameliyat sonrası hastanede kalış süresi ortalama 2,0±0,590 gün, takip süresi ise 80.54±24.775 gündü. Pinlerin çıkarılma süresi ortalama 4.46±0.658 hafta idi. Mayo El Bileği Skoru'na göre 4 hastada iyi, 20 hastada mükemmel sonuç elde edildi. Takiplerde yalnızca 2 hastada pin dibi enfeksiyonu gözlendi.
SONUÇ: Kapalı redüksiyonla azaltılamayan pediatrik deplase distal radius kırıklarında, fizyolojik salinin kademeli enjeksiyonu eşliğinde kapalı redüksiyon ve perkütan pinleme, etkili ve güvenli bir tedavi yöntemi olarak görünmektedir.

Anahtar sözcükler: Fizyolojik salin; pediatrik olgular; deplase kırık; distal radius.

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ORIGINAL ARTICLE

Are orthopedists mentally ready for the next disaster? Surgeons who performed amputations after the 2023 Kahramanmaraş earthquakes report high traumatic stress symptoms

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ABSTRACT

BACKGROUND: This study aims to evaluate the mental health outcomes of orthopedists after the 2023 Kahramanmaraş earthquakes through a comprehensive analysis based on orthopedic care and amputations.

METHODS: This cross-sectional, questionnaire-based study, conducted six months after the 2023 Kahramanmaraş earthquakes, included a total of 95 orthopedists. The online questionnaire assessed demographic characteristics, professional experience, and mental health outcomes using the Impact of Event Scale-Revised (IES-R) and the Depression Anxiety Stress Scale-21 (DASS-21). Scale scores were analyzed according to earthquake zone challenges, orthopedic care provision, and amputation-related stress factors.

RESULTS: Care for earthquake victims was provided by 61.5% of orthopedists in the earthquake area, including local (16.8%) and supporting orthopedists (42.1%), while 36.8% treated victims at referral hospitals outside the area. Overall, 76.8% of participants reported performing amputation surgery on earthquake victims. Performing amputations in the pediatric age group (82.2%), witnessing patients' losses or other earthquake-related difficulties (64.4%), and amputations involving multiple extremities (56.2%) were reported as the three most common stress factors related to amputations. Orthopedists at referral hospitals and local orthopedists reported higher total IES-R scores (11.0 [0-58] and 11.5 [0-46] vs. 1.0 [0-39]), as well as higher avoidance (3.0 [0-20] and 3.0 [0-17] vs. 0.0 [0-13]) and intrusion (4.0 [0-20] and 5.0 [0-20] vs. 0.0 [0-14]) subscale scores. Referral hospital orthopedists showed higher anxiety (2.0 [0-13] vs. 0.0 [0-7]), stress (5.0 [0-16] vs. 2.0 [0-12]), and total DASS-21 scores (11.0 [0-44] vs. 6.0 [0-29]) than supporting orthopedists in the disaster zone. Those performing amputations in patients with earthquake-related difficulties reported higher DASS-21 depression scores (4 [0-18] vs. 1 [0-15], p=0.013). IES-R scores were negatively correlated with age (r=-0.203, p=0.049), while other factors showed no correlation with IES-R or DASS-21 scores.

CONCLUSION: Our study shows that treating earthquake victims has a significant impact on orthopedists' emotional states and traumatic stress, especially for local and referral hospital orthopedists. The key stress factors included pediatric amputations, multiple extremity amputations, and patient-related difficulties. While tragic events involving relatives did not show a significant association with the scores, performing amputations on patients with earthquake-related difficulties increased depression scores, and younger orthopedists reported higher IES-R scores than older orthopedists. Our findings highlight the need for regular mental health screening, risk group identification, structured psychological support, and resilience training among orthopedic surgeons following large-scale disasters, as well as enhanced preparedness for future emergencies.

Keywords: Earthquake; disaster; orthopedists; amputations; mental health; traumatic stress.

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INTRODUCTION

The 7.7 and 7.6 magnitude Kahramanmaraş earthquakes in southeastern Türkiye on February 6, 2023, caused severe damage across 11 provinces, resulting in over 50,000 casualties and 118,000 injuries.[1] A total of 144,156 local healthcare professionals and 9,011 deployed personnel provided medical services in the region. Earthquakes cause extensive damage within minutes, creating a surge of patients. The mechanical energy released during earthquakes exceeds that of other natural disasters, increasing the risk of musculoskeletal injuries.[2-4]

Orthopedic experiences have been reported by several researchers.[5-9] Early data from the first week showed high rates of orthopedic interventions and amputations. Asfuroğlu et al.[10] reported that 132 of 204 victims had fractures, with 181 surgical procedures and a 15% amputation rate. Kundakçı et al.[11] reported a 30.9% amputation rate in 233 crush syndrome cases. Temel et al.[8] found that 77% of Intensive Care Unit (ICU) patients required surgery and 24% underwent amputations. Medical practice during disasters challenges orthopedic surgeons in terms of patient triage, injury management, infection risks, equipment shortages, and limited expert consultation.[12,13] In such settings, urgent amputation decisions may be required without full discussion or informed consent if patients are unable to respond.[13] Orthopedists face increased workload and stress, working rapidly with limited resources.[2,5] Healthcare professionals are vulnerable to occupational stressors during disasters, leading to mental fatigue, depression, anxiety, burnout, and Post-Traumatic Stress Disorder (PTSD). They also face challenges such as insufficient supplies, long working hours, and staff shortages.[1,14,15] The mental well-being of these professionals is crucial for maintaining sustainable healthcare services.[1,15,16,17]

While studies have shown that healthcare professionals experienced emotional challenges after the 2023 earthquakes, none have specifically examined the mental health outcomes of orthopedists. We hypothesized that orthopedists, most of whom had likely never encountered such stressful working conditions or performed so many amputations, would be psychologically affected by their experiences in the post-disaster setting. By evaluating mental health outcomes, our study aims to provide a deeper understanding of these challenges and to inform future disaster preparedness efforts.

MATERIALS AND METHODS

Study Population

A total of 95 orthopedists (mean±standard deviation [SD] age: 35.0±9.0 years, 97.9% male) voluntarily participated in this cross-sectional, questionnaire-based online survey conducted six months after the 2023 Kahramanmaraş earthquakes. Orthopedists across Türkiye were reached through the researchers' personal and social networks, as well as by snowball sampling, and were provided with a detailed explanation of the study's objectives and protocol. The only exclusion criterion was refusal to participate, as we aimed to reach the maximum number of participants to assess the situation of all orthopedists who had experienced such a disaster.

Afterward, an online link directing to the Google Forms survey was sent to orthopedists who agreed to participate in the study, according to their preferred method of contact.

The study was conducted in accordance with the ethical principles stated in the Declaration of Helsinki and approved by the İstanbul University İstanbul Faculty of Medicine Clinical Researches Ethics Committee (Date of Approval: 23/06/2023; Protocol No: 13). Participants' informed consent was obtained electronically in advance of data collection through an informed consent page that presented two options (yes/no).

Google Forms Survey

The first part of the survey included a questionnaire with 30 items on demographic and occupational characteristics, provision of orthopedic care to earthquake victims (within or outside the earthquake-stricken area), amputation performance and amputation-related stress factors, and personal earthquake experience (accommodation, hygiene, nutritional and safety conditions, tragic events involving relatives or close friends, and changes in habits). Personal difficulties related to accommodation, hygiene, nutritional and safety conditions, as well as the psychological impact of performing amputations, were scored on a 10-point Visual Analogue Scale (VAS) (from 0: not at all to 10: extremely difficult/extremely affected).

The second part of the survey included the Impact of Event Scale-Revised (IES-R) and the Depression Anxiety Stress Scale-21 (DASS-21). IES-R and DASS-21 scores were evaluated with respect to earthquake-related experiences, the type of orthopedic care provided to earthquake victims (local orthopedists, supporting orthopedists, and those working at referral hospitals outside the earthquake-stricken area), and amputation-related stress factors.

Impact of Event Scale-Revised (IES-R)

The IES-R is a 22-item self-reported scale with three domains (intrusion, avoidance, and hyperarousal) used to measure the impact of recent and specific traumatic events.[18,19] In this study, as the IES-R was administered only to orthopedists who performed amputation surgery on earthquake victims, the term "performed amputations" was used instead of "event" in the original scale. The total IES-R score ranges from 0 to 88, with scores over 24 indicating clinical concern, scores ≥33 representing the best cut-off for a probable diagnosis of PTSD, and scores ≥37 suggesting a possible severe mental disorder.[18,19] The Turkish adaptation and validation of the IES-R was performed by Çorapçıoğlu et al.[20] in 2006.

Depression Anxiety Stress Scale-21 (DASS-21)

The DASS-21 is a short version (21 items) of a 42-item self-report instrument designed to measure three related negative emotional states: depression, anxiety, and stress. Using a

4-point Likert scale ranging from 0 ("did not apply to me at all") to 3 ("applied to me very much or most of the time"), the DASS-21 yields three subscale scores for depression, anxiety, and stress.[21,22] The Turkish adaptation and validation of the DASS-21 was performed by Sarıçam in 2018.[23]

Statistical Analysis

Statistical analyses were conducted using IBM SPSS Statistics for Windows, Version 22.0 (IBM Corp., Armonk, NY, 2013).[24] Data are presented as mean±standard deviation, median (min–max), or number and percentage (%) where appropriate. The normality of continuous variables was assessed using the Kolmogorov–Smirnov test. For comparisons of non-normally distributed continuous variables between two independent groups, the Mann–Whitney U test was used, while the Kruskal–Wallis test was applied for comparisons involving three groups. In cases of significant group differences, post hoc pairwise comparisons with adjusted p-values were conducted. Correlation analysis was performed using Spearman's rank correlation coefficient. Correlation strength was interpreted as weak (0–0.3), moderate (0.31–0.7), or strong (>0.7). A p-value <0.05 was considered statistically significant.

RESULTS

Participants' Characteristics

The mean±SD age of participants was 35.0±9.0 years (range: 25.0-66.0 years), and 97.9% were male. Overall, participants had a median of 4.0 years (range: 1.0-40.0 years) of clinical experience, while 31.6% had previous disaster healthcare experience (Table 1).

Orthopedic Care Provided to Earthquake Victims

Orthopedic care for earthquake victims was provided in the earthquake-stricken area by 61.5% of orthopedists (local orthopedists: 16.8%; supporting orthopedists: 42.1%), while 36.8% treated earthquake victims at referral hospitals outside the affected area. For supporting orthopedists, the median time of arrival was 3 days (range: 0-40 days) after the earthquake, and the median length of stay in the area was 7 days (range: 2-99 days) (Table 1).

Table 1. Participants' characteristics and orthopedic care provided to earthquake victims

Demographic and occupational characteristic	
Age (years)	
Mean±SD	35.0±9.0
Median (min-max)	33.0 (25.0-66.0)
Gender, n (%)	
Female	2 (2.1)
Male	93 (97.9)
Years of clinical experience	
Median (min-max)	4.0 (1.0-40.0)
Previous disaster healthcare experience	
(yes), n (%)	30 (31.6)
Provision of orthopedic care to earthquake victims	**n (%)**
None	4 (4.2)
In a referral hospital outside the earthquake-stricken area	35 (36.8)
In the earthquake-stricken area	
Total	56 (61.5)
Local (living and working in the affected area)	16 (16.8)
Arrived to offer support	40 (42.1)
Earthquake-stricken area	
Province, n (%)	
Kahramanmaraş	18 (18.9)
Hatay	18 (19.9)
Other provinces*	17 (17.9)
Time of arrival in the earthquake-stricken area (days), median (min-max)	3 (0-40)
Length of stay in the earthquake-stricken area (days), median (min-max)	7 (2-99)

*Mersin (n=5), Adana (n=4), Malatya (n=3), Elazığ (n=2), Adıyaman (n=1), Gaziantep (n=1), Şanlıurfa (n=1)

Table 2. Amputation- and related stress factors, and earthquake self-experience

Amputation- and related stress factors	
Performed amputation surgery in earthquake victims (yes), n (%)	73 (76.8)
Total number of amputations performed, median (min-max)	2 (1-5)
Amputation-related stress factors (n=73), n(%)	
Pediatric age group	60 (82.2)
Patients' losses or other difficulties related to the earthquake	47 (64.4)
Amputation of multiple extremities	41 (56.2)
Emotional reaction of the patient to amputation decision	24 (32.9)
Amputation of a proximal extremity	19 (26.0)
Physical exhaustion due to overwork	17 (23.3)
Patient's resistance or refusal to amputation decision	13 (17.8)
VAS scores for the psychological impact of performing amputations, median (min-max)	5 (0-10)
Earthquake self-experience	
VAS scores for difficulties experienced in the area, median (min-max)	
Accommodation conditions	5 (0-10)
Hygiene conditions	5 (0-10)
Nutritional conditions	5 (0-10)
Safety conditions	6 (0-10)
Tragic events involving relatives or close friends living in the earthquake zone, n (%)	38 (40.0)
Changes in habits, n (%)	
Increase in smoking	29 (30.5)
Decrease in smoking	22 (23.2)
Increase in alcohol consumption	2 (2.1)
Decrease in alcohol consumption	6 (6.3)
Change in appetite (increased or decreased)	78 (82.1)
Receiving psychological support after the earthquake, n (%)	14 (14.7)

Amputations and Related Stress Factors

Overall, 76.8% of participants reported performing amputations in earthquake victims, with a median of two amputations (range: 1-5) per orthopedist. Performing amputations in the pediatric age group (82.2%), dealing with patients' losses or other earthquake-related difficulties (64.4%), and amputations involving multiple extremities (56.2%) were reported as the three most common amputation-related stress factors. Median [min-max] VAS scores related to the psychological impact of performing amputations were reported as 5 [0-10] (Table 2).

Earthquake Self-Experience

Median [min-max] VAS scores for difficulties experienced in the earthquake-stricken area were 5 [0-10] for accommodation, hygiene, and nutritional conditions, and 6 [0-10] for safety conditions. Overall, 40.0% of participants reported experiencing tragic events involving relatives or close friends living in the earthquake-stricken area, while 82.1% reported a change in appetite and 30.5% reported an increase in smoking after the earthquake (Table 2).

IES-R and DASS-21 Scores and Correlations

There were significant positive correlations between IES-R and DASS-21 total scores ($r=0.464$, $p<0.001$) and between the domain scores of each scale, with the strongest inter-domain correlations observed between depression and hyperarousal ($r=0.483$, $p<0.001$) and between depression and intrusion ($r=0.473$, $p<0.001$). The total and subscale scores of IES-R and DASS-21 are summarized in Table 3.

Correlations of IES-R and DASS-21 Scores with Continuous Variables

IES-R total scores were negatively correlated with age ($r=-0.203$, $p=0.049$). No significant correlations were found between IES-R or DASS-21 scores and years of experience, nor with VAS scores for difficulties in accommodation, hygiene, nutritional and safety conditions, or the psychological impact of amputations (Table 4).

Table 3. IES-R and DASS-21 scores and correlations

	Scale scores, median (min-max)
IES-R	
Intrusion domain	2 (0-20)
Hyperarousal domain	3 (0-20)
Avoidance domain	1 (0-18)
Total score	6 (0-58)
DASS-21	
Anxiety domain	1 (0-13)
Depression domain	3 (0-16)
Stress domain	3 (0-18)
Total score	8 (0-44)

Correlations between study scales	**DASS-21**			
	Anxiety	**Depression**	**Stress**	**Total**
IES-R				
Avoidance				
r	0.314	0.386	0.331	0.379
p	0.002	<0.001	0.001	<0.001
Intrusion				
r	0.323	0.473	0.380	0.445
p	0.001	<0.001	<0.001	<0.001
Hyperarousal				
r	0.381	0.483	0.397	0.458
p	<0.001	<0.001	<0.001	<0.001
Total				
r	0.361	0.486	0.401	0.464
p	<0.001	<0.001	<0.001	<0.001

IES-R: Impact of Event Scale-Revised; DASS-21: Depression Anxiety Stress Scale-21; r: Correlation coefficient. Spearman correlation analysis.

IES-R and DASS-21 Scores with Respect to Provision of Orthopedic Care

According to the Kruskal–Wallis test results, IES-R total and subscale scores differed significantly among the three groups of orthopedists (p values ranging from 0.001 to 0.019), indicating that their psychological responses to performing amputations varied depending on their roles and locations during the disaster. Post hoc analyses (based on pairwise comparisons) indicated that orthopedists working in referral hospitals outside the affected area and local orthopedists had higher IES-R total scores than supporting orthopedists. These group differences were observed across the total score (median [min–max]: 11.0 [0–58] and 11.5 [0–46] vs. 1.0 [0–39]), as well as the avoidance (3.0 [0–20] and 3.0 [0–17] vs. 0.0 [0–13]) and intrusion (4.0 [0–20] and 5.0 [0–20] vs. 0.0 [0–14]) subscales. For the hyperarousal subscale, only orthopedists in referral hospitals had significantly higher scores than supporting orthopedists (2.0 [0–18] vs. 0.0 [0–13]) (Table 5).

