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Biomechanical comparison of two fixation methods for pediatric femoral neck fractures: an *in vitro* study using ovis aries lambs

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ABSTRACT. – OBJECTIVE: In pediatric patients, femoral neck fracture is a relatively rare injury with a high complication rate despite proper diagnosis and treatment. Fixation of femoral neck fractures is usually performed with screws placed along the neck axis. In this study, we aim to compare two different implants and methods in terms of biomechanics.

MATERIALS AND METHODS: Twenty-eight right-left fresh femur bones of 6-month-old male Ovis aries lambs grown on the same farm were used. Bones were randomly divided into 4 groups (n=7). In group 1, the Delbet type III femoral neck fracture model was fixed with two 4.5 mm cannulated screws, one screw crossing the physis. In group 2, two 4.5 mm cannulated screws, which did not cross the physis, were used. In group 3, Delbet type III femoral neck fracture model was fixed with a 3.5 mm proximal femoral anatomical plate and five screws, one screw crossing the physis. Finally, in group 4, Delbet type III femoral neck fracture model was fixed with one 3.5 mm proximal femoral anatomical plate and five screws that did not exceed the physis.

RESULTS: Biomechanical tests were performed using a Zwick/Roell AllroundLine 100 kN device. While axial failure burden (F = 6.819, *p*<.05, d = .46) and axial stiffness (F = 3.576, *p*<.05, d = .30) have been found to be significantly different between the independent treatment groups, axial failure displacement (F = .622, *p*>.05) and axial failure energy (F = .727, *p*>.05) have been found not to be significant between the independent groups. The effect sizes of the axial failure load and axial stiffness variables were 0.46 and 0.30, respectively, suggesting a moderate clinical effect. The highest axial failure load was recorded in group 3, while the smallest load was recorded in group 2. Similarly, the axial stiffness level in group 3 was statistically higher than the axial stiffness measurement recorded in group 2, *p*<.05.

CONCLUSIONS: Consequently, we found that the biomechanical fixation success was the highest with a 3.5 mm proximal femoral anatomical plate, a 3.5 mm locking screw crossing the physis, and five 3.5 mm screws.

Key Words:
Femoral neck fracture, Delbet classification, Axial compression, Physis.

Introduction

In the United States, more than 250,000 hip fractures occur annually, which is equal to femoral neck and intertrochanteric fractures. It is expected to double by 2050[1]. Seventy-five percent of hip fractures are seen in women[2]. The incidence is very low in young patients and is primarily associated with high-energy trauma. It primarily occurs in the elderly (average age 72) due to low-energy falls[2]. Risk factors include female gender, white race, increasing age, poor health, tobacco and alcohol use, previous fracture, fall history, and low estrogen levels[3]. Low-energy trauma is most commonly seen in older patients and can involve direct or indirect mechanisms[4]. Direct mechanisms include falling directly onto the greater trochanter or striking the neck of the femur against the posterior rim of the acetabulum, resulting in forceful external rotation of the lower limb. Indirect mechanisms occur when muscle forces surpass the strength of the neck of the femur[5]. High-energy trauma, such as a motor vehicle accident or a significant fall from height, is responsible for most femoral neck fractures in young individuals[6]. Circular

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loading-stress fractures are seen in athletes, soldiers, and ballet dancers. Patients with a displaced femoral neck fracture typically complain of hip and thigh pain and are unable to walk with shortening and external rotation of the lower limb. However, a previous report[7] has indicated that there may not be deformity or the ability to bear weight in patients with damage or stress fractures in the femoral neck. All patients should undergo a comprehensive secondary evaluation to assess for any injuries related to the fracture. Pediatric hip fractures were initially classified into four types by Delbet[8]. This classification helps determine the type of surgical and non-surgical treatment and is used to estimate the risk of avascular necrosis of the femoral head (AVN). When children are brought to the clinic, they fear passive movement and cannot actively move. For pediatric femoral fractures, femoral nerve blocks and Fascia iliaca compartment blocks have been identified as the first pain relievers. The fracture diagnosis is confirmed with two-plane radiographs. An experienced radiologist can detect the fracture line and fracture hematoma in suspicious cases[9]. Magnetic resonance imaging can be used in special cases to detect stress fractures[10].

The most important complication encountered in pediatric femur neck fractures is AVN. The incidence of AVN is influenced by the type of fracture, the timing of surgery, and the child's age[11]. Moon and Mehlman[11] reported AVN rates as 38% in Delbet type I, 28% in Delbet type II, 18% in Delbet type III, and 5% in Delbet type IV. Another common complication is coxa vara, which occurs due to the reduction of the angle between the femur neck and shaft. Coxa vara can reduce hip abductor strength and shorten the limb[12]. Another treatment-related complication is malunion. Therefore, both biomechanical and clinical selection of the most effective implant and surgical technique are important for the management of pediatric femur neck fractures. Although a cause-and-effect relationship has not yet been established, the incidence of AVN after surgery has been found to be high in children who receive cannulated screws[13]. The literature is not clear on whether the current treatment methods increase or decrease the complication rate in displaced femur neck fractures. Additionally, the growth lines are open in pediatric femur neck fractures, which differs from adults. There are no controlled studies investigating the best stability-creating method from models that identify growth lines that cross and do not cross the limb where orthopedic surgery is performed in this group. Therefore, in this study, the authors aim to determine the surgical intervention that provides the best stability in the Delbet type III femur neck fracture model created in fresh sheep bones. For this purpose, different techniques and implants were compared.

Materials and Methods

After approval from the Local Ethics Committee of the Kahramanmaraş Sütçü Imam University, Faculty of Medicine for Animal Experiments, the study was started in the ÜSKİM Laboratory (application date: 15/02/2021, protocol No.: 03, session No.: 2012-01, decision No.: 03, date: 03.03.2021). In this study, 28 male fresh femur bones (right and left) from 6-month-old Ovis aries sheep raised on the same farm were obtained from the Yenice branch of meat product combination (Onikişubat/Kahramanmaraş, Turkey). Bones of animals were taken after the company slaughtered the animals. After the bones were taken, the remaining muscles were removed with a scalpel. After obtaining 7 femur bones for each group, the procedures were applied to each group in the same order. The femur bones removed from the muscles were planned for the type III fracture model of the Delbet-Colonna classification for pediatric femur neck fractures. A mold was made from plaster to provide standardization in osteotomies.