According to the Kruskal–Wallis test, the DASS-21 total and anxiety/stress subscale scores differed significantly among the three groups of orthopedists (p values ranging from 0.005 to 0.015), suggesting varied emotional responses depending on their workplace context during the earthquake. Post hoc comparisons revealed that orthopedists working in referral hospitals outside the earthquake-affected area had significantly higher scores than supporting orthopedists, particularly in terms of anxiety (median [min–max]: 2.0 [0–13] vs. 0.0 [0–7]), stress (5.0 [0–16] vs. 2.0 [0–12]), and total DASS-21 score (11.0 [0–44] vs. 6.0 [0–29]) (Table 5).

Table 4. Correlations of IES-R and DASS-21 scores with continuous variables

Variables	IES-R Total Score			DASS-21 Total Score		
	r	p	n	r	p	n
Age	-0.203	0.049	95	0.056	0.593	95
Years of experience	-0.198	0.054	95	0.091	0.381	95
Time of arrival to earthquake-stricken area	0.096	0.546	42	0.272	0.082	42
Length of stay in the earthquake-stricken area	0.275	0.051	51	0.212	0.135	51
VAS scores (0-10)						
Difficulties in accommodation conditions	0.092	0.501	56	0.138	0.311	56
Difficulties in hygiene conditions	0.030	0.825	56	0.094	0.491	56
Difficulties in nutritional conditions	0.184	0.176	56	0.211	0.119	56
Difficulties in safety conditions	0.063	0.642	56	0.066	0.628	56
Psychological impact of amputations	0.131	0.273	72	-0.064	0.595	72
Total number of amputations	-0.105	0.381	71	0.005	0.970	71

IES-R: Impact of Event Scale-Revised; DASS-21: Depression Anxiety Stress Scale-21; r: Correlation coefficient. Spearman correlation analysis.

Table 5. IES-R and DASS-21 scores with respect to provision of care to earthquake victims

Median (min-max)	Earthquake-stricken area			p value
	At referral hospitals outside the affected area (n=35)	Local orthopedists (n=16)	Orthopedists arriving to offer support (n=40)	
IES-R scores				
Avoidance	3.0 (0-20)	3.0 (0-17)	0.0 (0-13)	**<0.001**[a,b]
Intrusion	4.0 (0-20)	5.0 (0-20)	0.0 (0-14)	**0.001**[a,b]
Hyperarousal	2.0 (0-18)	1.5 (0-9)	0.0 (0-13)	**0.019**[a]
Total score	11.0 (0-58)	11.5 (0-46)	1.0 (0-39)	**0.001**[a,b]
DASS-21 scores				
Anxiety	2.0 (0-13)	1.0 (0-7)	0.0 (0-7)	**0.005**[a]
Depression	4.0 (0-18)	3.0 (0-14)	2.0 (0-11)	0.078
Stress	5.0 (0-16)	2.5 (0-8)	2.0 (0-12)	**0.015**[a]
Total score	11.0 (0-44)	5.0 (0-23)	6.0 (0-29)	**0.012**[a]

IES-R: Impact of Event Scale-Revised; DASS-21: Depression Anxiety Stress Scale-21. Post-hoc comparisons following a significant Kruskal-Wallis test revealed: [a]Significant difference between "referral hospitals outside the affected area" and "orthopedists arriving to offer support." [b]Significant difference between "local orthopedists" and "orthopedists arriving to offer support."

IES-R and DASS-21 Scores with Respect to Amputation-Related Stress Factors

DASS-21 depression domain scores (4 [0-18] vs. 1 [0-15], p=0.013) were significantly higher in orthopedists who considered performing amputations in patients with earthquake-related difficulties or losses to be stressful, compared with those who did not find it stressful (Table 6). Other commonly reported stress factors, including performing amputations in the pediatric age group and amputations involving multiple extremities, did not show significant associations with IES-R or DASS-21 scores (Table 6).

IES-R and DASS-21 Scores with Respect to Tragic Events Involving Relatives or Close Friends

No significant differences were observed in IES-R or DASS-21 scores among orthopedists with or without tragic events involving relatives or close friends living in the earthquake-stricken area (Table 6).

DISCUSSION

Our findings revealed a considerable impact of the 2023 Kahramanmaraş earthquakes on orthopedists' emotional

Table 6. IES-R and DASS-21 scores with respect to amputation-related stress factors and tragic events involving relatives or close friends

	Amputation-related stress factors (n=73)									Tragic events with relatives or close friends living in the earthquake zone		
	Pediatric age group			Multiple extremities			Difficulties/losses by the patient					
Median (min-max)	**Stressful**	**Not stressful**	**p**	**Stressful**	**Not stressful**	**p**	**Stress-ful**	**Not stressful**	**p**	**Yes (n=38)**	**No (n=57)**	**p**
IES-R scores												
Avoidance	1 (0-20)	4 (0-17)	0.298	0 (0-20)	3 (0-12)	0.092	0 (0-20)	3 (0-12)	0.203	1 (0-20)	2 (0-17)	0.796
Intrusion	2 (0-20)	4 (0-20)	0.219	1 (0-20)	4 (0-18)	0.055	2 (0-20)	3 (0-13)	0.523	2 (0-20)	3 (0-14)	0.550
Hyperarousal	1 (0-18)	2 (0-9)	0.338	0 (0-18)	2 (0-11)	0.350	0 (0-18)	1 (0-11)	0.859	2 (0-18)	1 (0-13)	0.325
Total score	5 (0-58)	11 (0-46)	0.311	3 (0-58)	10 (0-35)	0.074	3 (0-58)	7 (0-35)	0.366	7 (0-58)	6 (0-42)	0.911
DASS-21 scores												
Anxiety	1 (0-12)	1 (0-13)	0.277	0 (0-12)	1 (0-13)	0.176	1 (0-12)	0 (0-13)	0.279	1 (0-12)	1 (0-13)	0.896
Depression	3 (0-18)	3 (0-15)	0.954	3 (0-18)	3 (0-15)	0.560	4 (0-18)	1 (0-15)	0.013	3 (0-18)	4 (0-15)	0.251
Stress	3 (0-13)	2 (0-16)	0.983	3 (0-13)	3 (0-16)	0.586	3 (0-13)	2 (0-16)	0.169	3 (0-13)	3 (0-16)	0.275
Total score	7 (0-38)	4 (0-44)	0.845	6 (0-38)	8 (0-44)	0.285	9 (0-38)	4 (0-44)	0.033	7 (0-38)	8 (0-44)	0.247

IES-R: Impact of Event Scale-Revised; DASS-21: Depression Anxiety Stress Scale-21.

states (DASS-21 scores) and traumatic stress symptoms (IES-R scores) related to amputations. Previous studies on the effects of earthquakes on healthcare professionals' mental health have reported moderate levels of PTSD, depression, anxiety, and poor sleep quality.[15,16,17,25] Local orthopedists and those treating victims at referral hospitals reported higher IES-R scores than supporting orthopedists. Additionally, the hyperarousal scores of the IES-R and the anxiety, stress, and total DASS-21 scores were higher in referral hospital orthopedists than in supporting orthopedists. Higher negative emotional states in local orthopedists can be attributed to their dual role as both rescuers and victims, unlike their supporting colleagues.[1,26,27,28] Similarly, after the 2010 Yushu earthquake, local health professionals showed a higher incidence of PTSD than supporting teams.[29] Local medical systems remain partially functional within the first 48 hours before the arrival of support teams and again after the third week following their departure.[2] Population density in seismic regions and large earthquakes challenge emergency response efforts while increasing the risk of damage to healthcare infrastructure.[5,30,31,32] Supporting orthopedists in our study arrived three days after the earthquake, with a median stay of seven days. Local orthopedists often experience role conflict and burnout due to increased workload.[27] A systematic review of healthcare professionals' mental health following major earthquakes (2008-2020) found that providing rescue services within one's own community correlated with higher PTSD scores.[1]

Previous studies have also reported higher levels of PTSD in healthcare professionals who encountered danger during rescue operations and those who worked in the immediate aftermath of an earthquake.[1,29,33,34] In this regard, facing ongoing danger in the disaster zone (such as continuous aftershocks or structural damage to hospital buildings) may further explain the higher stress scores observed among local orthopedists compared to supporting teams.[1]

Our findings revealed high IES-R and DASS-21 scores not only among local orthopedists but also among those treating earthquake victims at referral hospitals outside the earthquake zone. In fact, total DASS-21 scores were highest in this group when compared with both local and supporting orthopedists. Increased negative emotional states and traumatic stress symptoms in orthopedists working at referral hospitals are likely associated with secondary traumatic stress, which arises from witnessing the traumatic experiences of others and parallels the experiences of teams operating in the affected area.[1,16,35,36]

Generally, patients who require referral need additional support in terms of more delicate and specialized care. Therefore, healthcare workers at these centers usually interact with more severe cases involving multiple or complex trauma, as well as with more disadvantaged patients due to their losses. Decisions regarding major surgical interventions are ideally made at referral centers, where all treatment options are available,

rather than at local hospitals, to reduce the risk of infection and poor judgment in an environment of panic. [37,38,39] In addition, the treatment of these severe cases requires longer hospitalization, leading to greater exposure of healthcare teams to the victims' traumatic experiences. Indeed, in a study conducted after the earthquakes in Türkiye, healthcare professionals who did not go to the earthquake-stricken area were found to have higher post-traumatic stress levels compared to those who worked in the earthquake area.[16]

There may be several explanations for the lower IES-R and DASS-21 scores observed in voluntarily supporting orthopedists. First, helping others with a sense of altruism, which can be defined as finding "meaning" and prosocial motivation in work, may enhance compassion satisfaction and create a positive effect under difficult circumstances. Altruistic acts in humanitarian contexts have been found to be associated with better mental health indicators and greater resilience among healthcare workers.[40-42]

Secondly, teamwork and solidarity were experienced at the highest level in healthcare facilities within the earthquake zones. Numerous doctors from across the country volunteered to work in the field and supported each other throughout the process. Even residents and medical students joined these teams. We believe that, despite limited resources, such a high level of solidarity could have had a positive impact on the mental resilience of the orthopedists who came to help. Studies show that working as a cohesive team buffers stress through shared situational awareness, mutual support, and a distributed workload. Teamwork processes are associated with improved psychological outcomes and reduced distress. [43,44]

Amputations are highly demanding interventions that should be performed only with clear indications, considering all the pros and cons of the operation.[45-47] While the rationale for the damage control surgery (DCS) approach in routine practice is to maximize the survivability of a single multi-trauma patient, its rationale in mass-casualty and disaster scenarios is to optimize the use of limited resources to achieve the greatest good for the greatest number.[2] Hence, the post-earthquake setting mandates a shift in decision-making across all aspects of care, including surgical indications, techniques, and even ethical considerations.[2] Consequently, the decision between limb salvage and amputation, already challenging under normal circumstances, becomes even more complex in a disaster setting due to the inapplicability of ideal guiding scoring systems in such low-resource environments.[2,45,47]

In our cohort, 73 orthopedists performed a median of two amputations in earthquake victims and rated the psychological impact of performing amputations as moderate (median VAS score: 5). Specifically, amputations performed in the pediatric age group, amputation involving multiple extremities, and performing amputations in patients with earthquake-related difficulties or losses were reported as key amputation-related stress factors. Notably, in the Marmara earthquake experience, where 95 of 639 crush victims underwent 121 amputations, a direct correlation was observed between the number of amputated extremities and mortality risk, explained by the presence of more severe injuries in patients requiring multiple amputations.[48]

Tragic situations affecting relatives or close friends in the earthquake zone, which were reported by 40% of our participants, were not statistically associated with IES-R or DASS-21 scores in our sample. In a previous study of healthcare professionals following the Kahramanmaraş earthquakes, the presence of injured family members and loss of relatives in the earthquake were not found to be determinants of anxiety or depression but were significant determinants of PTSD.[17] Similarly, experiencing tragic situations involving relatives or close friends living in the earthquake zone showed no significant association with the IES-R or DASS-21 scores of our participants. However, performing amputations in patients with multiple earthquake-related difficulties or losses was associated with significantly higher DASS-21 depression scores among orthopedists. These findings suggest that healthcare professionals tend to prioritize the needs of their patients over their own needs during crises such as earthquakes.[15] The positive correlation between IES-R hyperarousal and intrusion domain scores and DASS-21 depression scores is also notable, given the previously reported association between intense working conditions after earthquakes and direct involvement in traumatic events with an increased risk of depression.[17,49]

In our study, years of clinical experience, time of arrival, and length of stay in the earthquake-stricken area did not show significant associations with IES-R or DASS-21 scores. Similarly, a study investigating the effects of the Kahramanmaraş earthquakes on the mental health of healthcare professionals found that years of experience and total working days in the field had no significant impact on PTSD scores.[25] However, other studies have indicated that suffering personal losses and having limited work experience are risk factors for adverse mental health outcomes in healthcare professionals involved in rescue efforts, while older age, male gender, professional experience, and social support from family and friends are considered protective factors against PTSD.[1,29,50,51]

Although years of experience showed no significant association with IES-R or DASS-21 scores in our sample, amputations performed by younger orthopedists were associated with higher IES-R scores. The negative correlation between age and IES-R scores in our cohort supports previous findings consistently reporting an inverse relationship between age and secondary traumatic stress or mental health problems among healthcare professionals after earthquakes, emphasizing that psychological resilience increases with age. [1,15,26,51,52] Indeed, having more work experience is considered a protective factor against emotional exhaustion among health professionals but a risk factor for the development of PTSD.[17,53]

Working in an earthquake zone often involves potential exposure to hazardous situations such as lack of secure accommodation, and shortages of water and food during the earthquake relief efforts, which may lead to adverse mental health outcomes.[34,54,55] In our study, difficulties related to accommodation, hygiene, nutritional, and safety conditions in the earthquake-stricken area were rated as moderate by the orthopedists, and none of these factors were associated with IES-R or DASS-21 scores.

Passive and dysfunctional coping strategies such as smoking, alcohol consumption, and irregular eating habits have been reported to be associated with higher levels of PTSD among healthcare professionals.[1,34] Overall, 82.1% of our participants reported a change in appetite and 30.5% reported an increase in cigarette consumption after the earthquakes, while only 14.7% received psychological support afterward.

The results of our study, conducted six months after the 2023 Kahramanmaraş earthquakes, indicate that the early post-disaster period significantly burdens orthopedists, affecting their mental well-being. Hence, our findings emphasize the need for periodic screening of mental health status in the post-disaster setting, particularly among vulnerable frontline healthcare professionals such as orthopedists, along with the provision of long-term psychological support services to improve trauma processing, stress-coping strategies, and overall psychological well-being among those experiencing burnout and distress.[17,25,27,53,56] Previous disaster healthcare experience was reported by only one-third of our participants, further highlighting the potential importance of psychological readiness training before disasters to help ensure the continued functionality of healthcare services in the post-disaster period.[13,15]

Certain limitations of this study should be considered. First, the potential lack of generalizability is an important limitation due to the small sample size. Second, the assessment of mental health status relied on self-reported scales completed by volunteers, which may be subject to unintended response bias, leading to over- or underestimation of results. Third, no causal relationships could be identified due to the cross-sectional design, along with the lack of longitudinal data on emotional states, traumatic experiences, and other factors likely to affect the mental health status of orthopedists.

CONCLUSION

As the first study investigating the mental health outcomes of orthopedists after the 2023 Kahramanmaraş earthquakes, our findings indicate a considerable impact of treating earthquake victims on orthopedists in terms of negative emotional states and traumatic stress symptoms, particularly among local orthopedists and those working at referral hospitals. Amputations performed in the pediatric age group, amputations involving multiple extremities, and difficulties or losses experienced by patients were reported as key amputation-related stress factors. Tragic events involving relatives or close friends living in the earthquake zone did not show a significant association with IES-R or DASS-21 scores in our sample. However, performing amputation surgery on patients with earthquake-related difficulties or losses was associated with significantly higher DASS-21 depression scores. Additionally, amputations performed by younger orthopedists were associated with higher IES-R scores. In the post-earthquake setting, periodic mental health screening of orthopedic surgeons, identification of at-risk groups, and provision of appropriate psychological support are crucial for sustaining the quality of orthopedic care. Moreover, integrating routine mental health evaluations and resilience training into emergency preparedness programs for surgical healthcare professionals is essential to enhance their psychological well-being and readiness for future crises.

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ORİJİNAL ÇALIŞMA - *ÖZ*

Ortopedistler bir sonraki afete psikolojik olarak hazır mı? 2023 Kahramanmaraş depremleri sonrasında ampütasyon uygulayan cerrahlar travmatik stres belirtileri yaşıyor.