Grouping

During the experiment, the sheep femurs were randomly divided into four groups, with a total of 7 bones in each group (n=7) (Table I). In group 1, the model was fixed with two 4.5 mm cannulated screws, one passing through the fracture and the other not. In group 2, the model was fixed with two 4.5 mm cannulated screws, neither of which passed through the fracture. In group 3, the model was fixed with one 3.5 mm locking screw passing through the fracture, one 3.5 mm locking screw not passing through the fracture, one 3.5 mm proximal femoral anatomical plate, and five 3.5 mm screws used to secure the distal end of three plates. Finally, in group 4, the model was fixed with two 3.5 mm locking screws not passing through the fracture, one 3.5 mm proximal femoral anatomical plate, and five 3.5 mm screws used to secure the distal end of three plates. The fixation methods for each group are summarized in Table I.

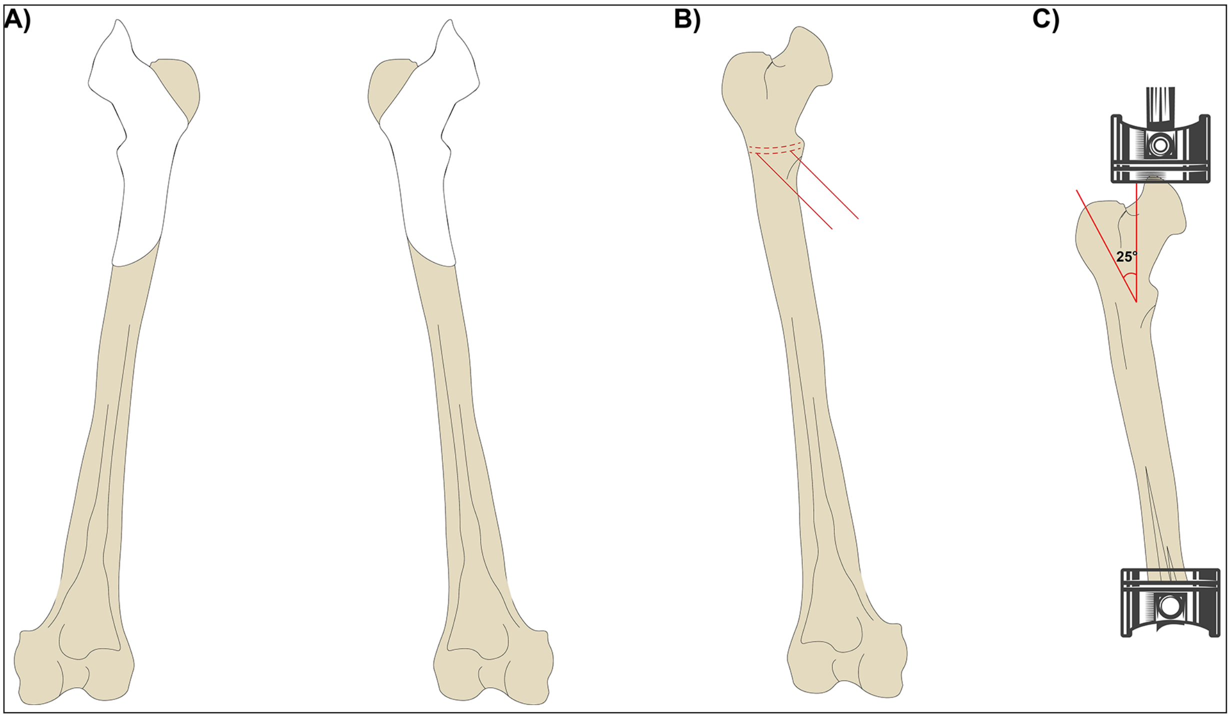

Figure 1. Surgical procedure. **A**, The mold plasters. **B**, Two guide wires guided by the mold. **C**, Femur models.

Experiment Procedure

An osteotomy was planned for type III Delbet femoral neck fractures in pediatrics. A mold was made of plaster to standardize the osteotomies (Figure 1). The osteotomy angle was measured using a goniometer, with the angle between the line extending from the greater trochanter to the lesser trochanter and the transverse line passing through the lesser trochanter set at 45°. Prior to the osteotomy, the most distal point of the greater trochanter, 4 cm below its peak, was marked and accepted as standard in each femur model. Two guide wires were then used to mark the screw insertion sites, and their placement was guided by the mold (Figure 2). Firstly, a 1.8 mm Kirschner wire was used to make a hole, followed by a 1.2 mm Kirschner wire, and then drilling was performed using a 3.5 mm drill (Figure 3). Following the drilling process, the osteotomy site was planned using the plaster mold, and the osteotomy was performed using a Kirschner wire saw (Knitex brand KTX-629; Istanbul, Turkey).

After osteotomy, the reduction was achieved. Then, for group 1, two 4.5 mm cannulated screws were placed in a manner that would pass through the physis (growth plate) line in the fluoroscopic image, while for group 2, fixation was performed in a manner that would not cross the physis line in the fluoroscopic image. group 1 was fixed with one 4.5 mm diameter and 52 mm length (crossing the physis) cannulated compression screw and one 38 mm length (not crossing the physis) cannulated compression screw. Group 2 was fixed with two 4.5 mm diameter and 38 mm length (not crossing the physis) cannulated compression screws (Figure 4). In group 3 and group 4, the location was marked with Kirschner wires, and proximal

Table I. Design group and the applied experimental procedure.