AMAÇ: Bu çalışmada, 2023 Kahramanmaraş depremleri sonrasında ortopedistlerin ruh sağlığı sonuçlarının, ortopedik bakım ve ampütasyonlarla ilişkisi bağlamında kapsamlı bir analizle değerlendirilmesi amaçlanmıştır.
GEREÇ VE YÖNTEM: 2023 Kahramanmaraş depremlerinden 6 ay sonra yürütülen, kesitsel araştırmamıza toplam 95 ortopedist dahil edilmiştir. Katılımcılara demografik ve mesleki bilgiler, deprem mağdurlarına sağlanan ortopedik tedaviler, ampütasyonlar ve stres faktörleri, deprem alanındaki deneyimler, Olay Etkisi Ölçeği-gözden geçirilmiş (OEÖ-r) ve Depresyon Anksiyete Stres Ölçeği-21 (DASÖ-21) maddelerini içeren çevrimiçi anket gönderilmiştir. OEÖ-r ve DASÖ-21 skorları, depremle ilişkili deneyimler, ortopedik tedavi ve ampütasyon uygulamalarına bağlı stres faktörlerine göre analiz edilmiştir.
BULGULAR: Deprem bölgesindeki hastalara bakım sağlayan ortopedistlerin oranı %61.5 olup, bunun %16.8'i afet bölgesinde yaşayan, %42.1'i ise destek için bölgeye gelen ortopedistlerden oluşmaktadır. Katılımcıların %36.8'i ise bölge dışındaki sevk hastanelerinde tedavi uygulamıştır. Katılımcıların %76.8'i deprem mağdurlarında ampütasyon ameliyatı gerçekleştirdiğini bildirmiştir. Pediatrik yaş grubunda ampütasyon (%82.2), hastaların kayıpları veya depreme bağlı diğer zorlukları (%64.4) ve çoklu ekstremite ampütasyonları (%56.2) en sık bildirilen stres faktörleri olmuştur. Sevk hastanelerindeki ve afet bölgelerinde yaşayan ortopedistler, bölgeye destek için sonradan gelen ortopedistlere oranla daha yüksek toplam OEÖ-r skorları (11.0 [0-58] ve 11.5 [0-46] ve 1.0 [0-39]), kaçınma (3.0 [0-20] ve 3,0 [0-17] ve 0.0 [0–13]) ve yeniden yaşantılama (4.0 [0-20] ve 5.0 [0-20] ve 0.0 [0-14]) alt ölçek skorları bildirmiştir. Sevk hastanelerindeki ortopedistler ayrıca bölgeye gelenlere oranla daha yüksek anksiyete (2.0 [0-13] ve 0.0 [0-7]), stres (5.0 [0-16] ve 2.0 [0-12]) ve toplam DASÖ-21 skorları (11,0 [0-44] ve 6.0 [0-29]) belirtmiştir. Depremle ilişkili zorlukları olan hastalara ampütasyon yapan ortopedistler, daha yüksek depresyon skorları bildirmiştir (4 [0-18] ve 1 [0-15], p=0.013). OEÖ-r skorları yaşla negatif korelasyon göstermiştir (r=-0.203, p=0.049); diğer faktörler OEÖ-r veya DASÖ-21 skorları ile ilişki göstermemiştir.
SONUÇ: Çalışmamız, deprem mağdurlarına uygulanan tedavilerin ortopedistlerin ruhsal etkilenme düzeyleri ve travmatik stres belirtileri üzerinde belirgin etkisi olduğunu göstermektedir. Özellikle afet bölgesinde yaşayan ve sevk hastanelerindeki ortopedistler daha fazla etkilenmiştir. Temel stres faktörleri arasında pediatrik ampütasyonlar, çoklu ekstremite ampütasyonları ve hastaların yaşadığı zorluklar yer almaktadır. Depremle ilişkili zorlukları olan hastalarda yapılan ampütasyonlar ortopedistlerin depresyon skorlarını artırmıştır. Ayrıca, genç ortopedistler, ileri yaştakilere oranla daha yüksek OEÖ-r skorları bildirmiştir. Bulgularımız, büyük çaplı afetlerin ardından ortopedistler için düzenli ruh sağlığı taraması, risk grubu belirleme, yapılandırılmış psikolojik destek ve dayanıklılık eğitimi ile gelecekteki acil durumlara karşı daha iyi hazırlık yapılması gerektiğine dikkat çekmektedir.

Anahtar sözcükler: Afet; ampütasyon; deprem; ortopedist; ruh sağlığı; travmatik stres.

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ORIGINAL ARTICLE

Open versus percutaneous short-segment posterior instrumentation in thoracolumbar junction burst fractures

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ABSTRACT

BACKGROUND: This research aimed to compare the surgical data and the clinical and radiological results of patients who underwent open posterior versus percutaneous posterior instrumentation for burst-type spinal fractures in the thoracolumbar junction.

METHODS: This study included 73 patients; 43 underwent open posterior instrumentation, and 30 underwent percutaneous posterior instrumentation. Perioperative parameters included the time between fracture and surgery, duration of surgery, perioperative blood loss, fluoroscopy duration, and total length of hospital stay. Clinical evaluation was performed using the Visual Analogue Scale (VAS) and the Oswestry Disability Index (ODI). Preoperative, postoperative, 7th-day, and last follow-up values were analyzed. Radiological evaluation included the anterior vertebral body height ratio (AVBHR) and Cobb angle.

RESULTS: Fluoroscopy time was significantly longer in the percutaneous surgery group than in the open surgery group (12.77±1.89 minutes vs. 4.33±1.24 minutes; p<0.001). Hospitalization time was significantly longer in the open surgery group (3.79±1.53 days vs. 2.13±0.76 days; p<0.001). VAS scores differed significantly between the open and percutaneous surgery groups on the 7th postoperative day (p=0.02) and at the last follow-up (p=0.02). Similarly, lower ODI scores were observed in the percutaneous group compared to the open surgery group on the 7th postoperative day and at the last follow-up (p<0.001). Regarding radiological outcomes, significant postoperative improvements were achieved in both groups in terms of AVBHR, but differences in the Cobb angle in the sagittal plane were not statistically significant (p=0.07).

CONCLUSION: According to the results of this study, the percutaneous surgery group showed significantly better improvement in VAS and ODI scores on postoperative day 7 and at the final follow-up. Similar postoperative improvements were achieved in both groups in terms of AVBHR and sagittal Cobb angle.

Keywords: Blood loss; fluoroscopy; spinal fractures; surgery; visual analogue scale.

INTRODUCTION

Thoracolumbar spine fractures (TLSF) are the most common of all spinal fractures, as this region represents the anatomical and biomechanical transition region of the thoracolumbar area. These fractures can cause severe morbidity and mortality. The social, functional, and economic effects of traumatic spinal injuries are more pronounced than those of other injuries because they often result in severe disability in the long term.[1] Thoracolumbar burst fractures occur due to the collapse of the anterior and middle columns caused by severe axial forces applied to the vertebrae. Similar to compression fractures, burst fractures most commonly occur following motor vehicle accidents and falls from height.[2] Thoracolumbar junction fractures (TLJF) involve the T11-L2 vertebrae. Fractures in this region are more common due to the transition from an area with a limited range of motion, partially stabilized by the ribs, to the lumbar region, which has a greater range of motion.[3]

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The thoracolumbar junction represents a transitional area between the thoracic region, a rigid area with limited mobility, partially stabilized by the ribs, and the lumbar region, which allows for greater movement. For this reason, both pathological and traumatic fractures are frequently observed in this region. While spinal fractures account for 4-23% of all fractures, 10-20% of all spinal fractures are TLJFs. Fractures in other vertebrae can be detected in 25% of TLJFs, may be accompanied by neurological deficits in 15%, and may lead to kyphotic deformity during follow-up.[4] Evaluating stability or instability in TLJFs is vital for determining the appropriate treatment approach. In the surgical treatment of unstable thoracolumbar junction burst fractures, there are two main options: classical open surgery and percutaneous surgery.[5,6]

Within the scope of this research, we aimed to elucidate and compare the surgical data, as well as the clinical and radiological outcomes, of patients who underwent open posterior instrumentation or percutaneous posterior instrumentation for burst-type spinal fractures in the thoracolumbar junction region.

MATERIALS AND METHODS

This study included 73 patients: 43 underwent open posterior instrumentation, and 30 underwent percutaneous posterior instrumentation. All procedures were conducted in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Declaration of Helsinki of 1964, as revised in 2024. Our institution granted ethics committee approval under protocol number 2023-28/26, and informed consent was obtained from all participants.

This article was prepared in accordance with the Enhancing the Quality and Transparency of Health Research Network (EQUATOR) reporting guidelines and checked against the Strengthening the Reporting of Observational studies in Epidemiology (STROBE) Guidelines.

Inclusion Criteria

The study inclusion criteria were as follows: patients over 18 years of age who underwent surgery using the percutaneous or open posterior instrumentation method for type A3 or A4 fractures, according to the AO Spine thoracolumbar fracture classification system, in the thoracolumbar junction region (T11-L2); those with a single-level fracture; and those without neurological deficits.

Exclusion Criteria

Patients were excluded if they had pathological fractures, osteoporosis (DEXA T-score 2.5 or above), any bone pathology, systemic inflammatory diseases, had undergone decompression, had cement-augmented screws, underwent cement augmentation techniques, or received additional spinal surgical interventions other than instrumentation, such as corpectomy.

Evaluation Criteria

The following data were recorded for all patients included in the study: age, gender, Body Mass Index (BMI), Charlson Comorbidity Index, fracture level, fracture type according to the AO Spine thoracolumbar classification system, surgical method applied (open or percutaneous), and follow-up period.

In the perioperative surgical evaluation, the time between fracture and surgery, duration of surgery, perioperative blood loss, fluoroscopy duration, and total length of hospital stay were recorded. In the clinical evaluation, the Visual Analogue Scale (VAS) and the Oswestry Disability Index (ODI) were used. The preoperative, postoperative, 7th-day, and last follow-up scores were analyzed. In the radiological evaluation, the anterior vertebral body height ratio (AVBHR) and sagittal plane Cobb angle values were assessed. In the postoperative period, the time required for patients to return to their daily routine activities was compared. Additionally, complications observed during follow-up in both groups were recorded.

Surgical Procedures

Short-Segment Open Posterior Instrumentation

All patients underwent general anesthesia and were positioned prone on a radiolucent table for the procedure. A midline posterior longitudinal skin incision was made longitudinally over the spinal fracture. The paraspinal muscles were dissected subperiosteally to expose the spinous processes, laminae, and vertebral transverse processes.

Using the free-hand technique, polyaxial pedicular screws were placed bilaterally on both sides of the fractured vertebra, as well as on the upper and lower levels (CD Horizon Legacy, Medtronic®, Memphis TN, USA). In cases with an intact pedicle at the fracture level, intermediate screws were also placed on the fractured vertebra to provide additional structural stability. Screw placement accuracy was verified with fluoroscopy, and malpositioned screws were revised if necessary. Pedicle screws measuring 5.5 mm were used at T10 and above, and 6.5 mm pedicle screws were used at T11 and distal levels.

The rods were then fixed to the screws after being adjusted to the appropriate level. Gentle rod distraction was applied to achieve ligamentotaxis, facilitating fracture reduction. During the operation, the position of the reduction, along with the supporting posts, was checked and confirmed using fluoroscopy. The patients' neurological stability was the reason no laminectomy or decompression was performed; they were neurologically intact.

After cleaning the surgical site, a drain was placed, and the wound was closed. Radiological checkups were conducted regularly to ensure fracture healing and the integrity of the instrumentation. A case example of this method is shown in Figure 1.

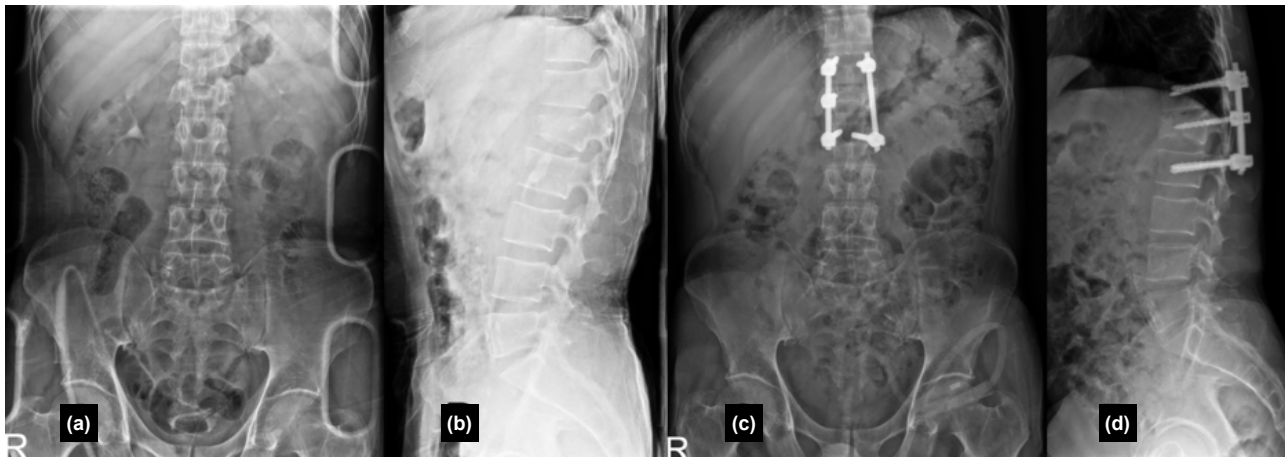

Figure 1. (a) Anteroposterior X-ray of a patient diagnosed with an AO Type A4 fracture of the L1 vertebra, taken in the emergency room after trauma. **(b)** Lateral X-ray of a patient with an AO Type A4 fracture of the L1 vertebra, taken in the emergency room after trauma. **(c)** Anteroposterior X-ray after open posterior instrumentation surgery. **(d)** Lateral X-ray after open posterior instrumentation surgery.

Short-Segment Percutaneous Posterior Instrumentation

Throughout the procedure, the patient was positioned prone, with the spine aligned in the neutral position on a fluoroscopic, radiolucent table. The fractured vertebra and adjacent levels were visualized using intraoperative fluoroscopy.

Under fluoroscopic guidance, Jamshidi needles were placed at the pedicle entry points of the vertebrae one level above and one level below the fracture through small stab incisions. The needles were then exchanged for guidewires, which were advanced into the pedicles before needle removal. The guidewires were secured, and cannulated pedicle screws were placed over them after working channels were created using sequential dilators (CD Horizon Longitude, Medtronic®, Memphis TN, USA). In selected cases, intermediate screws were placed at the fractured vertebra to provide additional support and enhance stability. Pedicle screws measuring 5.5 mm were used at T10 and above, and 6.5 mm screws were used at T11 and below.

The rods, repositioned externally beneath the fascia, were aligned with the screws. Fracture reduction was achieved through controlled distraction using the instrumentation system, under fluoroscopic monitoring. Using fluoroscopy, the position of the reduction, along with the supporting poses, was checked and confirmed during the operation. Because the patients were neurologically intact, no laminectomy or decompression was performed.

The incision areas were cleaned and closed with sutures in multiple layers, and a sterile dressing was applied. Radiological checkups were performed regularly to ensure fracture healing and the integrity of the instrumentation. A case example of this method is shown in Figure 2.

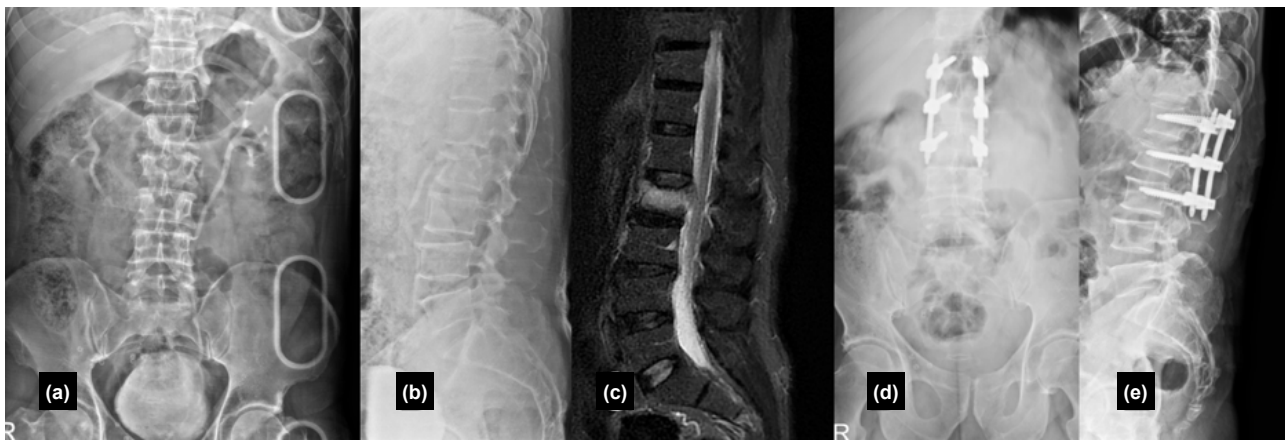

Figure 2. (a) Anteroposterior X-ray of a patient diagnosed with an AO Type A3 fracture of the L2 vertebra, taken in the emergency room after trauma. **(b)** Lateral X-ray of a patient diagnosed with an AO Type A3 fracture of the L2 vertebra, taken in the emergency room after trauma. **(c)** Sagittal T2 Short Tau Inversion Recovery (STIR) magnetic resonance image showing the L2 fracture. **(d)** Anteroposterior X-ray after percutaneous posterior instrumentation surgery. **(e)** Lateral X-ray after percutaneous posterior instrumentation surgery.

Table 1. Baseline demographics of the study population

Parameters	Open Instrumentation (N=43)	Percutaneous Instru-Mentation (N=30)	P value
Age (Years)	58.95±5.62	58.67±4.89	0.394
Sex		0.707	
Female	21 (48.84%)	16 (53%)	
Male	22 (51.16%)	14 (47%)	
Body Mass Index (kg/m^2)	30.16±8.72	32.10±7.54	0.211
Charlson Comorbidity Index	1.88±1.17	1.90±0.83	0.654
Fracture Level			0.675
T11	3	4	
T12	10	7	
L1	19	11	
L2	11	8	
Fracture Type *			0.247
A3	26	14	
A4	17	16	
Follow-up Period (months)	14.95±2.36	15.07±1.82	0.597

*According to the AO Spine Thoracolumbar Fracture Classification System.

Table 2. Surgical parameters of the study population

Surgical Parameters	Open Instrumentation		Percutaneous Instrumentation		P Value
	Mean	± SD	Mean	± SD	
Time between fracture and surgery (days)	4.63	2.66	3.97	2.02	0.462
Duration of surgery (minutes)	176.65	37.41	95.67	15.90	<0.001
Perioperative blood loss (ml)	230.12	55.37	29.17	23.35	<0.001
Fluoroscopy duration (times)	4.33	1.24	12.77	1.89	<0.001
Length of hospital stay (days)	3.79	1.53	2.13	0.76	<0.001

SD: Standard deviation.

Statistical Analysis

Number, percentage, frequency, and standard deviation data were used in descriptive statistics. The normality of variables was checked using the Shapiro-Wilk test. The independent samples t-test was used for comparisons between groups for variables showing a normal distribution (age, BMI, Cobb angle, and AVBHR). The Mann Whitney-U test was used to determine differences between groups for variables not showing a normal distribution. All results are presented as mean±standard deviation (SD). The significance level was set at $p<0.05$. Data were analyzed using SPSS (Statistical Package for the Social Sciences, Version 28.0; Armonk, NY: IBM Corp.).

RESULTS

This study included 73 patients: 43 underwent open posterior instrumentation, and 30 underwent percutaneous posterior instrumentation. Both groups showed similar characteristics in terms of age, gender distribution, Body Mass Index, Charlson Comorbidity Index, fracture level, fracture type, and follow-up period, with no statistically significant differences between these variables (Table 1).

When evaluated in terms of surgical parameters, the operation time was significantly longer in the open surgery group, with an average of 176.65±37.41 minutes, compared to 95.67±15.90 minutes in the percutaneous group ($p<0.001$).

Similarly, perioperative blood loss was significantly higher in the open surgery group (230.12±55.37 ml) than in the percutaneous group (29.17±23.35 ml) (p<0.001). However, fluoroscopy time was significantly longer in the percutaneous surgery group than in the open surgery group (12.77±1.89 minutes vs. 4.33±1.24 minutes; p<0.001). The hospitalization time was also significantly longer in the open surgery group (3.79±1.53 days vs. 2.13±0.76 days; p<0.001) (Table 2).

When the clinical results were evaluated, significant improvements were observed in VAS and ODI scores on the 7th postoperative day and at the last follow-up in both groups. VAS scores were 2.91±0.67 in the open surgery group and 2.53±0.56 in the percutaneous surgery group on the 7th postoperative day, and this difference was statistically significant (p=0.02). At the last follow-up, VAS scores were 0.63±0.48 and 0.35±0.47, respectively, and the difference was significant (p=0.02). Similarly, ODI scores were lower in the percutaneous group compared to the open surgery group on the 7th postoperative day and at the last follow-up (p<0.001) (Table 3).

When the groups were compared in terms of the time to return to daily routine activities, this duration was significantly shorter in the percutaneous surgery group (p=0.003). The mean duration was 17.33±4.22 weeks in the percutaneous surgery group and 20.35±3.46 weeks in the open surgery group.

When evaluated in terms of radiological results, significant postoperative improvements were achieved in both groups regarding AVBHR and Cobb angle in the sagittal plane, with no statistically significant differences between the groups. AVBHR was measured as 86.23±4.67% in the open surgery group and 85.10±4.17% in the percutaneous group at the last follow-up (p=0.594). At the last follow-up, the Cobb angle was recorded as 11.60°±4.09 in the open surgery group and 12.27°±3.99 in the percutaneous group (p=0.707) (Table 4).

DISCUSSION

Since the thoracolumbar region is the transition point between the thorax and the abdomen, the probability of developing mortality and morbidity is relatively high. Therefore, patient management and treatment options should be well understood. On direct radiographs, more than 50% collapse of the vertebral body and 30-35° angulation are indicators of posterior complex damage and are considered signs of instability.[7] The general view in the treatment approach is conservative management for stable TLJFs with pain control, while surgical treatment is preferred for vertebral fractures with progressive neurological deficits, rapid deformity progression,

Table 3. Clinical outcome parameters of the study population

Clinical Outcome Parameters	Surgery Type	Preoperative		P value	Postoperative Day 7		P value	Last Follow-up		P value
		Mean	± SD		Mean	± SD		Mean	± SD	
VAS	Open	7.00	1.11	0.62	2.91	0.67	0.02	0.63	0.48	0.02
	Percutaneous	7.13	1.06		2.53	0.56		0.35	0.47	
ODI	Open	41.93	1.91	0.97	22.23	1.64	<0.001	6.23	1.64	<0.001
	Percutaneous	42.03	2.17		19.97	1.28		3.17	0.90	

VAS: Visual Analogue Scale; ODI: Oswestry Disability Index; SD: Standard Deviation.

Table 4. Radiological outcome parameters of the study population

Radiological Outcome Parameters	Surgery Type	Preoperative		P value	Last Follow-up		P value
		Mean	± SD		Mean	± SD	
AVBH (%)	Open	63.23	7.07	0.323	86.23	4.67	0.594
	Percutaneous	65.37	7.96		85.10	4.17	
COBB (°)	Open	24.14	6.84	0.634	11.60	4.09	0.707
	Percutaneous	22.70	6.13		12.27	3.99	

SD: Standard deviation; AVBH: Anterior vertebral body height ratio.

or instability. The goals of TLJF surgery are to decompress neural structures, protect and improve neurological function, correct spinal deformity, restore vertebral height, correct angular deformity, reduce pain and potential subsequent deformities, preserve anatomical structure, provide stabilization, enable early mobilization and rehabilitation, and minimize changes in the patient's quality of life.[7-9]

The posterior approach is generally preferred, as implant technology has advanced in recent years. Currently, the transpedicular screwing method, which is frequently used and familiar to most spine surgeons, is the standard posterior approach. Interspinous and sublaminar wiring, distraction rods, and sublaminar hooks are now rarely used. In the transpedicular screw fixation technique, screws placed through the pedicle allow segmental fixation, stabilize the end column, and are effective in achieving and maintaining spinal alignment. In addition, since there is a risk of kyphosis in TLJFs, kyphosis correction is an essential component of morphological recovery.[10] This method also allows early postoperative mobilization. The fusion rate is relatively high when there is no severe damage to the anterior or middle columns. To avoid iatrogenic injury to the upper and lower parts of the segment to be fused, care should be taken to prevent facet joint damage.[10]

Long-segment or short-segment fixation in the posterior approach is still a controversial issue. Short-segment stabilization involves placing screws in one lower and one upper pedicle of the fractured vertebra. Aly et al.[11] conducted a meta-analysis of 365 cases, finding no significant differences between the two groups in terms of implant failure rate, neurologic improvement, functional outcomes, or radiological results. According to the findings of this meta-analysis, short-segment posterior stabilization for thoracolumbar burst fractures does not require extension of fixation.

Posterior stabilization can be performed using either the classical open approach or the percutaneous approach. The main difference between percutaneous and open surgery is the relatively minimal muscle damage during the former. In open surgery, postoperative atrophy develops due to ischemia and denervation of the paraspinal muscles.[12] Furthermore, this damage results in increased intraoperative blood loss and greater postoperative pain.[13] In contrast, during percutaneous surgery, the paraspinal muscles are protected by dilation throughout the surgical procedure. Clinical studies in the literature have confirmed that percutaneous surgery is associated with reduced intraoperative blood loss, shorter operative times, fewer wound complications, and earlier mobilization.

The most suitable cases for the isolated percutaneous pedicle screw-rod system (PPRS) are vertebral fractures that do not require decompression. Isolated PPRS is not appropriate for patients with bony fragments in the spinal canal or neurological deficits.[14] Low load-sharing score burst fractures are among those that can be treated with PPRS, as the anterior column is supported by this system. Ni et al.[15] treated 36 cases with low load-sharing scores (≤ 6) and Magerl Type A3 (burst) fractures using short-segment PPRS. After an average follow-up of 48.5 months, excellent results were achieved in 19 cases, good in 12 cases, and fair in five cases. Oh et al.[16] treated 30 neurologically intact patients with thoracolumbar fractures using PPRS. In their follow-up, they found that range of motion (ROM) values were significantly better in cases where the PPRS system was removed within 12 months after surgery than in those where it was removed after 12 months. They also found that the anterior vertebral height ratio (AVHR) and sagittal Cobb angle values did not differ significantly between the two groups.

Grossbach et al.[17] demonstrated that the percutaneous method is more advantageous than the open method in terms of blood loss and hospital stay. Yang et al.[18] found that the percutaneous pedicle screw technique is associated with shorter operative times, less bleeding, and less pain, but requires longer radiation exposure. Peters et al.[19] compared open and percutaneous surgery for thoracolumbar fractures in a large cohort of 691 patients and found that percutaneous surgery resulted in shorter operative times, lower blood loss, and lower infection rates. In our study, the operation time was significantly longer in the open surgery group. Additionally, perioperative blood loss was significantly higher in the open surgery group. However, fluoroscopy duration was significantly longer in the percutaneous group, and hospitalization time was significantly longer in the open surgery group.

With the increasing use of minimally invasive approaches in spine surgery, both the duration and dose of radiation exposure during surgery have been rising. According to the recommendations of the International Commission on Radiological Protection, the annual average radiation exposure dose should be below 20 mSv (based on the average over the last five years).[20] All surgeries in our study were performed by the same surgeon. Personal dosimeters were used during all procedures, and the annual average radiation dose remained below 20 mSv.

There is no consensus in the literature regarding implant removal after TLJFs. Although implant removal generally improves range of motion, pain reduction, and functional scores, it also increases local kyphosis and secondary surgical complications.[21] Smits AJ et al.[22] evaluated 102 patients who underwent implant removal after thoracolumbar fractures and found that, while patients experienced improvements in pain and quality of life scores, there was an increase in kyphosis of 3.5-4.9 degrees and an 8% incidence of secondary surgery-related complications. Oh et al.[16] assessed implant removal outcomes in 30 patients with thoracolumbar vertebral fractures treated with percutaneous posterior instrumentation and observed significant improvements in VAS and ODI scores after implant removal. A loss of correction of 5.0±5.8 degrees was observed in the AVHR and 3.9±7.3 degrees in the Cobb angle. For these reasons, the literature

recommends implant removal in selected patients with postoperative pain and disability, taking into account the potential for complications.[21] Therefore, we do not routinely perform implant removal in our clinic.

One of the most important distinctions of the percutaneous method is that the facet joints are preserved and no arthrodesis is performed. Diniz et al.[23] found that arthrodesis did not enhance clinical outcomes in their study of 220 patients with an average follow-up period of 69.1 months. Nevertheless, it did not significantly improve radiological indicators and was associated with longer operative times and greater intraoperative hemorrhage.

An important point in the radiological evaluation of TLJFs is the preservation of the height of the fractured spine and the restoration of disrupted sagittal alignment. In this respect, studies comparing the percutaneous technique with the open technique have yielded controversial results in the literature. Neeley et al.[24] reported that the percutaneous fixation technique allowed better fracture reduction and improved postoperative alignment. Erichsen et al.[25] compared percutaneous and open surgery in AO Type 3 fractures and found no difference in postoperative kyphosis radiologically (p=0.588). Our study demonstrated significant postoperative improvements in both groups regarding AVBHR and Cobb angle in the sagittal plane, with similar differences between the groups.

CONCLUSION

In this study, the percutaneous surgery group showed significantly greater improvement in VAS and ODI scores on postoperative day 7 and at final follow-up. Similar postoperative improvements were achieved in both groups in terms of AVBHR and sagittal Cobb angle. Although operative time, perioperative blood loss, hospitalization duration, and time to return to routine daily activities were significantly longer in the open surgery group, fluoroscopy duration was significantly longer in the percutaneous surgery group.

Ethics Committee Approval: This study was approved by the Uludağ University Ethics Committee (Date: 15.12.2023, Decision No: 2011-KAEK-26-1032).

Peer-review: Externally peer-reviewed.

Authorship Contributions: Concept: Y.B., S.B.G.; Design: Y.B., S.B.G.; Supervision: B.A.; Data collection and/or processing: Y.B., S.B.G., B.A.; Analysis and/or interpretation: Y.B., B.A.; Literature review: S.B.G.; Writing: Y.B., S.B.G., B.A.; Critical review: B.A.

Conflict of Interest: None declared.

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ORİJİNAL ÇALIŞMA - *ÖZ*

Torakolomber bileşke patlama kırıklarında açık ve perkütan kısa-segment posterior enstrümentasyonun karşılaştırılması

AMAÇ: Bu araştırma, torakolomber bileşkede patlama tipi omurga kırıkları için açık posterior veya perkütan posterior enstrümantasyon kullanılarak ameliyat edilen hastaların cerrahi verilerini, klinik ve radyolojik sonuçlarını karşılaştırmayı amaçlamaktadır.
GEREÇ VE YÖNTEM: Bu çalışmaya 73 hasta dahil edildi; 43'üne açık posterior enstrümantasyon, 30'una perkütan posterior enstrümantasyon uygulandı. Perioperatif cerrahi değerlendirmede, kırık ile ameliyat arasındaki süre, ameliyat süresi, perioperatif kan kaybı, floroskopi süresi ve toplam hastanede kalış süresi kullanıldı. Klinik değerlendirmede, görsel analog skala (VAS) ve Oswestry sakatlık indeksi (ODI) kullanıldı. Ameliyat öncesi, ameliyat sonrası 7. gün ve son takip değerleri analiz edildi. Radyolojik değerlendirmede anterior vertebral gövde yükseklik oranı (AVBHR) ve COBB açısı kullanıldı.
BULGULAR: Perkütan cerrahi grubunda floroskopi süresi açık cerrahi grubuna göre anlamlı derecede daha uzundu (12.77±1.89 dakikaya karşı 4.33±1.24 dakika; p<0.001). Hastanede kalış süresi açık cerrahi grubunda anlamlı derecede daha uzundu (3.79±1.53 gün, 2.13±0.76 gün; p<0.001). VAS skorları açık cerrahi grubunda ve perkütan cerrahi grubunda ameliyat sonrası 7. günde (p=0.02) ve son takipte (p=0.02) daha düşüktü. Benzer şekilde, perkütan grupta açık cerrahi grubuna kıyasla ameliyat sonrası 7. günde ve son takipte daha düşük ODI skorları elde edildi (p<0.001). Radyolojik sonuçlar açısından değerlendirildiğinde, her iki grupta da anterior vertebral gövde yükseklik oranı (AVBHR) ve sagital planda COBB açısı açısından anlamlı postoperatif iyileşmeler elde edildi fakat gruplar arasındaki fark istatistiksel olarak anlamlı değildi (p=0.07).
SONUÇ: Bu araştırmanın sonuçlarına göre, perkütan cerrahi grubunda postoperatif 7. günde ve son takipte VAS ve ODI skorlarında anlamlı olarak daha iyi iyileşme gözledi. Her iki grupta da anterior vertebral gövde yükseklik oranı ve sagital COBB açısı açısından benzer postoperatif iyileşme elde edildi.

Anahtar sözcükler: Cerrahi; floroskopi; görsel analog skala; kan kaybı omurga kırıkları.

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ORIGINAL ARTICLE

Elbow collateral ligament repairs with suture anchors after acute complex elbow dislocations have favorable outcomes; clinical results at a mean follow-up of eight years, a stress radiography-based study

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ABSTRACT

BACKGROUND: This study aimed to compare the medium- to long-term results of elbow collateral ligament repairs performed with suture anchors.

METHODS: Patients undergoing surgery for elbow collateral ligament repairs between 2011 and 2023 were retrospectively analyzed. We included patients who had undergone surgery for complex elbow dislocations. Patients were excluded from the study if they had a previous infection, a fracture, an operation on the same elbow, a stiff elbow, or a follow-up period of less than 1 year. For the functional evaluation, the range of motion (ROM) and the Mayo Elbow Performance Score (MEPS) were used for the postoperative functional assessments. The radiological evaluation used varus and valgus stress radiographs of healthy and operated extremities taken while applying an 80 N force with a digital dynamometer.