Gruplar	N	Physis passing status	Screw type
Group 1	7	1 physical pass	2 cannulated screws – 4.5 mm
Group 2	7	Not exceeding 2 physiques	2 cannulated screws – 4.5 mm
Group 3	7	1 physical pass	1 anatomical plate – 3.5 mm, 5 3.5 mm fixed with screw
Group 4	7	Not exceeding 2 physiques	1 anatomical plate – 3.5 mm, 5 3.5 mm fixed with screw

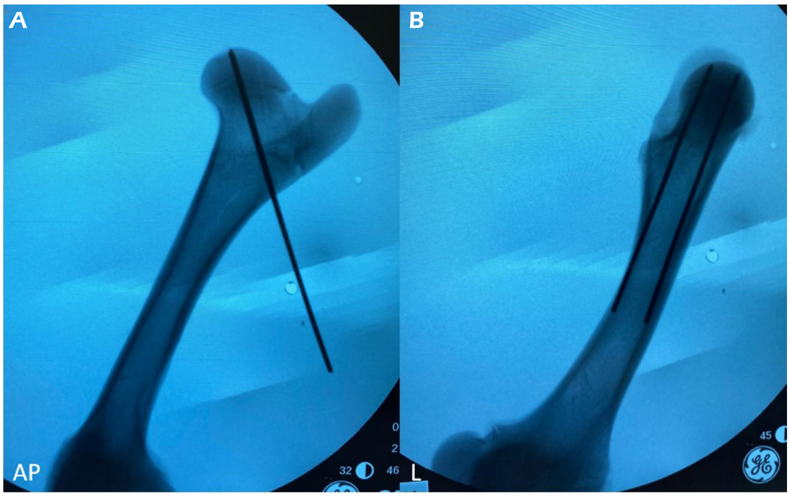

Figure 2. **A,** Anterior posterior x-ray view of Kirschner wire and a 3.5 mm drill. **B,** Lateral x-ray view of Kirschner wire and a 3.5 mm drill.

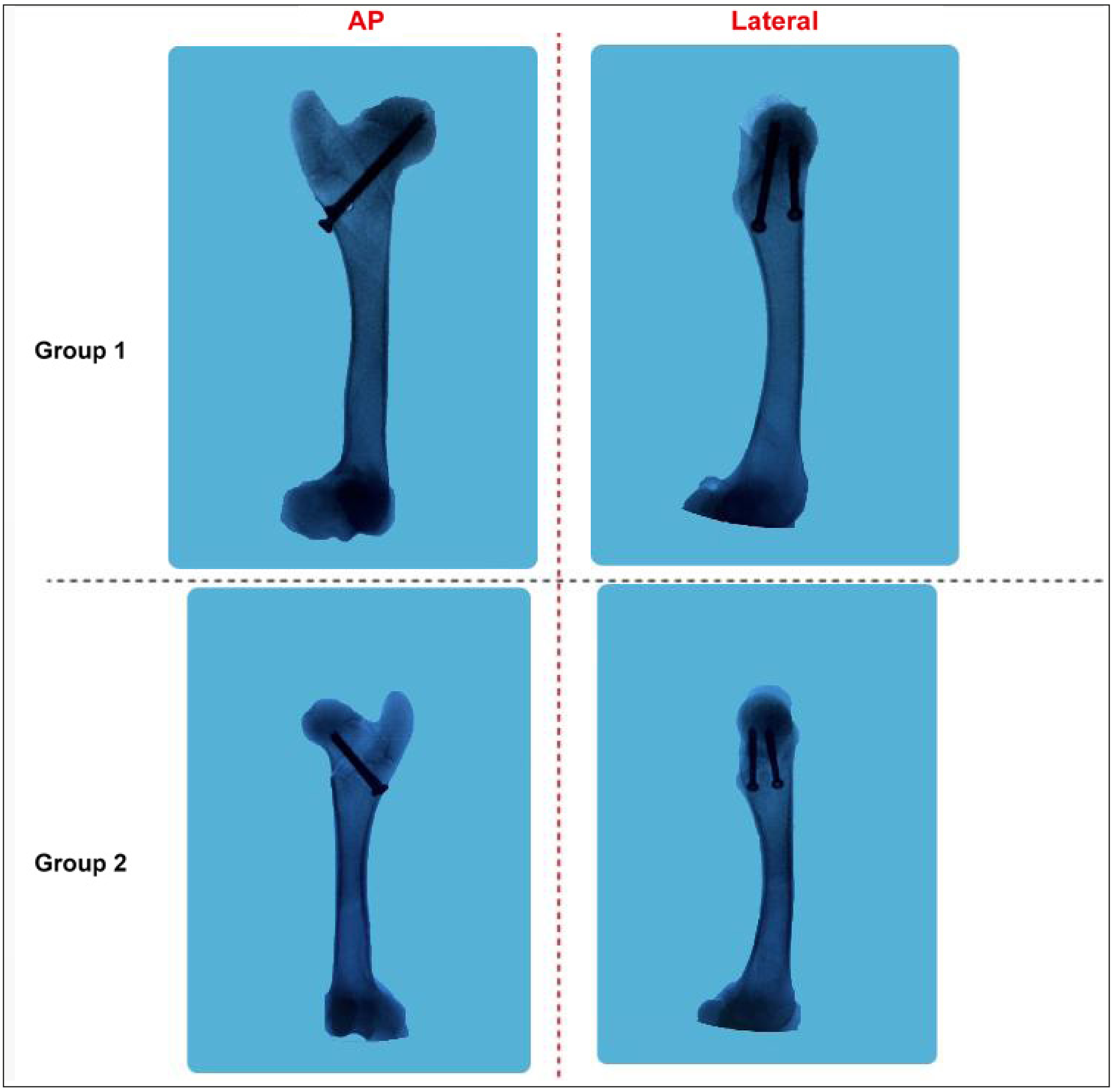

Figure 3. Radiographic images showing fixation using two 4.5 mm diameter and 38 mm length cannulated compression screws (not crossing the physis) in both AP (anteroposterior) and lateral views. Group 1 (top row) and Group 2 (bottom row) demonstrate the positioning and orientation of the screws.

and distal ends were drilled with a 2.7 mm drill. Then, reduction was achieved, and a 3.5 mm pediatric femoral proximal anatomical plate was placed (Figure 5). In group 3, one of the two proximal screws was a 3.5 mm locking screw that would cross the physis, while the other screw would not cross the physis. In group 4, there were two 3.5 mm locking screws in the proximal region that would not cross the physis. In group 3, one 52 mm length (crossing the physis) and one 38 mm length (not crossing the physis) cannulated locking screw were used along with two 3.5 mm locking screws. Distally, one 26 mm cortical screw was fixed with two 28 mm locking screws. In group 4, two 38 mm length (not crossing the physis) 3.5 mm locking screws were used. Distally, one 26 mm cortical screw was fixed with two 28 mm