RESULTS: Thirty-five patients (24 male and 11 female) were included in the study. Eighteen patients had isolated lateral collateral ligament (LCL) injuries, nine patients had isolated medial collateral ligament (MCL) injuries, and eight patients had LCL and MCL injuries. The mean age was 32 (18–68) years, and the follow-up period was 104.8 (32–147) months. The mean value of the MEPS was 92.1±10.3; 22 patients had excellent, 11 patients had good, and only two patients had fair results. Patients with isolated LCL and MCL repairs achieved better flexion motion than patients with combined ligament repairs (142.5° and 141.7° vs. 138.6°). When comparing operated and healthy extremities, radiocapitellar joint distance (RCJD) was found to increase by 0.8±0.5 mm, and ulnotrochlear joint distance (UTJD) was found to increase by 1.18±0.5 mm, but these changes were not statistically significant.

CONCLUSION: The results of this study suggest that the use of suture anchors in elbow collateral ligament injuries is a valid solution for treatment and prevention of instability in patients with isolated or combined repairs.

Keywords: Collateral ligament; elbow dislocation, repair; stability.

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INTRODUCTION

The elbow joint is the second most commonly dislocated joint of the upper limb, with the shoulder being the most commonly dislocated joint, and more than a quarter of elbow dislocations are associated with elbow fractures.[1] Complex dislocations can be accompanied by radial head, coronoid, capitellum, and olecranon fractures.[2] Depending on the severity of the trauma, injuries to the lateral collateral ligament complex (LCLc), the joint capsule, and the common extensor tendon may occur.[3,4] If reduction can be maintained through flexion of more than 45° after reduction under anesthesia, then this condition is considered an unstable elbow dislocation, which necessitates surgical treatment.[5,6]

A review of the literature reveals that two main methods are used to treat elbow collateral ligament injuries. The first is the ligament reconstruction technique described by Jobe et al., which has been the gold standard for elite athletes, heavy laborers, and patients undergoing surgery for chronic posterolateral rotational instability.[7] However, the development of implant technology and patients' changing expectations over the years have prompted the search for new techniques. In recent years, collateral ligament repairs with fiber suture augmentation have gained popularity. Studies have shown that this technique allows patients to return to sports earlier (around 6.7 months compared to 11.6 months after modified Jobe reconstruction) and results in fewer gaps in the medial joint space.[8-10] These results highlight the favorability of repair instead of reconstruction after the initial trauma, especially among people who are not elite athletes. However, there is limited literature available on studies that use only suture anchors.

Residual instability can develop due to inadequate healing after repair. This condition, which can negatively affect a patient's ability to return to their pre-injury activity levels, can be prevented by performing a solid repair followed by an appropriate rehabilitation program. Aside from the functional results of the elbow joint assessed through physical examination after surgery, radiological findings may also be necessary. The most basic methods for this purpose are varus and valgus stress radiographs. However, there are few studies on the radiological evaluation of collateral ligament repair outcomes.

The purpose of this study was to evaluate the clinical and radiological outcomes of collateral ligament repair using suture anchors in patients with acute complex elbow dislocations. Although suture anchor techniques have become increasingly preferred for ligament repair, existing literature has primarily focused on clinical outcomes, and studies addressing objective radiological findings remain limited. This study was therefore conducted to fill this gap by providing comprehensive clinical and radiological evidence regarding the effectiveness of suture anchor fixation in restoring elbow stability.

MATERIALS AND METHODS

Patient Selection and Study Design

Ethical approval was obtained from the institution with which the authors are affiliated (KAEK-291298). Verbal and written informed consent was obtained from the patients who agreed to participate in the study. All procedures conducted in studies involving human subjects adhered to the ethical criteria set forth by the institutional and/or national research committee, as well as the 1964 Helsinki Declaration and its subsequent revisions or equivalent ethical standards.

This retrospective study analyzed patients who underwent elbow collateral ligament injury surgery between January 2011 and June 2023. The study included patients older than 18 years and younger than 75 years who had undergone surgery for periarticular elbow fractures and associated elbow dislocations. Patients who had previously undergone surgery for the same elbow fracture or for any other reason (1), who were diagnosed with a stiff elbow (2), who developed fractures due to pathological bone disease (3), and who had a follow-up period of less than one year (4) were excluded from the study. The patients' preoperative data, such as the mechanism of injury and the time between trauma and surgery, were obtained from their medical records. Figure 1: Flowchart

Patients who met the inclusion criteria were divided into three groups: patients with isolated lateral collateral ligament (LCL) repairs (Group I), patients with isolated medial collateral ligament (MCL) repairs (Group II), and patients with combined MCL and LCL repairs (Group III).

Surgical Technique and Rehabilitation

Closed reduction was attempted for all complex elbow dislocations at the initial presentation in the emergency department. In the operating room, an acute open reduction was performed for dislocations that were unstable or could not be reduced by closed reduction. The operations were performed in a single center by two different surgeons with 18 years' (T.G.) and 8 years' (M.A.) experience in elbow surgery. During surgery, all possible fractures were fixed with screws/plates/screws. Mason type 4 radial head fractures were replaced with a radial head prosthesis. After osteosynthesis, the elbow joints were examined for instability. If the joints were unstable, then LCL repairs were performed first, and, if necessary, MCL repairs were performed using 5.0 mm metal suture anchors (Arthrex, Munich, Germany). The anchor was placed up to the isometric point during surgery under fluoroscopic control. The collateral ligament was repaired together with the surrounding soft tissues (joint capsule, common extensor origin, flexor/pronator muscle group). The sutures emerging from the anchor were passed using the Krakow technique.

After surgery, prophylactic antibiotic therapy (first-generation cephalosporin) was applied for 24 hours postoperatively, and 75 mg indomethacin was administered once daily for 3 weeks

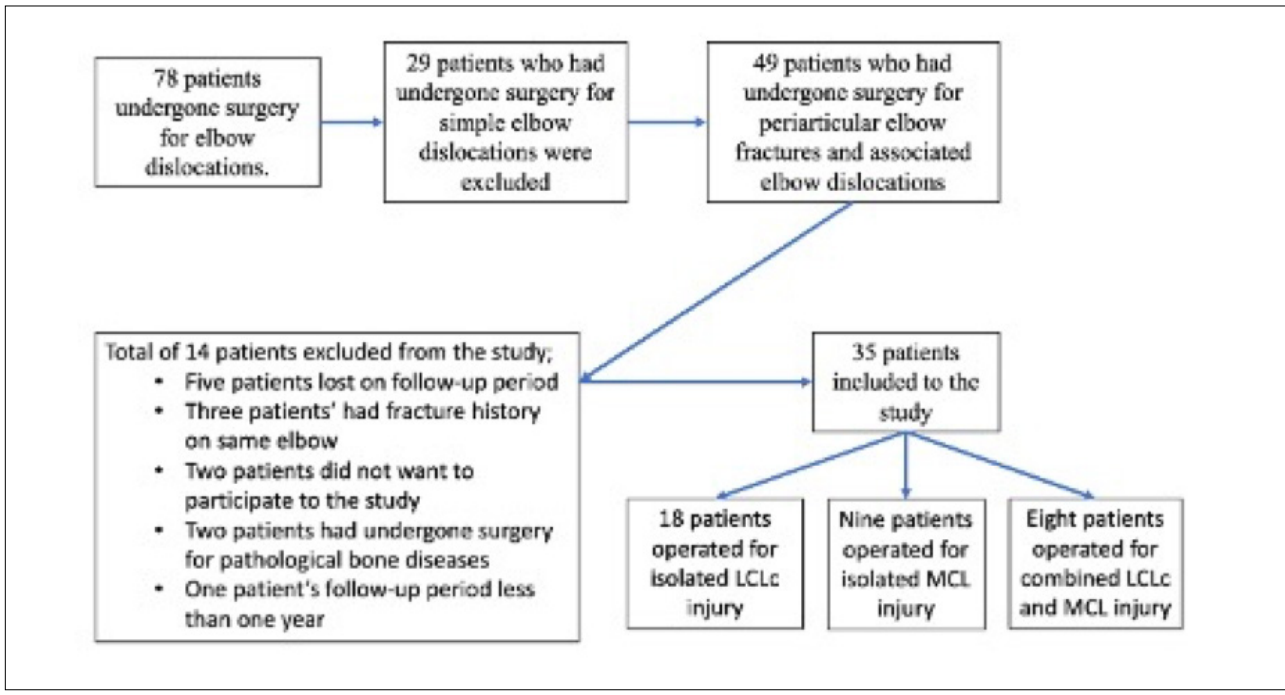

Figure 1. Presentation of the patients participating in our study in the form of a flowchart according to the inclusion and exclusion criteria.

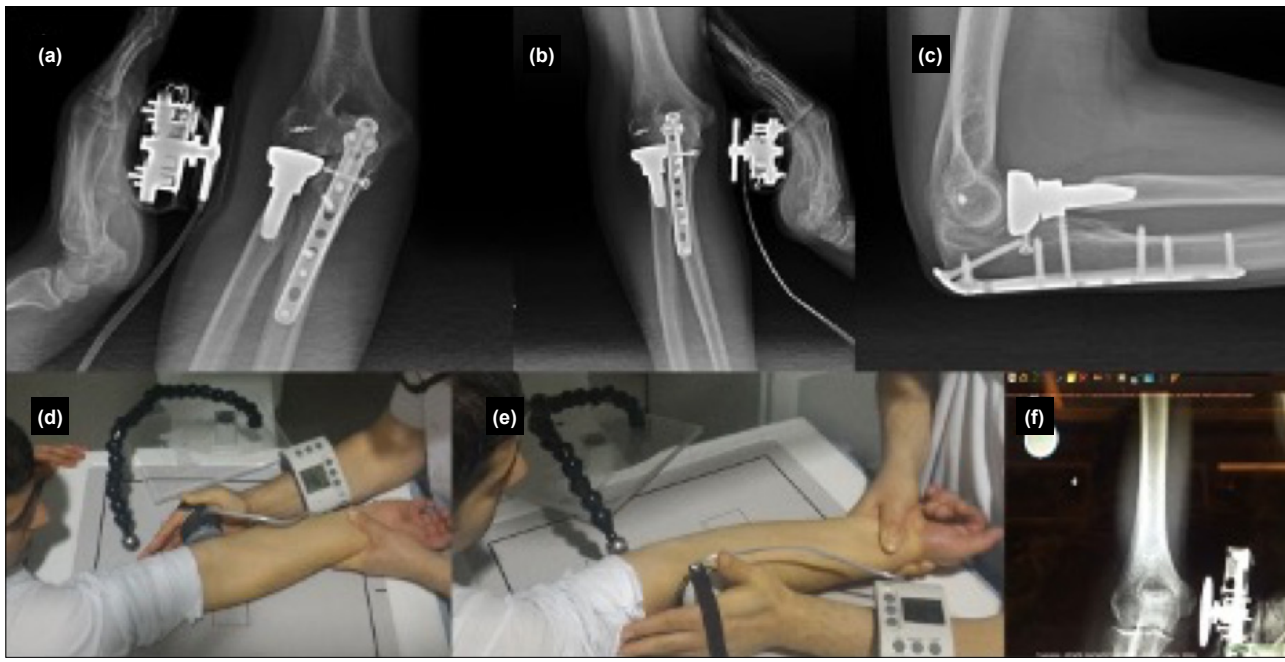

Figure 2. (a) Valgus stress radiograph; **(b)** Varus stress radiograph; **(c)** Lateral elbow radiograph showing the anchor used for the LCLc repair at the isometric point; **(d)** Varus stress radiograph with an 80 N force applied using a dynamometer; **(e)** Valgus stress radiograph with an 80 N force applied using a dynamometer; **(f)** The actual joint distance measured after removing magnification errors in the TraumaCad program.

to prevent the development of heterotopic ossification.[11] After the operation, all patients underwent a step-by-step rehabilitation program that included temporary immobilization, exercise, strengthening, and a return to sports.[12,13] After two weeks of immobilization at 90° of flexion in the early postoperative period, the patients began to perform a controlled range of motion in a functional splint to ensure elbow joint range of motion and muscle strengthening until the fifth week

after surgery. When controlled motion was started, 30°-110° of flexion was allowed in the first week, 15°-130° of flexion in the second week, and full motion in the splint in the last week, similar to the protocol used by Wilk et al.[12]

Postoperative Evaluations

Preoperative and final follow-up examinations of the patients were performed by two orthopedic and traumatological surgeons who were not involved in the operations or the study (Ö.C.Ç., U.S.). Functional and radiological examinations were performed during the final examination. A consensus meeting was held to establish a clear methodology before conducting the measurements. The measurements were then performed jointly by two orthopedic and trauma surgeons. Radiological assessment included examination of fracture healing, joint congruency, osteoarthritis, and development of heterotopic ossification (HO), as well as varus and valgus stress radiographs of the healthy and operated extremities using a digital dynamometer (JTech Medical, Midvale, USA) with a force of 80 N applied by an orthopedic surgeon who was not involved in the surgery to detect possible residual instability. Radiographs were taken with a one-inch diameter calibration sphere to eliminate magnification errors (minimum 1° angle and 0.1 mm measurement difference). The radiographs were calibrated using the TraumaCad® program (BrainLab, Munich, Germany), and distance measurements were taken on the stress radiographs (Figure 2).

The postoperative functional assessment included the range of motion (ROM) and the Mayo Elbow Performance Scale (MEPS). The Mayo Elbow Performance Score (MEPS) is a comprehensive evaluation system that assesses pain, range of motion, elbow stability, and activities of daily living. It is scored on a scale from 0 to 100, with higher scores indicating better functional outcomes.

Statistical Analysis

The data were analyzed using SPSS Statistics Software (version 23.0, IBM Corp.). The distribution of the data was evaluated with the Shapiro–Wilk test. The categorical data were assessed with the Pearson chi-square test, Fisher's exact test, and the Fisher–Freeman–Halton test. The parametric and non-parametric data were evaluated with the Student's t-test and Mann–Whitney U test, respectively. The dependent groups (for non-normally distributed data) were evaluated with the Wilcoxon test. Inter-observer reliability of radiographic measurements was assessed using the Intraclass Correlation Coefficient (ICC) with 95% confidence intervals. A p-value of <0.05 was considered significant in all the tests.

A post hoc power analysis revealed that the statistical power required to compare ASES scores between the groups when there were 22 patients exceeded 0.95, and an effect size of f=0.528 indicated that the sample size was sufficient to detect between-group differences.

Table 1. Descriptive characteristics of patients

	n	%
Gender		
Female	11	30.8
Male	24	69.2
Injured extremity		
Right	16	46.2
Left	19	53.8
Repaired collateral ligament		
MCL	9	25.7
LCLC	18	51.4
Both	8	22.9
Associated bone injuries		
Isolated radial head fractures		
(Mason Type II/III/IV)	15 (5/7/3)	42.8
Isolated coronoid fractures		
(R-M Type 1/2/3)	5 (1/2/2)	14.2
Terrible triad	9	25.7
Medial epicondyle fractures	4	11.4
Olecranon fractures	2	5.7
Associated soft tissue injuries		
Common extensor tendon rupture	6	17.1
Common flexor tendon rupture	3	8.5
Capsule rupture	9	25.7
Open fracture	3	8.5
MEPS		
Excellent	22	62.8
Good	11	31.4
Fair	2	5.8
Instability		
Yes	0	0
No	35	100

R-M: Regan and Morrey Classification, MEPS: Mayo Elbow Performance Score, MCL: medial collateral ligament, LCLC: lateral collateral ligament complex.

RESULTS

Thirty-five patients were included in the study. The mean age of our patients at the time of surgery was 32 years (range: 18–68 years). The mean follow-up time was 104.8 months (32–147 months). The descriptive characteristics of the patients are listed in Table 1.

Osteosynthesis of the concomitant fractures was completed before the ligaments were repaired. Eight patients with non-reconstructable comminuted fractures of the radial head underwent radial head prosthesis. Meanwhile, six patients underwent osteosynthesis with a plate screw, and seven pa-

Table 2. Investigating the impact of LCL, MCL and combined ligament repair on radiocapitellar and ulnotrochlear joint distances

	LCLc (n=18)	Combined (n=8)	p
Radiocapitellar width (uninjured)**	3.9±0.9	3.9±1.0	0.932
Radiocapitellar width (injured)**	4.8±1.0	4.7±1.1	0.966
	MCL (n=9)	**Combined (n=8)**	
Ulnotrochlear width (uninjured)**	3.8±0.8	3.8±1.1	0.917
Ulnotrochlear width (injured)**	5.1±0.9	5.0±1.0	0.881

One-way ANOVA was performed. *The Kruskal–Wallis test was conducted. ** Student's t-test was performed. MCL: medial collateral ligament, LCLc: lateral collateral ligament complex.

Table 3. Investigating the impact of LCL, MCL and combined ligament repair on functional outcomes

	MCL (n=9)	LCLc (n=18)	Combined (n=8)	P
MEPS				
Fair	0	0	2	0.047
Good	2	6	3	
Excellent	7	12	3	

One-way ANOVA was performed. *The Kruskal–Wallis test was conducted. ** Student's t-test was performed. MCL: medial collateral ligament, LCLc: lateral collateral ligament complex.

tients underwent osteosynthesis with a headless cannulated screw. Eight coronoid fractures were fixed with screws, while no intervention was made for two type 1 coronoid fractures. Other concomitant fractures were fixed with screws/plate screws.