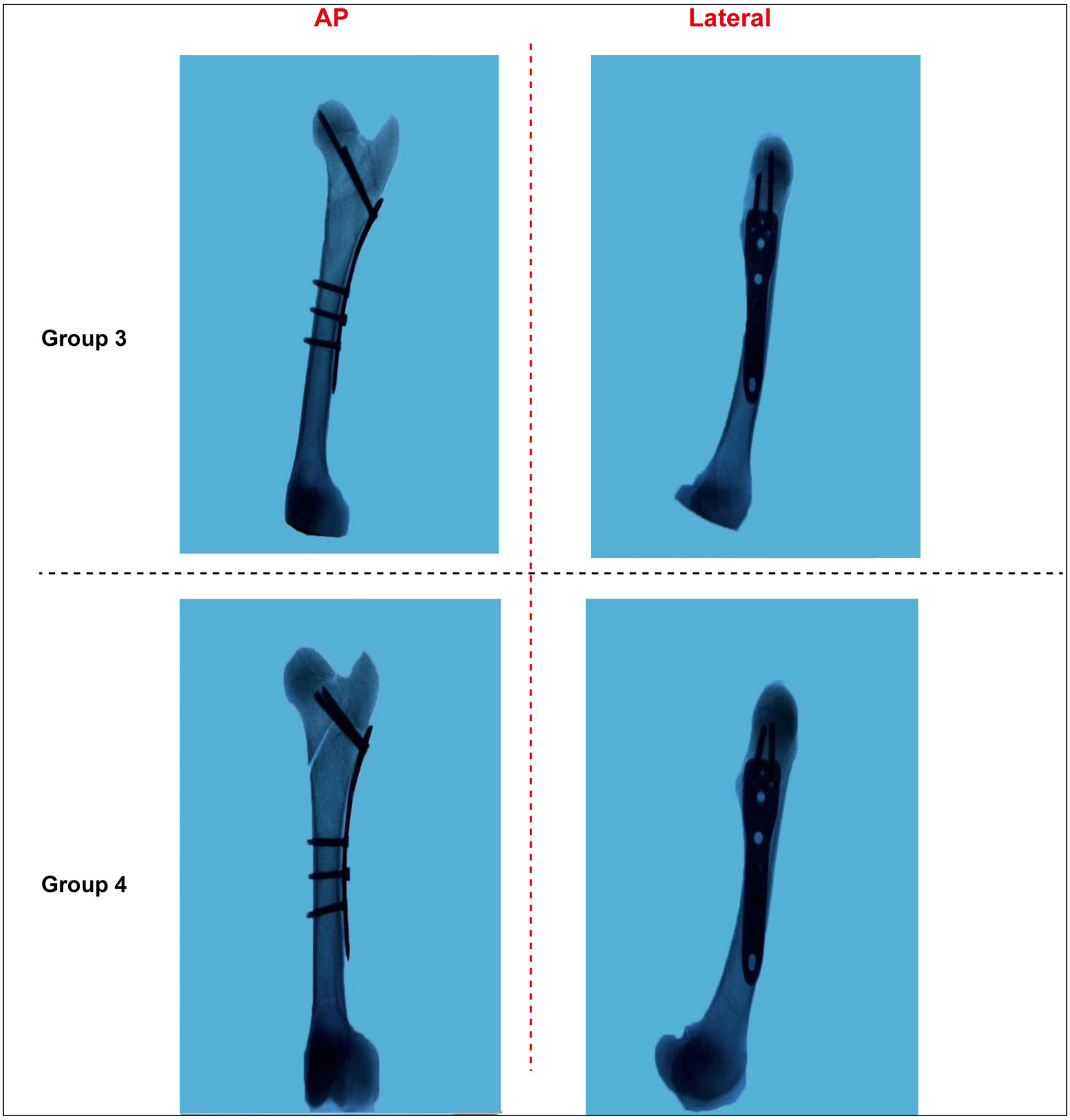

Figure 4. Radiographic images showing fixation using a 3.5 mm pediatric femoral proximal anatomical plate in both AP (anteroposterior) and lateral views. Group 3 (top row) and Group 4 (bottom row) demonstrate the positioning and orientation of the plate.

Table II. Results of normality test.

	Kolmogorov-Smirnov			Shapiro-Wilk		
	Statistic	SD	*p*	Statistic	SD	*p*
ABL	.128	28	.200	.942	28	.124
ABD	.098	28	.200	.948	28	.172
AS	.146	28	.131	.921	28	.037
AED	.182	28	.058	.879	28	.004

ABL: Axial buckling load, ABD: Axial buckling displacement, AS: Axial stiffness, AED: Axial energy dissipation.

locking screws. After fixation procedures were completed, the femoral bones were cut with an oscillating saw to a length of 13 cm between the distal metaphyseal and diaphyseal junction and the highest point of the greater trochanter.

Biomechanical Tests

The study's biomechanical tests were conducted in two stages: static and fracture tests. During these stages, axial stiffness, axial failure load, displacement amount, and energy dissipation were evaluated for each group. The static test was performed by applying a force increase that creates 5 mm/min displacement with 50N pre-loading. During the tests, upper-end separation of the fracture line, displacement amount, and static stiffness measurements were taken.

Static and Fracture Test Application

The static test started with a 50N pre-load. The force was applied to the femoral head through a round surface (acetabulum) at a force increase rate that creates 5 mm/min displacement. All femur models were positioned 25 degrees in adduction in the coronal plane and neutral in the sagittal plane for axial compression tests to be completed (Figure 6). A 50N pre-load was used in all axial loading tests performed for all groups, and 5 mm/min compression was applied. After taking the force/displacement data where the static test reached its peak in the graph, the test continued, and when the bone fracture was completed, the fracture test was terminated. The targeted variables were calculated using the embedded program of the Zwick/Roell AllroundLine 100 kN device (ZwickRoell LP, Kennesaw, GA, USA). After loading was completed, upper-end separation and sliding displacement amounts at the fracture line were calculated using digital image correlation. The damages that occurred after the test were recorded.

Statistical Analysis

The data obtained during the study were evaluated using the SPSS 28.0 program (IBM Corp., Armonk, NY, USA). Descriptive statistical methods (mean, standard deviation, median, frequency, percentage, minimum, maximum) were used when evaluating the study data. The distribution of continuous variables was investigated for differences between normal distribution and non-normal distribution using Shapiro-Wilk and Kolmogorov Smirnov tests and Skewness and Kurtosis statistics. One-Way ANOVA test was used to compare means of continuous variables that did not differ from normal distribution in more than two independent groups. The post-hoc LSD method was used to identify which groups exhibited significant differences, assuming the homogeneity of variances. $p<.05$ was considered statistically significant.

Results

The distribution of continuous variables was investigated to determine any difference between normal distribution and Kolmogorov-Smirnov and Shapiro-Wilk tests (Table II). There was no significant difference between the distribution of continuous variables recorded during the study, namely axial buckling load (ABL), axial buckling displacement (ABD), axial stiffness (AS), and axial energy dissipation (AED), and normal distribution ($p>.05$). Therefore, parametric test methods were preferred for independent group comparisons. ABL, ABD, AS, and AED variables were compared among independent groups (Table III). According to the test results, ABL, F=6.819, $p<.05$, d=.46, and AS, F=3.576, $p<.05$, d=.30, showed significant differences between independent treatment groups statistically, while ABD, F=.622, $p>.05$, and AED, F=.727, $p>.05$, did not show significant differences between independent groups. The effect sizes for ABL and

Table III. Comparisons of biomechanical parameters between the groups.

	Mean	SD	SE		95% CI Lower	95% CI Upper	F	*p*
ABL	Group 1	1,298.71	455.574	172.191	877.38	172.05	6.819	.002
	Group 2	804.86	303.126	114.571	524.51	108.20		
	Group 3	1,675.14	409.638	154.829	129.29	205.99		
	Group 4	1,075.86	298.111	112.675	800.15	135.56		
	Total	1,213.64	478.455	90.419	102.12	139.17		
ABD	Group 1	15.916	4.870	1.840	11.411	20.420	.622	.608
	Group 2	18.974	5.448	2.059	13.936	24.013		
	Group 3	15.086	7.972	3.013	7.712	22.459		
	Group 4	17.671	4.529	1.711	13.483	21.860		
	Total	16.912	5.738	1.084	14.687	19.137		
AS	Group 1	191.425	53.809	20.337	141.66	241.190	3.576	.029
	Group 2	150.815	38.246	14.455	115.44	186.188		
	Group 3	235.094	49.931	18.872	188.91	281.272		
	Group 4	189.210	49.415	18.677	143.50	234.912		
	Total	191.636	54.665	10.330	170.43	212.833		
AED	Group 1	223.214	129.646	489.238	103.338	342.091	.727	.546
	Group 2	162.857	990.1959	377.939	696.467	254.247		
	Group 3	266.186	186.5341	705.798	936.822	439.550		
	Group 4	200.857	107.8531	404.298	101.369	299.345		
	Total	213.529	133.8320	251.754	161.678	264.379		

ABL: Axial buckling load, ABD: Axial buckling displacement, AS: Axial stiffness, AED: Axial energy dissipation.

Table IV. Post-hoc comparisons of biomechanical parameters between the groups.

Dependent variable	(I) Group	(J) Group	Mean difference (I-J)	SE	*p*	95% CI Lower	95% CI Upper
ABL	Group 1	Group 2	493.857	199.303	**.021**	82.52	905.20
		Group 3	-376.429	199.303	.071	-787.77	34.91
		Group 4	222.857	199.303	.275	-188.48	634.20
	Group 2	Group 1	-493.857	199.303	.021	-905.20	-82.52
		Group 3	-870.286	199.303	<.001	-1,281.63	-458.94
		Group 4	-271.000	199.303	.187	-682.34	140.34
	Group 3	Group 1	376.429	199.303	.071	-34.91	787.77
		Group 2	870.286	199.303	**<.001**	458.94	1,281.63
		Group 4	599.286	199.303	.006	187.94	1,010.63
	Group 4	Group 1	-222.857	199.303	.275	-634.20	188.48
		Group 2	271.000	199.303	.187	-140.34	682.34
		Group 3	-599.286	199.303	**.006**	-1,010.63	-187.94
AS	Group 1	Group 2	40.61000	25.764	.128	-12.56	93.78
		Group 3	-43.668	25.764	.103	-96.84	9.50
		Group 4	2.215	25.764	.932	-50.95	55.39
	Group 2	Group 1	-40.610	25.764	.128	-93.78	12.56
		Group 3	-84.278	25.764	**.003**	-137.453	-31.10
		Group 4	-38.394	25.764	.149	-91.56	14.78
	Group 3	Group 1	43.668	25.764	.103	-9.50	96.84
		Group 2	84.278	25.764	.003	31.1034	137.45
		Group 4	45.884	25.764	.088	-7.29	99.05
	Group 4	Group 1	-2.215	25.764	.932	-55.39	50.95
		Group 2	38.394	25.764	.149	-14.78	91.56
		Group 3	-45.884	25.764	.088	-99.05	7.29

ABL: Axial buckling load, AS: Axial stiffness.