Radiological results

Stress radiographs showed that the radiocapitellar joint distance (RCJD) was 3.9 mm in the healthy extremity, 4.8±1.0 mm in patients with isolated LCL repair, and 4.7±1.1 mm in patients with combined repair. The mean increase in RCJD on the operated side was 0.8±0.5 mm, which was not statistically significant (p>0.05). Similarly, the RCJD values of patients with isolated and combined repairs were comparable (p=0.996). The ulnotrochlear joint distance (UTJD) measured 3.8 mm in the healthy extremity, 5.1±0.9 mm in patients with isolated MCL repair, and 5.0±1.0 mm in patients with combined repair. The mean UTJD increase of 1.18±0.5 mm was not statistically significant (p>0.05). Inter-observer reliability was assessed using a two-way mixed-effects model with absolute agreement. The intraclass correlation coefficient (ICC) was: for UTJD of extremity 0.969 (95% CI: 0.009–0.994), UTJD stress 0.983 (95% CI: 0.067-0.997), for RCJD 0.987 (95% CI: 0.172-0.998), and RCJD stress 0.944 (95% CI: 0.169-0.987). Importantly, although minor widening (0.8-1.1 mm) was observed in both the RCJD and UTJD after repair, no signs of instability were observed in any patient during follow-up examinations. These small increases in joint space were considered to have no clinical relevance (Table 2).

Clinical results

The mean MEPS was 92.1±10.3: excellent in 22 cases, good in 11 cases, and fair in 2 cases (Table 1). All isolated MCL or LCL repair cases achieved only excellent or good results in MEPS. Meanwhile, 2 of 8 cases with combined MCL and LCL repairs had mediocre results. While the MEPS results of patients with isolated repair were similar, the combined repair results were worse (p<0.05) (Tables 3 and 4).

The mean ROM was 133±12.5°, the mean extension loss was 7.6±3°, and the mean flexion was 140.7±12°. In the cases where only the LCLc was repaired, the average ROM was 135.2±11.9°, the average extension loss was 7.2±1.9°, and the average flexion was 142.5±12.1°. In the cases where only the MCL was repaired, the average ROM was 134.8±9.3°, 6.8±1.9°, and 141.7±9.5°, respectively. The mean ROM was 129.8±14.7°, the mean extension loss was 8.8±4.5°, and the mean flexion was 138.6±14.2° in the patients who underwent both MCL and LCL repair (Table 4). The range of joint motion of patients who underwent isolated repair was similar, while the range of joint motion of patients who underwent combined repair was less, although it was not statistically significant (Table 5).

Table 4. Investigating the impact of LCL, MCL and combined ligament repair on Mayo Elbow performance score results

	MCL (n=9)	LCLc (n=18)	Combined (n=8)	p
MEPS	96.1±7.8	91.6±11.1	88.1±11.3	0.288
Pain*	47.7±20.6	38.3±10.8	35.6±11.1	0.337
Motion*	19.4±1.6	18.8±2.2	18.5±2.1	0.449
Stability	10±0	10±0	10±0	N/A
Function*	25.0±0	24.4±1.6	24.3±1.7	0.573

One-way ANOVA was performed. *The Kruskal–Wallis test was conducted. ** Student's t-test was performed. MCL: medial collateral ligament, LCLc: lateral collateral ligament complex.

Table 5. Investigating the impact of LCL, MCL and combined ligament repair on range of motion results

	Overall (n=35)	MCL (n=9)	LCLc (n=18)	Combined (n=8)	p
Flexion	140.7±12	141.7±9.5	142.5±12.1	138.6±14.2	0.432
Extension loss	7.6±3	6.8±1.9	7.2±1.9	8.8±4.5	0.507
Range of motion	133±12.5	134.8±9.3	135.2±11.9	129.8±14.7	0.679

The Kruskal–Wallis test was conducted. MCL: medial collateral ligament, LCLc: lateral collateral ligament complex.

Table 6. Investigating the complication distribution

	Overall (n=10)	MCL (n=2)	LCLc (n=3)	Combined (n=5)	p
Knot irritation	2	1	-	1	
Heterotopic os-sificatiom	6	1	2	3	0.442
Osteoarthrosis	2	-	1	1	

The Kruskal–Wallis test was conducted. MCL: medial collateral ligament, LCLc: lateral collateral ligament complex.

Eight of our patients (22.8%) exhibited a total of 10 complications: two in Group I, two in Group II, and four in Group III. Two patients developed low-grade osteoarthritis, two patients experienced nodal irritation, and six patients had type I HO. Half of all osteoarthritis and HO complications occurred in Group III (Table 6).

DISCUSSION

The most important finding of this study is that none of the patients demonstrated residual instability during follow-up examinations, and excellent or good functional outcomes were achieved in nearly all cases, as reflected by a mean MEPS of 92.1. These results indicate that primary collateral ligament repair with suture anchors can provide sufficient joint stability and long-term functional recovery after acute complex elbow dislocations. The absence of instability findings was also supported radiologically, as the minimal increases observed in RCJD and UTJD (0.8-1.1 mm) were not statistically or clinically significant. Taken together, these findings suggest that anchor-based repairs, when performed in the acute setting, can restore both mechanical stability and joint congruency, thereby minimizing the risk of chronic instability or degenerative changes.

Our findings are consistent with those of previous studies reporting satisfactory outcomes following anchor-based ligament repair. Kim et al.[14] found that patients who underwent LCL repair using suture anchors achieved a mean MEPS of 86.9, with most cases demonstrating stable elbows. Similarly, Heo et al.[15] reported a mean MEPS of 91 after isolated or combined collateral ligament repairs, while Greiner et al.[16] demonstrated comparable functional recovery (mean MEPS 92.4) using internal bracing techniques. In our study, the mean MEPS of 92.1 and the absence of postoperative instability confirm that suture anchor repair provides stability and functional outcomes equivalent to or better than those achieved with ligament reconstruction or internal bracing.

Kim et al.'s study on LCL injuries treated with anchors found that the mean MEPS score of the patients was 86.9, and only 1 of the 20 patients included in the study had a satisfactory outcome.[14] In another study, which analyzed the results of patients treated with the internal bracing technique for complex elbow dislocations, the mean MEPS score was 92.4.[16] In a study conducted by Heo et al., 21 patients who underwent surgery for isolated LCL and both collateral ligament injuries were examined, and the mean MEPS score was 91. They found outcomes of 19 patients were good and excellent.[15] When we analyzed the results of our patients, we found that the mean MEPS score was 92.1, similar to the literature, while good and excellent results were obtained in 33 of our 35 patients. Given these results, we believe that when performed appropriately in the acute phase, primary collateral ligament repair with anchors provides outcomes that are similarly successful to those of internal bracing and ligament reconstruction.

In a study conducted by Heo et al., the outcomes of patients who underwent repair of both collateral ligaments were worse than those of patients who underwent isolated LCL repair.[15] In addition, Jakobi et al. stated that more extensive soft tissue damage in patients requiring combined repairs may account for the relatively lower functional scores and increased stiffness observed in this subgroup.[17] The joint range of motion and functional score of patients who underwent repair of both collateral ligaments were lower than those of patients who underwent isolated repair, similar to the previous studies. We believe that a higher severity of trauma to which the patients were exposed resulted in more severe soft tissue damage and concomitant bone pathologies.

Residual instability may develop after repair due to potentially inadequate healing, which may prevent patients from reaching their pre-injury activity levels. In addition to the functional assessment to be performed during the postoperative physical examination, a necessary step is to check radiologically if complete healing has taken place. The most basic method is to take comparative varus and valgus stress radiographs and assess the joint distances. Giannicola et al.'s study on the effects of soft tissue injuries in complex elbow dislocations and Berquist et al.'s studies on imaging of the elbow joint reported that an opening of more than 2 mm in the comparative radiographs is assumed to be an injury to the medial collateral ligament.[18,19] The stress radiographs taken in our patients, which involved applying a standardized force with a dynamometer, showed a difference of less than 2 mm in the isolated and the combined repaired patients. Given the absence of instability findings in our patients and the fact that the joint opening measurements were less than 2 mm, we consider that primary repair using suture anchors was successful.

Although the small postoperative increases observed in radiocapitellar and ulnotrochlear joint spaces in our cohort were neither statistically nor clinically significant in the midterm, subtle alterations in joint congruency can shift contact areas and increase focal contact stresses—particularly under valgus loading—thereby predisposing to progressive cartilage wear over time. Biomechanical and clinical literature indicate that valgus instability elevates compressive forces across the radiocapitellar articulation and alters contact mechanics in both the radiocapitellar and ulnohumeral joints, changes associated with chondromalacia and degenerative progression.[20,21] Accordingly, long-term surveillance with periodic clinical and radiographic follow-up may be warranted to detect progressive widening or early post-traumatic osteoarthritis (PTOA), especially in patients with stiffness or recurrent symptoms. Preventive strategies include meticulous rehabilitation to restore motion, early treatment of stiffness, optimization of stability, and attention to fracture reduction and implant position in fracture-dislocation patterns to preserve joint congruency.[15,21,22] Although small increases in joint space currently have no clinical relevance, it should be kept in mind that they may predispose patients to osteoarthritis in longer follow-ups.

Limitations

Our study has some limitations: it is a retrospective study, two different surgeons performed the operations, and the number of patients is relatively small. Another limitation is that it uses a single scoring system to evaluate the patients' functional scores. The assessment with the dynamometer was conducted by a single surgeon on a single occasion, precluding the evaluation of both inter- and intra-observer reliability. However, using the same brand and size of anchor in all our patients has advantages; it eliminates the risk of bias that may arise from implants with different characteristics, the condition requires a long follow-up period, and two independent assessors can evaluate the functional outcomes. Another important strength of our study is that the same force was applied to all patients by the same observer using a dynamometer, stress radiographs were taken, and changes in the joint space were analyzed, which were not done in previous literature.

CONCLUSION

Suture anchor repair provided stable fixation and favorable functional and radiological outcomes after complex elbow dislocations. The absence of residual instability and high MEPS scores support this technique as a reliable option, especially for non-athlete patients and acute injuries where primary repair is feasible. Suture anchor repair may serve as a less invasive alternative to ligament reconstruction. Future prospective studies with larger patient groups are needed to confirm these results and further define its role in elbow instability management.

Ethics Committee Approval: This study was approved by the Bilecik Şeyh Edebali University Ethics Committee (Date: 06.11.2024, Decision No: KAEK-291298).

Peer-review: Externally peer-reviewed.

Authorship Contributions: Concept: M.A.; Design: M.A., M.G.; Supervision: M.A., T.G.; Resource: R.K., M.G.; Materials: M.G.; Data collection and/or processing: M.G.; Analysis and/or interpretation: F.E.; Literature review: Y.Ş.; Writing: M.G., Y.Ş.; Critical review: M.A., T.G.

Conflict of Interest: None declared.

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ORİJİNAL ÇALIŞMA - *ÖZ*

Akut kompleks dirsek çıkıklarından sonra dikişli çapalar kullanılarak yapılan dirsek kollateral bağ onarımları olumlu sonuçlar verir; Ortalama sekiz yıllık takipte klinik sonuçlar, stres radyografisine dayalı bir çalışma

AMAÇ: Bu çalışmanın amacı, sütür çapa kullanılarak yapılan dirsek kollateral bağ tamirlerinin orta ve uzun vadeli sonuçlarını karşılaştırmaktır.
GEREÇ VE YÖNTEM: 2011-2023 yılları arasında dirsek kollateral bağ onarımı yapılan hastalar retrospektif olarak analiz edildi. Kompleks dirsek çıkıkları nedeniyle ameliyat edilen hastalar çalışmaya dahil edildi. Daha önce aynı dirsekten enfeksiyon geçiren, aynı dirsekten kırık ve ameliyat geçirme öyküsü olan veya sert dirsek tanısı olan ve 1 yıldan daha kısa takip süresi olan hastalar çalışmaya dahil edilmedi. Fonksiyonel değerlendirme için eklem hareket açıklığı (EHA) ve Mayo Elbow Performance Score (MEPS) kullanıldı. Radyolojik değerlendirmede sağlam ve ameliyat edilen ekstremitelere dijital dinamometre ile 80 N kuvvet uygulanırken çekilen varus ve valgus stres radyografileri kullanıldı.
BULGULAR: Çalışmaya 35 hasta (24 erkek ve 11 kadın) dahil edildi. On sekiz hastada izole lateral kollateral ligament (LKL) yaralanmaları, dokuz hastada izole medial kollateral ligament (MKL) yaralanmaları ve sekiz hastada LKL ve MKL yaralanmaları vardı. Ortalama yaş 32 (18-68) yıldı ve takip süresi 104.8 (32-147) aydı. Hastalarımızın ortalama MEPS değeri 92.1±10.3 idi; 22 hastada mükemmel, 11 hastada iyi ve sadece iki hastada orta sonuç vardı. İzole LKL ve MKL onarımlı hastalar, kombine bağ onarımlı hastalara göre daha iyi fleksiyon hareketi elde ettiler (142.5° ve 141.7°'ye karşı 138.6°). Ameliyat edilen ve sağlam ekstremiteler karşılaştırıldığında ameliyat edilen tarafta radyokapitellar eklem mesafesinin (RKEM) 0.8±0.5 mm, ulnotroklear eklem mesafesinin (UTEM) ise 1.18±0.5 mm arttığı bulundu, ancak bu değişiklikler istatistiksel olarak anlamlı değildi.
SONUÇ: Bu çalışmanın sonuçları, dirsek kollateral bağ yaralanmalarında dikişli çapa kullanılarak yapılan izole veya kombine bağ tamirlerinin instabilitenin tedavisi ve önlenmesi için geçerli bir çözüm olduğunu göstermektedir.

Anahtar sözcükler: Dirsek çıkığı; kollateral bağ; stabilite; onarım.

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CASE REPORT

Sigmoid colon obstruction caused by a giant gallstone: A case report of successful endoscopic management

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ABSTRACT

Mechanical bowel obstruction due to a giant colonic calculus is an exceedingly rare clinical entity, typically associated with gallstone ileus or migration through a cholecystocolonic fistula. This case report describes the clinical presentation, diagnostic process, and treatment of an 81-year-old male with a history of cholelithiasis who developed acute mechanical large bowel obstruction due to a 5 cm sigmoid colon calculus. The patient, with comorbidities including diabetes mellitus, hypertension, chronic renal failure, prior prostatectomy, and appendectomy, presented with abdominal pain, nausea, and vomiting. Physical examination revealed tenderness in the left lower quadrant without rebound or guarding, indicating no evidence of perforation. Laboratory findings showed leukocytosis (white blood cell count [WBC]: 12,000/μL, neutrophil percentage: 85.2%) and elevated C-reactive protein [CRP] (33 mg/L). Non-contrast abdominal computed tomography (CT) revealed a 5 cm calculus in the sigmoid colon, with proximal dilatation, air-fluid levels, and pneumobilia. A prior hepatobiliary ultrasound had documented a 49 mm gallstone, suggesting migration via a cholecystocolonic fistula. Sigmoidoscopy, performed using an Olympus CF-HQ190 colonoscope with tripod grasping forceps, successfully extracted the calculus. Due to the patient's advanced age and significant comorbidities, surgical repair of the cholecystocolonic fistula was not pursued. A follow-up hepatobiliary ultrasound one month post-procedure revealed no residual gallstones. The patient achieved rapid recovery and was discharged the following day. This case is notable for the exceptionally large 5 cm calculus, which is rare compared to the 2–3 cm stones typically reported, and highlights the efficacy of sigmoidoscopy in managing such cases in elderly patients with significant comorbidities.

Keywords: Sigmoid colon; gallstone ileus; giant calculus; sigmoidoscopy.

INTRODUCTION

Colonic obstruction due to a giant calculus is an exceptionally rare condition, primarily associated with gallstone ileus secondary to biliary-enteric fistulae. Gallstone ileus accounts for 1-4% of mechanical bowel obstructions, predominantly affecting elderly patients.[1] Sigmoid colon obstruction due to a 5 cm gallstone is particularly uncommon because of the colon's narrow lumen, with few reported cases of such large calculi successfully managed endoscopically. This report describes an 81-year-old male with acute large bowel obstruction caused by a 5 cm sigmoid colon calculus, likely resulting from gallstone migration through a cholecystocolonic fistula. The diagnostic approach, endoscopic management, and clinical implications of this rare condition are discussed, emphasizing the role of minimally invasive techniques in achieving optimal outcomes in high-risk patients.

CASE REPORT

An 81-year-old male presented to the emergency department with a three-day history of cramping abdominal pain, nausea, and vomiting. His medical history included diabetes mellitus, hypertension, chronic renal failure, prostatectomy, and appendectomy. Physical examination revealed tenderness in the left lower quadrant without rebound or guarding, indicating

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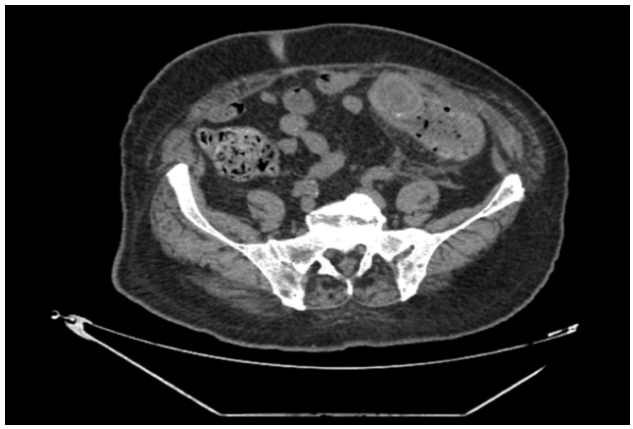

Figure 1. Transverse plane abdominal computed tomography (CT) scan showing a calcified gallstone within the sigmoid colon.

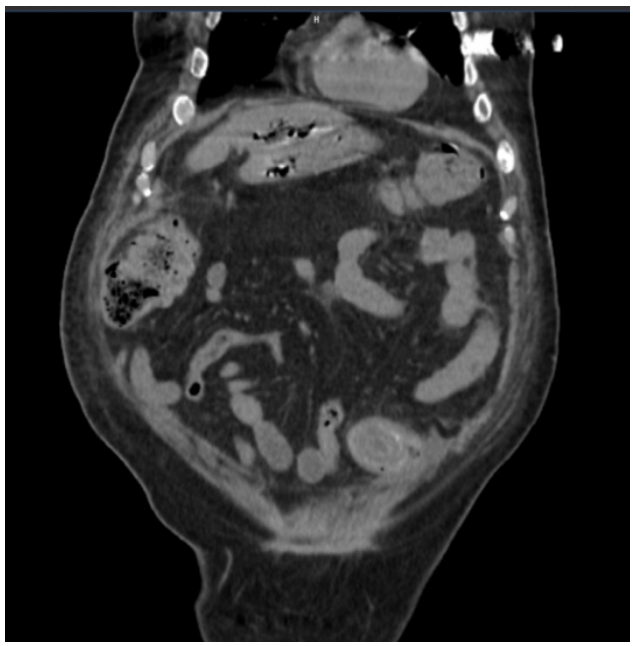

Figure 2. Coronal plane abdominal computed tomography (CT) scan demonstrating a gallstone in the sigmoid colon.

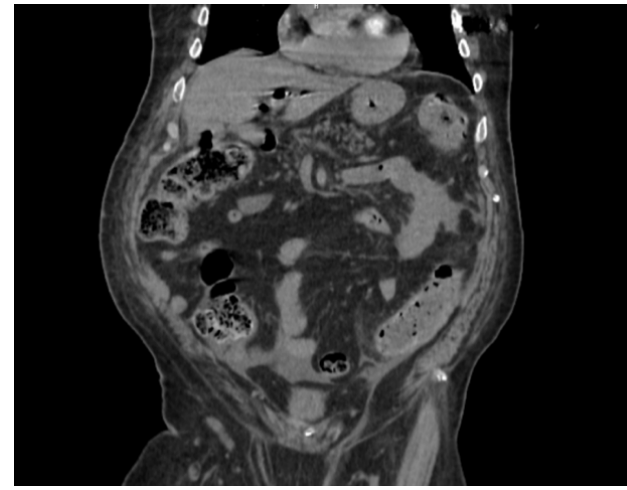

Figure 3. Coronal plane abdominal computed tomography (CT) scan revealing a cholecystocolonic fistula, characterized by an abnormal communication between the gallbladder and the colon.

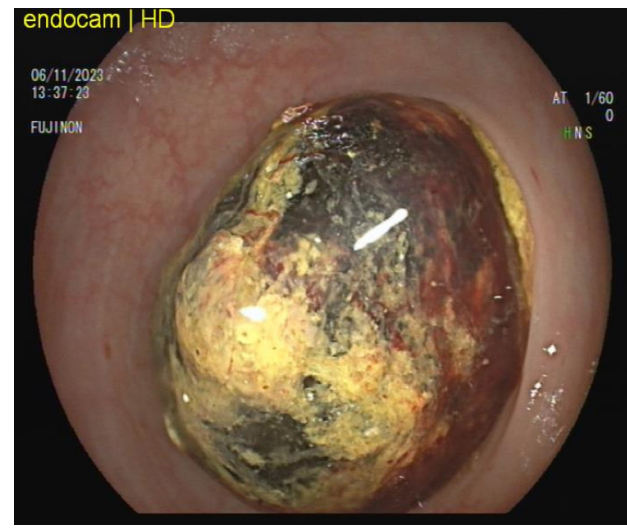

Figure 4. Endoscopic image of the gallstone within the sigmoid colon, visualized during sigmoidoscopy.

no evidence of perforation. The patient reported absence of gas and stool passage. Laboratory findings showed leukocytosis (white blood cell count [WBC]: 12,000/μL, neutrophil percentage: 85.2%) and elevated C-reactive protein (CRP: 33 mg/L), with other parameters within normal limits.

Non-contrast abdominal computed tomography (CT) demonstrated a 5 cm hyperdense calculus within the sigmoid colon lumen, causing proximal dilatation and air-fluid levels (Figs. 1, 2, and 3). Pneumobilia was noted, and a hepatobiliary ultrasound from one year earlier had identified a 49 mm gallstone, supporting the hypothesis of gallstone migration through a cholecystocolonic fistula.

Given the patient's stable condition, urgent sigmoidoscopy was performed under moderate sedation using an Olympus CF-HQ190 colonoscope. Over a 30-minute procedure, the 5 cm calculus was extracted using tripod grasping forceps, with no trauma to the surrounding mucosa (Figs. 4 and 5). The absence of mucosal injury or bleeding was confirmed. Written informed consent was obtained for both the procedure and publication of this case report, in accordance with institutional ethical guidelines.

Due to the patient's advanced age and significant comorbidities, including diabetes mellitus, hypertension, and chronic renal failure, surgical repair of the suspected cholecystocolonic fistula was not pursued. A follow-up hepatobiliary ultrasound performed one month post-procedure revealed no residual gallstones, supporting a conservative approach to fistula management. Post-procedure, a regular diet was initiated on postoperative day 1, and the patient was discharged following significant clinical improvement. At one-year follow-up, no

Figure 5. Photograph of the extracted gallstone following successful colonoscopic removal.

recurrence of symptoms was reported, indicating successful management.

DISCUSSION

Gallstone ileus is a rare cause of bowel obstruction, accounting for 1–4% of all mechanical small bowel obstructions, predominantly affecting elderly patients.[1] Colonic impaction, particularly in the sigmoid colon, is exceptionally uncommon, representing less than 1% of gallstone ileus cases. It often results from gallstone migration through a biliary-enteric fistula, most commonly cholecystoduodenal, though cholecystocolonic fistulae have also been documented.[2-4] The presence of pneumobilia and a prior 49 mm gallstone in this case strongly suggest migration via a cholecystocolonic fistula.

Sigmoid gallstone ileus is an exceedingly rare cause of large-bowel obstruction, as highlighted in recent literature.[5,6] O'Brien et al.[5] (2017) reported a case of a 4.4 cm gallstone impacted in the sigmoid colon, where sigmoidoscopy failed to extract the stone, necessitating a trephine loop colostomy under local anesthesia due to the patient's comorbidities. Similarly, Carlsson et al.[6] (2015) described a 3.0 cm gallstone causing sigmoid obstruction that could not be retrieved endoscopically; due to pelvic adhesions from prior diverticular disease, enterotomy was avoided, and stone extraction was achieved via loop colostomy. In contrast, the successful endoscopic management of a 5.0 cm gallstone in our case, which is notably larger than those previously reported, underscores the potential of sigmoidoscopy as a viable first-line approach, particularly when surgical risks are elevated due to patient comorbidities.

The calculus in this case, measuring 5.0 cm, significantly exceeds the 2–3 cm stones typically described in the literature.[4,7,8] For instance, Mouni et al.[7] (2023) reported a 3.0 cm gallstone requiring surgical intervention due to endoscopic failure, whereas the successful extraction of a larger calculus in this case underscores the potential of sigmoidoscopy even in challenging scenarios. Similarly, Balzarini et al.[8] (2015) utilized endoscopic mechanical lithotripsy for a 3.5 cm stone, but the use of tripod grasping forceps in this case avoided fragmentation, reducing procedural risks. Inukai et al.[9] (2018) reported a case of sigmoid colon ileus secondary to a cholecystocolonic fistula, where a 7.0 cm gallstone caused obstruction requiring surgical intervention via enterotomy for stone extraction. Likewise, Osman et al.[10] (2010) described a 4.0 cm gallstone causing large-bowel obstruction in the sigmoid colon, managed surgically through enterotomy following an unsuccessful endoscopic attempt. These cases, involving larger stones, highlight the complexity of managing significant impactions and underscore the exceptional rarity of endoscopic resolution for a 5.0 cm sigmoid calculus, as achieved in our patient. Recent literature further illustrates the variability in management strategies for sigmoid gallstone ileus, reflecting its rarity as a cause of large-bowel obstruction. Tonog et al.[11] (2023) reported a case managed surgically via enterotomy, emphasizing the challenges of gallstone-related obstructions. In contrast, AlMuhsin et al.[12] (2023) described a non-operative approach in a patient with sigmoid gallstone ileus, utilizing conservative measures such as colonic lavage, highlighting the potential for non-invasive management in select cases. These reports collectively underscore the uncommon nature of sigmoid gallstone ileus and the need for tailored therapeutic approaches, further distinguishing our case, in which a 5.0 cm stone was successfully managed endoscopically.

Diagnosis relies on computed tomography, which identifies the calculus, obstruction site, and associated findings such as pneumobilia, often presenting as Rigler's triad (pneumobilia, ectopic gallstone, bowel obstruction).[4] The absence of rebound or guarding and lack of gas or stool passage in this case likely reflected early ileus presentation, enabling endoscopic intervention before complications such as perforation. This case is compared with prior reports of sigmoid gallstone ileus, emphasizing the rarity of large calculi and the success of endoscopic intervention (Table 1).

Endoscopic management is a well-established approach for gallstone ileus in stable patients with accessible calculi, particularly in cases involving the sigmoid colon. Pavlidis et al.[13] (2003) emphasized that colonoscopy or sigmoidoscopy can effectively extract gallstones in stable patients, avoiding the need for invasive procedures when the stone is accessible and no complications are present. Similarly, Nuño-Guzmán et al.[14] (2016) highlighted the role of endoscopic techniques, such as colonoscopy, as a first-line treatment for colonic gallstone ileus in stable patients, noting their efficacy in achieving stone extraction with minimal morbidity. However, both sources underscore that surgical intervention, including enterolithotomy or, in rare cases, colectomy, is indicated when endoscopic attempts fail or when complications such as bowel perforation or necrosis arise.[13,14] In our case, the successful endoscopic extraction of a 5.0 cm sigmoid gallstone

Table 1. Comparison of sigmoid gallstone ileus cases reported in the literature

Study	Stone Size	Patient Age/ Gender	Treatment Methods	Fistula Repair	Hospital Stay
Present case (2025)	5 cm	81/Male	Endoscopic (sigmoidoscopy, tripod grasping forceps)	Not performed	1 day
O'Brien et al. (2017)[5]	4.4 cm	88/Female	Endoscopic (colonoscopy, failed due to stone impaction), trephine loop colostomy	Not performed	5 days
Carlsson et al. (2015)[6]	3 cm	80/Female	Endoscopic (colonoscopy, failed due to pelvic adhesions), loop co-lostomy	Not performed	N/A
Mouni et al. (2023)[7]	3 cm	74/Female	Endoscopic (colonoscopy, failed due to stone size), surgical (entero-lithotomy)	Not performed	6 days
Balzarini et al. (2015)[8]	3.5 cm	94/Female	Endoscopic (mechanical lithotrip-sy)	Not performed	4 days
Inukai et al. (2018)[9]	7 cm	65/Male	Surgical (enterolithotomy) + chole-cystectomy + partial transverse colon resection	Performed	20 days
Osman et al. (2010)[10]	3.8 cm	92/Male	Surgical (enterolithotomy)	Not performed	28 days
Tonog et al. (2023)[11]	4.5 cm	69/Female	Surgical (enterolithotomy)	Not performed	4 days
AlMuhsin et al. (2023)[12]	2.5 cm	89/Male	Conservative (non-operative, co-lonic lavage)	Not performed	3 days
Zielinski et al. (2010)[15]	4.1 cm	92/Male	Endoscopic (electrohydraulic litho-tripsy)	Not performed	25 days
Waterland et al. (2014)[16]	4 cm	73/Male	Endoscopic (mechanical lithotrip-sy)	Not performed	1 day

using sigmoidoscopy and tripod grasping forceps aligns with these findings, demonstrating the feasibility of endoscopic management even for unusually large calculi in a stable patient with significant comorbidities. Further supporting the efficacy of endoscopic approaches, Zielinski et al.[15] (2010) reported successful management of a 4.0 cm sigmoid gallstone in a 92-year-old patient using electrohydraulic lithotripsy, highlighting its utility in high-risk patients where surgery poses significant risks. Similarly, Waterland et al.[16] (2014) described the endoscopic extraction of a 4.0 cm gallstone via mechanical lithotripsy, achieving complete resolution of large-bowel obstruction without surgical intervention. In contrast, our case demonstrates the successful endoscopic removal of a larger 5.0 cm gallstone using sigmoidoscopy with tripod grasping forceps, avoiding the need for lithotripsy and minimizing procedural risks such as stone fragmentation. These comparisons underscore the feasibility of endoscopic management for large calculi and highlight the technical advantage of direct extraction in stable patients with significant comorbidities.

The management of the underlying fistula remains controversial; some advocate for spontaneous closure in the absence of persistent cholelithiasis, while others recommend a one-stage surgical approach involving cholecystectomy and fistula repair in low-risk patients.[2] Given the patient's advanced age and lack of ongoing biliary symptoms, a conservative approach post-extraction was adopted, validated by the absence of complications at one-year follow-up.

This case underscores the importance of considering gallstone ileus in elderly patients with cholelithiasis and acute abdominal symptoms. The successful use of sigmoidoscopy highlights its role as a first-line approach in stable patients, particularly when comorbidities preclude surgery. The balance of technical expertise and patient-centered care is critical for achieving optimal outcomes, as demonstrated by the minimally invasive management of this rare 5.0 cm sigmoid gallstone.

CONCLUSION

This case illustrates a rare large bowel obstruction caused by a 5 cm sigmoid colon calculus, likely due to gallstone migration through a cholecystocolonic fistula. The successful endoscopic management of this unusually large calculus, which is rare compared to the 2–3 cm stones typically reported, underscores the efficacy of sigmoidoscopy in stable patients. This approach avoided invasive surgery in an elderly patient with significant comorbidities. Clinicians should maintain a high index of suspicion for gallstone-related complications in similar presentations. Endoscopic techniques offer valuable options for managing such rare cases and provide important insights for future practice.

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OLGU SUNUMU - *ÖZ*

Dev safra taşına bağlı sigmoid kolon tıkanıklığı: Endoskopik tedavi ile başarılı bir vaka

Dev kolonik taşlara bağlı mekanik bağırsak tıkanıklığı, genellikle safra taşı ileusuna veya kolesistokolonik fistül yoluyla taşın migrasyonuna bağlı gelişen nadir bir klinik durumdur. Bu olgu sunumunda, 5 cm'lik sigmoid kolon taşına bağlı akut mekanik bağırsak tıkanıklığı gelişen kolelitiasis öyküsü olan 81 yaşında erkek bir hastanın klinik bulguları, tanı süreci ve tedavisi ele alındı. Diyabet, hipertansiyon, kronik böbrek yetmezliği, prostatektomi ve apendektomi öyküsü olan hasta, karın ağrısı, bulantı ve kusma şikayetleriyle başvurdu. Fizik muayenede sol alt kadranda hassasiyet tespit edildi, ancak rebound veya defans olmaması perforasyon olmadığını gösterdi. Laboratuvar bulguları lökositoz (WBC: 12.000/µL, nötrofil yüzdesi: %85,2) ve yüksek CRP (33 mg/L) gösterdi. Kontrastsız abdominal bilgisayarlı tomografide sigmoid kolonda 5 cm'lik bir taş, kolonik dilatasyon, hava-sıvı seviyeleri ve pnömobili tespit edildi. Önceki hepatobiliyer ultrasonografide 49 mm'lik bir safra taşı raporlanmıştı, bu da taşın kolesistokolonik fistül yoluyla migrasyonunu düşündürdü. Olympus CF-HQ190 kolonoskop ve tripod tutucu forseps kullanılarak yapılan sigmoidoskopi ile taş başarılı bir şekilde çıkarıldı. Hastanın ileri yaşı ve komorbiditeleri nedeniyle kolesistokolonik fistül onarımı yapılmadı; bir ay sonraki kontrol hepatobiliyer ultrasonografide taş görülmedi. Hasta, girişim sonrası hızlı iyileşme göstererek postoperatif birinci günde taburcu edildi. Bu olgu, literatürde genellikle 2-3 cm olarak bildirilen taşlara kıyasla 5 cm'lik nadir bir sigmoid kolon taşının endoskopik olarak başarıyla yönetildiğini göstermektedir. Sigmoidoskopi, komorbiditeleri olan yaşlı hastalarda bu tür olguların yönetiminde etkili bir yöntemdir.