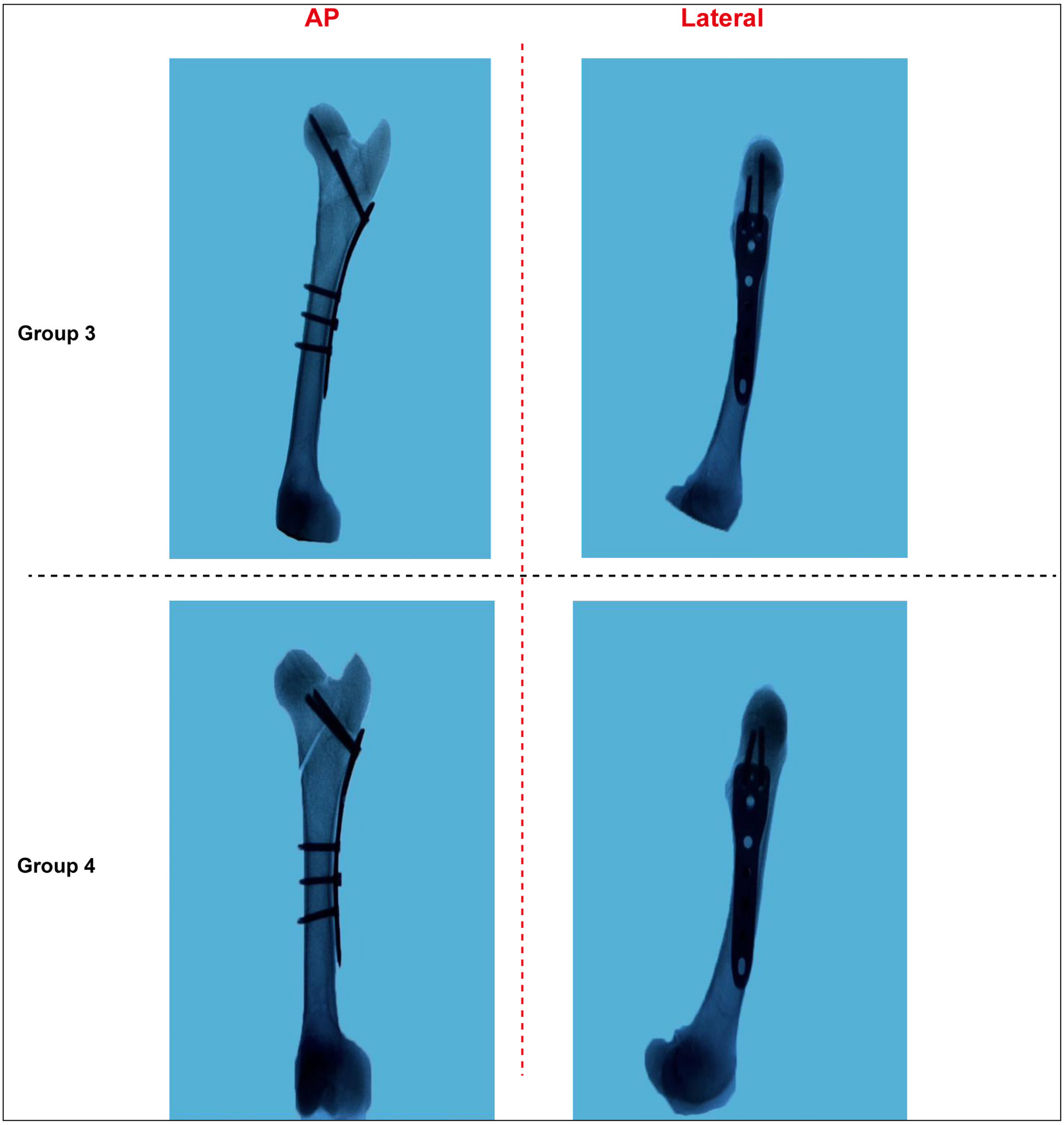

Figure 5. Comparison of axial displacement, axial failure, failure energy, and axial stiffness between groups.

AS, which showed significant differences, were 0.46 and 0.30, respectively, indicating moderate clinical effects (Table II).

The axial displacement amounts recorded in different groups are shown in Figure 7. Accordingly, the largest displacement amount was recorded in group 2, while the least displacement was recorded in group 3. The displacement amounts were in descending order of 2-4-1-3. The axial energy dissipation recorded in different groups is shown in Figure 7. Accordingly, the largest axial energy dissipation was recorded in group 3, while the least was recorded in group 2. The axial energy dissipation amounts were in descending order of 3-1-4-2. Accordingly, the largest axial energy dissipation was recorded in group 3, while the least was recorded in group 2. The axial energy dissipation amounts were in

Figure 6. A, Femur model. **B,** Axial compression tests for femur model.

descending order of 3-1-4-2. Finally, the recorded axial stiffness amount is summarized in Figure 7. Accordingly, the largest axial stiffness was recorded in group 3, while the least was recorded in group 2. The axial stiffness amounts were in descending order of 3-1-4-2.

Post-hoc LSD test was conducted to determine between in which group the statistical difference in ABL and AS was found. According to the test results, the axial buckling load recorded in group 1 was statistically higher than that in group 2 (p<.05), the axial buckling load recorded in group 2 was statistically higher than that in group 3 (p<.05), and finally, the axial buckling load recorded in group 3 was statistically higher than that in group 4 (p<.05). On the other hand, the axial stiffness level found in group 3 was statistically higher than the axial stiffness measurement recorded in group 2 (p<.05; see Table IV).

Discussion

Displaced femoral neck fractures are rare in children. One of the most serious complications is avascular necrosis (AVN)[14]. It is unclear from the literature whether current treatment methods increase the rate of complications in the treatment of displaced femoral neck fractures. Additionally, growth plates are open in pediatric femoral neck fractures, unlike in adults. There is no controlled experiment investigating the best method for creating the best stability in the extremity where orthopedic surgical intervention is applied, crossing and not crossing the growth line in this group. Therefore, this study aims to determine the most stable, economical, and socially less impactful surgical application in the Delbet type III femoral neck fracture model created in fresh lamb femur bone. To achieve this goal, two different techniques and implants were compared.

Pediatric femoral neck fractures carry the risk of serious complications and long-term disability. According to data obtained from a tertiary academic center, an incidence rate of 1.2-2 cases of pediatric femoral neck fracture is reported annually, representing 0.3-0.5% of all fractures seen in children. The incidence is 1.3-1.7 times higher in boys than in girls, and the highest incidence is reported between the ages of 10-13[15]. Osteonecrosis, coxa vara, proximal femoral physeal closure, and pain due to non-union were reported in 20-50% of cases during long-term follow-up[16,17]. To optimize patient populations, clinicians should provide standardization in the basic principles of diagnosis, treatment, prospective care, and management of complications.