Anahtar sözcükler: Sigmoid kolon; safra taşı ileusu; dev kalkül; sigmoidoskopi.

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CASE REPORT

Recurrent self-inflicted abdominal stab injuries leading to isolated Meckel's diverticulum perforation: A surgical case report and literature-backed review

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ABSTRACT

Meckel's diverticulum (MD) is a frequently silent congenital anomaly of the gastrointestinal tract. While complications such as bleeding and obstruction are more common, traumatic perforation remains extremely rare, particularly from penetrating injuries. To date, isolated perforation of MD following self-inflicted abdominal stab wounds has been reported only sporadically. We present the case of a 39-year-old male with a long-standing history of schizophrenia and epilepsy who arrived at the emergency department following his fifth self-inflicted abdominal stab injury over the past decade. On physical examination, a segment of small bowel was found protruding from a 4 cm periumbilical wound. Emergency exploratory laparotomy revealed extensive intra-abdominal adhesions and an isolated perforation of a Meckel's diverticulum located 60 cm proximal to the ileocecal valve. No other visceral injuries or hemorrhage were detected. The diverticulum was resected using a linear stapler, and serosal defects were repaired. The postoperative course was uneventful, and the patient was discharged on postoperative day five. Isolated MD perforation caused by penetrating abdominal trauma is exceedingly rare and diagnostically challenging. When occurring in psychiatric patients with repetitive self-harm behavior, it presents an even more complex scenario. This case underscores the importance of meticulous intra-abdominal exploration in stab wound patients and contributes novel insight to the limited literature on traumatic MD injuries.

Keywords: Meckel's diverticulum; penetrating trauma; stab wound; self-inflicted injury; psychiatric patient; case report.

INTRODUCTION

Meckel's diverticulum (MD) is the most common congenital anomaly of the gastrointestinal tract, affecting approximately 2% of the population.[1] It results from incomplete obliteration of the omphalomesenteric duct during embryogenesis. Although often asymptomatic, MD may occasionally present with complications such as gastrointestinal bleeding, intestinal obstruction, diverticulitis, and, more rarely, perforation.[2,3]

Perforation of MD is typically associated with inflammation, ulceration, or foreign body ingestion. Traumatic perforation, particularly from penetrating abdominal injuries, is exceedingly rare and sparsely documented in the literature.[4,5] The atypical location and mobility of MD along the ileum contribute to diagnostic challenges during trauma evaluation. In most cases, perforation is discovered incidentally during exploratory laparotomy performed for other suspected intra-abdominal injuries.[6]

Self-inflicted abdominal stab wounds represent a distinct subset of trauma care, particularly among patients with psychiatric disorders. Chronic self-harm behavior poses unique diagnostic and therapeutic challenges due to its recurrent nature and variable injury patterns.[7] To our knowledge, only a limited number of reports have described isolated traumatic

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MD perforation in patients with repeated self-inflicted stab wounds.

Herein, we present a unique case of a 39-year-old male with schizophrenia and epilepsy who developed an isolated perforation of Meckel's diverticulum following his fifth self-inflicted abdominal stab wound over a ten-year period. This case aims to contribute to the limited literature on traumatic MD injuries and highlight the importance of comprehensive intraoperative evaluation in patients presenting with penetrating trauma and psychiatric comorbidities.

CASE REPORT

A 39-year-old male with a long-standing history of schizophrenia and epilepsy presented to the emergency department following a self-inflicted stab wound to the abdomen—his fifth such attempt over the past decade. On admission, the patient was alert and hemodynamically stable. Physical examination revealed a single stab wound approximately 2 cm superior to the umbilicus, with visible herniation of a small bowel loop through the abdominal wall.

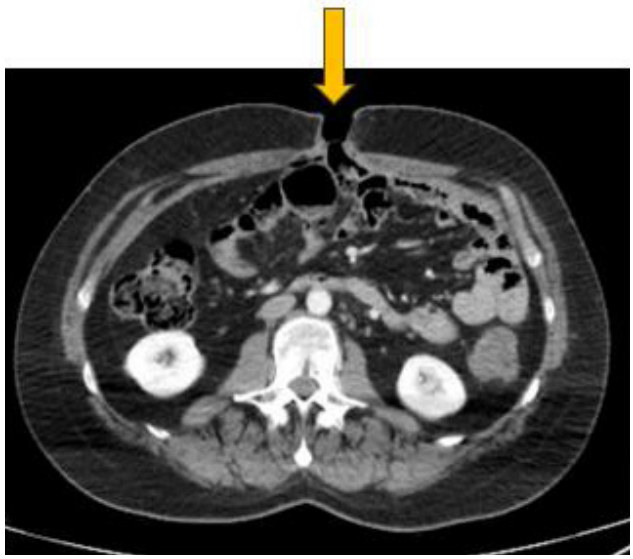

Figure 1. Abdominal computed tomography (CT) showing protrusion of a small bowel loop through the periumbilical stab wound.

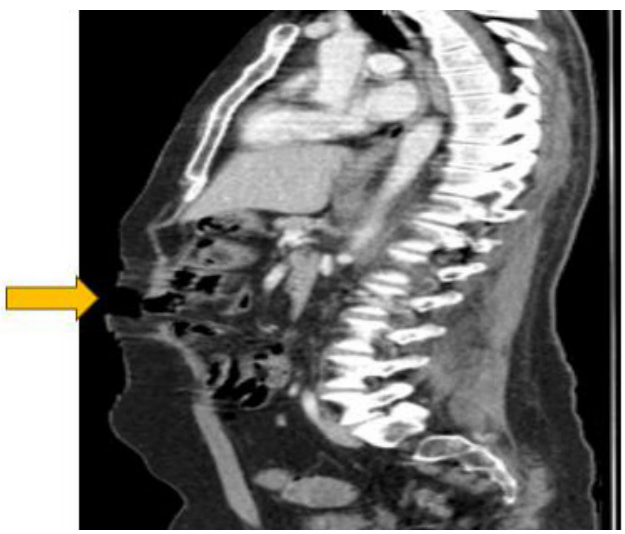

Figure 2. Intraoperative image revealing adhesions and herniated bowel.

Figure 3. Perforated Meckel's diverticulum visible during laparotomy.

Laboratory investigations, including complete blood count and coagulation parameters, were within normal limits. Contrast-enhanced computed tomography (CT) of the abdomen revealed small bowel loops herniating through an anterior abdominal wall defect without evidence of free intraperitoneal air or active hemorrhage (Figs. 1 and 2).

The patient was urgently transferred to the operating room for exploratory laparotomy under general anesthesia. A midline incision incorporating the stab site was made. Upon entering the peritoneal cavity, no hemoperitoneum or fecal contamination was identified. Extensive fibrous adhesions were encountered between small bowel loops, likely secondary to previous abdominal injuries. Careful adhesiolysis was performed (Fig. 3).

During systematic examination of the small intestine, a perforated Meckel's diverticulum was identified approximately 60 cm proximal to the ileocecal valve. The tip of the diverticulum exhibited a clean perforation consistent with direct injury from the stab wound (Fig. 4). There was no evidence of mesenteric injury or adjacent bowel perforation.

A representative intraoperative video recorded during exploration demonstrates the herniated small bowel and the perforated diverticulum prior to resection (Video 1). The diverticulum was subsequently resected using a 60 mm linear stapler (Endo GIA), and the staple line was reinforced with interrupted 3-0 polypropylene sutures to ensure hemostasis and prevent leakage (Fig. 5). Minor serosal injuries in adjacent loops were repaired with 3-0 Vicryl sutures.

The stomach, colon, solid organs, and diaphragm were in-

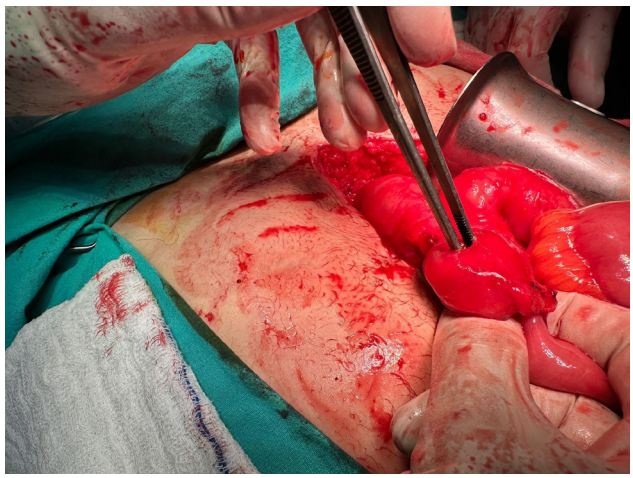

Figure 4. Repair of serosal defects with 3-0 Vicryl sutures.

Figure 5. Resected diverticulum using Endo GIA linear stapler; staple line reinforced with 3-0 polypropylene sutures.

spected and found to be intact. A Jackson-Pratt drain was placed in the rectovesical pouch.

The patient's postoperative course was uneventful. Oral intake was resumed on postoperative day three, and he was discharged in stable condition on day six. Histopathological evaluation confirmed the presence of a perforated Meckel's diverticulum without ectopic mucosa or neoplasia.

The intraoperative findings were recorded, and a supplementary video demonstrating the initial abdominal exploration and identification of the perforated Meckel's diverticulum has been provided as a visual reference.

Written informed consent was obtained from the patient for the publication of this case report and accompanying images and video.

DISCUSSION

Meckel's diverticulum, though common in occurrence, seldom presents with complications such as traumatic perforation. Penetrating abdominal injuries—especially stab wounds—very rarely result in isolated MD perforation. This makes intraoperative identification crucial, as such injuries often lack classical radiological signs such as free air or fluid collections.

Dogjani et al. described one of the few documented cases of combined MD and jejunal injury following abdominal stab trauma, emphasizing the diagnostic challenge posed by such presentations.[1] Arkuszewski et al. further stressed the difficulty in preoperative detection of traumatic MD perforation, particularly due to its variable location and mobility, leading to delayed or incidental findings during surgery.[2] Kamath's analysis of penetrating abdominal trauma indicated that small bowel perforations, including those involving MD, frequently go undetected without overt clinical signs,[3] and Nirmala reported similar observations regarding non-specific nature of imaging and clinical findings in ileal perforations.[4]

Damodar, Reddy, and Smiley all underscored the under-recognition of small bowel injury in patients with stab wounds. Damodar emphasized the clinical challenge of ileal perforations often being misdiagnosed or diagnosed late, while Reddy highlighted the need for meticulous intraoperative assessment in hemodynamically stable trauma patients. Smiley's early work also pointed to the diagnostic ambiguity surrounding gastrointestinal tract injuries, advocating for complete exploration when suspicion persists.[5-7] This notion is particularly applicable in patients with psychiatric disorders who present with self-inflicted injuries—a patient population at risk of recurrent and anatomically unpredictable trauma.

A comparison of similar reported cases of traumatic or self-inflicted Meckel's diverticulum perforation is presented in Table 1.

While self-inflicted abdominal trauma is rare overall, it presents a unique diagnostic and ethical challenge for trauma surgeons. Smiley's historical review of gastrointestinal injuries identified self-inflicted trauma as a distinct, under-reported clinical subgroup requiring more vigilant intraoperative assessment.[8] More recently, Chui et al. demonstrated that self-harm remains a relevant and increasing subset of trauma surgery, often associated with higher rates of isolated inju-

Table 1. Reported cases of Meckel's diverticulum perforation due to trauma or self-inflicted injury

Author(s)	Year	Mechanism of Injury	Meckel's Diverti-culum Involvement	Key Findings
Dogjani et al.[1]	2016	Stab wound	Meckel's diverticu-lum and jejunum	Simultaneous Meckel's diverticulum (MD) and jejunal injury; difficult diagnosis
Arkuszewski et al.[2]	2024	Blunt trauma	Suspected post-traumatic MD in-volvement	MD injury likely mimics diverticuli-tis post-trauma
Kamath[3]	2006	Stab wound	Small bowel; pos-sible MD in-volvement	Small bowel injuries often missed radiologically
Nirmala[4]	2010	Stab wound	Ileal perforation; not specific to MD	Non-specific signs; perforations under-diagnosed
Damodar[5]	2010	Stab wound	Possible Meckel's diverticulum in-volvement	Advocates thorough bowel explo-ration
Reddy[7]	2007	Penetrating trauma	General gastroin-testinal tract (GIT) trauma; no MD detail	Emphasizes in-traoperative detection in stable patients
Smiley[8]	1943	Self-inflicted trauma (historic)	Descriptive case series; MD in-volvement rare	Early recognition of self-inflicted gastrointestinal (GI) trauma
Chui et al.[8]	2023	Self-inflicted penetrating trauma	Isolated MD among multiple cases	Psychiatric associa-tion with high rate of isolated visceral injury

ries to abdominal viscera and requiring individualized surgical strategies.[8]

In our case, the patient had inflicted five stab wounds over ten years, yet this was the only instance in which the weapon directly perforated Meckel's diverticulum. The injury was isolated, with no adjacent bowel, mesenteric, or vascular damage—a pattern scarcely reported in the literature. The surgical finding, supported by intraoperative visuals, highlights the critical importance of systematic bowel inspection even in seemingly low-impact trauma mechanisms.

Given the rarity of isolated MD perforation from penetrating trauma, our case contributes valuable insight into the diverse presentations of abdominal injury and emphasizes the importance of including embryologic remnants such as Meckel's diverticulum in the differential diagnosis, especially in psychiatric populations. Early laparotomy remains the definitive approach to prevent missed injuries and associated complications.

CONCLUSION

Isolated perforation of Meckel's diverticulum due to penetrating trauma is an exceptionally rare occurrence, especially in the context of recurrent self-inflicted abdominal injuries. This case underscores the importance of high clinical suspicion and thorough intraoperative exploration in such presentations. Given the anatomical variability and potential psychiatric comorbidities, early surgical intervention with a multidisciplinary approach remains essential to optimize outcomes and prevent delayed complications.

Informed Consent: Written informed consent was obtained.

Peer-review: Externally peer-reviewed.

Authorship Contributions: Concept: Ö.K., M.K.; Design: B.T., M.A.K.; Supervision: Ö.K., G.G.; Materials: Ö.K., B.T.; Data collection and/or processing: Ö.K., M.A.K.; Analysis and/or interpretation: M.K., G.G.; Literature review: Ö.K., B.T.; Writing: Ö.K.; Critical review: B.T., M.K.

Conflict of Interest: None declared.

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OLGU SUNUMU - *ÖZ*

Tekrarlayan kendine zarar verici karın bölgesi bıçaklanma yaralanmalarına bağlı izole meckel divertikülü perforasyonu: Cerrahi olgu sunumu ve literatür destekli derleme

Meckel divertikülü (MD), gastrointestinal sistemin en yaygın konjenital anomalilerinden biridir, ancak komplikasyonlarla birlikte görülme sıklığı düşüktür. MD perforasyonu genellikle divertikülit, ülserasyon veya yabancı cisim ile ilişkilidir. Travmatik perforasyon, özellikle penetran abdominal yaralanmalar sonucu gelişen izole MD hasarı ise son derece nadirdir. Bu makalede, tekrarlayan kendine zarar verme davranışı gösteren psikiyatrik bir hastada, yalnızca Meckel divertikülüne sınırlı, diğer intraabdominal yapılarda hasar gözlenmeyen bir bıçaklanma yaralanmasına bağlı MD perforasyonu sunulmuştur. Otuzlu yaşlarında erkek hasta, acil servise karın ağrısı ve önceki bıçaklanma girişimlerine benzer yeni bir bıçaklanma travması ile başvurdu. Fizik muayene, hassasiyet ve defans ile uyumlu klinik bulgular gösterdi. Bilgisayarlı tomografi, net bir perforasyon bulgusu içermemekle birlikte bağırsak anslarında segmenter distansiyon ve sıvı izlenimi nedeniyle hasta acil laparotomiye alındı. Operasyon sırasında, ileoçekal valvden yaklaşık 60 cm proksimalde yer alan Meckel divertikülünde tek başına perforasyon saptandı. Diğer intestinal yapılar sağlamdı. Perfore MD segmenti rezeksiyonla çıkarıldı ve histopatolojik inceleme, heterotopik mukoza veya neoplazi içermeyen perfore divertikül tanısını doğruladı. Hastanın postoperatif dönemi sorunsuz geçti ve stabil klinik durumda taburcu edildi. Olgu, hem travmatik MD perforasyonlarının tanısal güçlüklerini hem de psikiyatrik hastalarda abdominal travmaların yönetiminde dikkat edilmesi gereken ayırıcı tanıları vurgulamaktadır. Literatürde çok az sayıda benzer vaka bildirilmiş olup, bu olgu serisi travma cerrahlarının klinik farkındalığını artırmak amacıyla literatür bilgileri ile karşılaştırmalı olarak sunulmuştur.
Anahtar sözcükler: Meckel divertikülü; travmatik perforasyon; penetran karın yaralanması; psikiyatrik hasta; kendine zarar verme; vaka sunumu.

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