Although good results have been achieved in the early reduction of adult hip fractures, the outcomes in children who undergo early fracture reduction still remain uncertain. A systematic review of 30 studies involving 935 patients showed that the

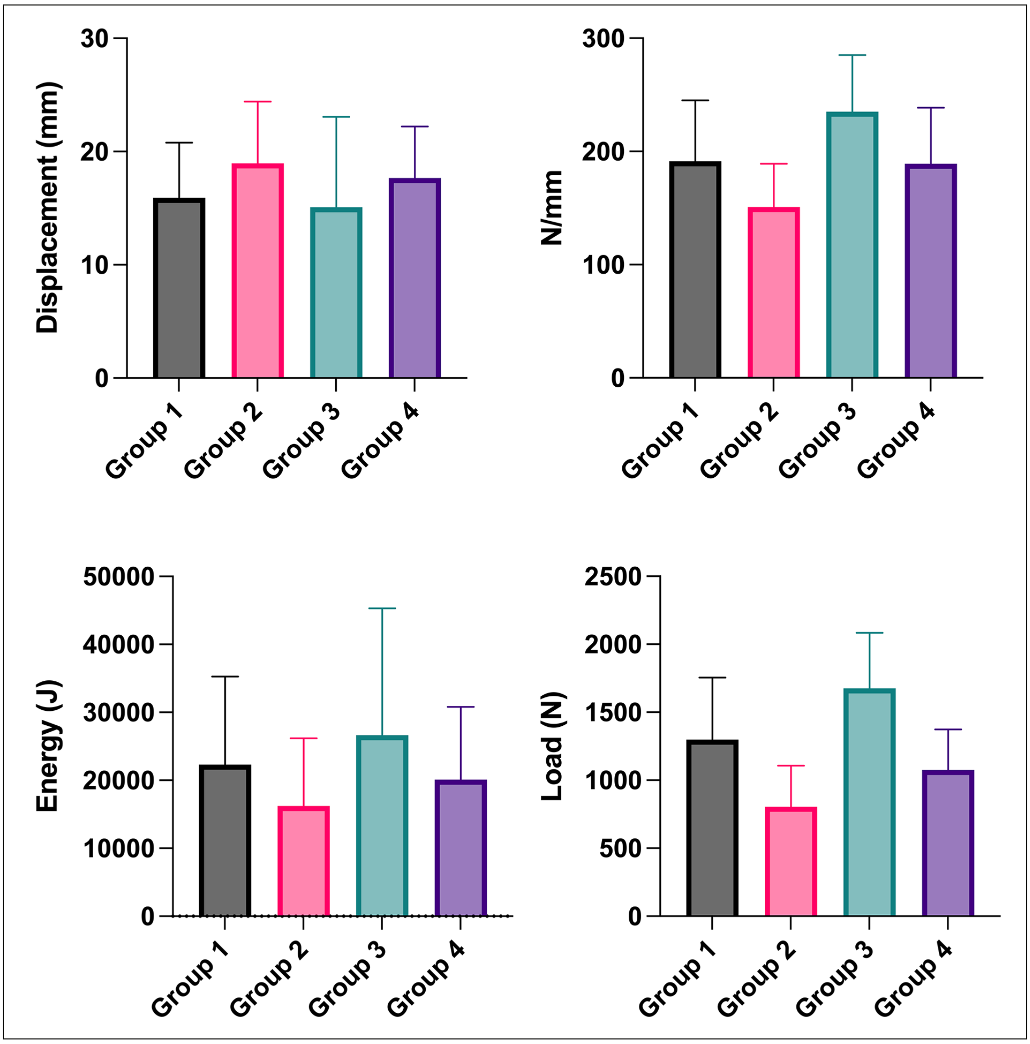

Figure 7. Comparison of axial displacement, axial failure, failure energy, and axial stiffness between groups.

incidence of osteonecrosis in patients with delayed treatment was 4.2 times higher than in those treated within 24 hours of injury[16]. Delaying fixation until 24 hours after the injury caused early physeal closure in 64% of patients and osteonecrosis in 55%[18]. However, scholars have shown that shortening the reduction time (<12 hours) does not reduce the incidence of osteonecrosis but rather increases it[19]. Despite limited and conflicting evidence in the literature on the timing of fixation, Spence et al[24] and Gopinathan et al[20] have suggested that anatomical reduction of the hip should be performed as soon as possible.

Selection between closed or open reduction depends on the amount of current fracture displacement and the surgeon's ability to achieve closed anatomical or near-anatomical reduction. Patients are placed supine on a radiolucent operating table or fracture table, and reduction is assessed intraoperatively with fluoroscopy. When closed reduction is performed on the fracture table, the hip is in abduction and internal rotation with hip hyperextension, and slight knee flexion is maintained. The hip is slowly placed into a hip spica cast, or percutaneous fixation is performed by applying longitudinal traction. Open reduction is recommended in cases where anatomical reduction cannot be achieved through these methods.

Delbet type II and III fractures are the most common types of pediatric femoral neck fractures and are frequently displaced. Non-displaced fractures in young children (<6 years old) can be treated with closed reduction and immobilization with a spica cast. Additional fixation can be used in 2-year-old patients to prevent displacement within the cast. Due to the risk of nonunion and malunion resulting in femoral head-neck translation, acceptable reduction for type II fractures consists of <5° angulation and <2 mm cortical translation. Acceptable reduction for type III fractures consists of <10° angulation, most commonly in varus alignment. Displaced fractures that cannot be treated with closed reduction are treated with open reduction and internal fixation using straight Kirschner wires for patients under 4 years old, physeal-sparing cannulated screws for patients between 4-9 years old, and transphyseal cannulated screws for patients over 10 years old. Transphyseal screw fixation is recommended for small metaphyseal fragments with insufficient stability. These different surgical recommendations in the literature have not been compared in terms of fixation success. Therefore, in our study, the biomechanical success of cannulated compression screws and anatomical plates was compared in Delbet type III femoral neck fractures modeled in sheep femurs. The increase in ABY, AS, and ABE scores and the decrease in ABD scores in biomechanical tests indicate an increase in detection success.

According to the findings obtained in our study, there was a statistically significant difference between the independent treatment groups in ABY ($F=6.819$, $p<.05$, $d=.46$) and AS ($F=3.576$, $p<.05$, $d=.30$), while there was no statistically significant difference between independent groups in ABD ($F=.622$, $p>.05$) and ABE ($F=.727$, $p>.05$). The effect sizes of the variables ABY and AS, which significantly differed, were 0.46 and 0.30, respectively, indicating a moderate level of clinical effect. In other words, the difference in clinical success between the applied techniques is moderate. A post-hoc LSD test was conducted to determine between which two groups the statistical difference in ABY and AS was found. According to the test results, the measurement obtained with two 4.5 mm cannulated compression screws that crossed the growth plate in ABY was statistically significantly higher than the measurement obtained with compression screws that did not cross the growth plate ($p<.05$). In group 3 and group 4, the wire locations were determined with a Kirschner wire, drilled with a 2.7 mm drill, and reduction was achieved, after which a 3.5 mm proximal anatomical plate was placed on the femur. In group 3, five cortical screws were used to cross the growth plate, while in group 4, five cortical screws were used that did not cross the growth plate. ABY obtained with 4.5 mm cannulated compression screws that did not cross the growth plate was statistically significantly higher than ABY obtained with anatomical plate and five cortical screws that crossed the growth plate ($p<.05$). Finally, according to the score obtained in group 4, where the cortical screws crossed the growth plate, significantly more ABY was obtained than in the experimental design where they did not cross ($p<.05$). In addition, AS obtained in the group where anatomical plate and cortical screws crossing the growth plate were applied was significantly higher than AS obtained in the group where 4.5 mm cannulated compression screws were used that did not cross the growth plate ($p<.05$). These findings obtained in our study are consistent with the literature.

Talebi et al[21] presented a case report of a 14-year-old male patient who was brought to the emergency department with a Delbet type Ib fracture of the left femoral neck and epiphyseal femoral head detachment due to a traffic accident. Two cannulated compression screws crossing the growth plate were used for reduction and fixation. Talebi et al[21] preferred cannulated compression screws crossing the growth plate in a young male patient who could experience high-energy movements and successfully applied it. Despite the occurrence of ANV during the eight-month follow-up after surgery, fixation success was maintained. In our study, the same protocol was applied to group 1, and biomechanical findings that overlap with Talebi et al's clinical findings were obtained[21]. Accordingly, in group 1, higher ABY, ABE, and AS were obtained compared to cannulated screw compression that did not cross the growth plate in group 2.

The most important complication encountered in femoral neck fractures in children is AVN. The incidence of AVN is affected by fracture type, timing of surgery, and the age of the child[15]. Moon and Mehlman[11] reported AVN rates of 38% in Delbet type I, 28% in Delbet type II, 18% in Delbet type III, and 5% in Delbet type IV. Coxa vara can decrease the strength of the hip abductor and shorten the limbs. Another complication related to the treatment method is nonunion. Improper fixation or reduction can lead to nonunion. Early physeal closure may be a result of the tools used for fixation. Therefore, the selection of the most efficient implant and surgical method is important for the management of femoral neck fractures in children from both biomechanical and clinical perspectives. Although no causal relationship has yet been established, it has been observed that the rate of AVN after surgery is high in children who use cannulated screws.

Ratilff et al[22] first described different types of AVN after pediatric femoral neck fractures in 1962. In 2002, Mohammad et al[23] used a cannulated compression screw in a patient with a transepiphyseal fracture of the femoral neck and observed AVN within 24 months of follow-up. In 2006, Akahane et al[24] performed fixation with a cannulated screw in a child with a transepiphyseal fracture of the proximal femur combined with a mid-shaft fracture of the ipsilateral femur. In 2008, Abbas et al[25] reported posttraumatic avascular necrosis of the femoral head in three teenagers treated with a modified transtrochanteric rotational osteotomy. Venkatadass et al[26] reported bilateral femoral neck fractures classified as Delbet type II in one child, Kim et al[27] reported Delbet type II femoral neck fracture in a child in 2018, Naik et al[28] reported bilateral Delbet type II femoral neck fractures in one child in 2021, and finally, Rinat et al[29] reported femoral neck fractures classified as Delbet type II and III in one child in 2021.

Limitations

In the discussed studies, femoral neck fractures were fixed with cannulated compression screws that did not exceed the femoral head. Although this surgical preference provides adequate fixation from a biomechanical point of view, AVN findings were reported in three studies during the follow-up period. In our study, the biomechanical success of the implants and methods used was evaluated by measuring ABY, ABD, AS, and ABE scores. As a result of the test, the group with the highest biomechanical success in terms of ABY, AS, and ABE variables was group 3, where fixation was performed with one anatomical plate and five 3.5 mm screws that passed through the femoral head. However, since the clinical effects of the implants and methods tested in this study were not evaluated, their success in terms of frequently reported side effects in the literature is unknown.

Conclusions

This study compared the fixation success of 4.5 mm cannulated compression screws and 3.5 mm screws, both passing through and not passing through the femoral head, in conjunction with anatomical plates. It was found that the biomechanical fixation success was the highest with the fixation method of the anatomical plate and five 3.5 mm screws that passed through the femoral head. This biomechanical study does not provide information on how the results will impact clinical outcomes. Therefore, it is necessary to evaluate the clinical benefits with prospective and randomized studies.

Conflict of Interest

The authors declare that they have no conflict of interest.

Authors' Contributions

DT and AAK contributed to the conceptualization, design, acquisition, analysis, figure preparation, manuscript writing, and drafting. ÖB, BK, and AT were involved in the conception, design, acquisition, analysis, figure preparation, manuscript writing, and drafting. FD and MT participated in conceptualizing, designing, figure preparation, main manuscript writing, and drafting. All authors reviewed and approved the final manuscript.

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Availability of Data and Materials

The datasets analyzed during the current study are available from the corresponding author upon reasonable request.

Ethics Approval

This study was approved by the Kahramanmaras Sutcu Imam University Faculty of Medicine Animal Experiments Local Ethics Committee with the approval number 2021/01-03.

Informed Consent

Not applicable.

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