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Comparison of Different Kirschner Wire Configurations in the Treatment of Pediatric Supracondylar Femoral Fractures: An Animal Experiment and Comparative Biomechanical Study

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ABSTRACT

Background and Aims: Pediatric femoral fractures are rare among all pediatric fractures but are one of the most common causes of hospitalization due to trauma in children. Supracondylar femur fractures (SCFs) account for 12% of all femoral fractures in pediatric patients. However, the optimal treatment strategy for SCF fractures remains unclear. In this study, we aimed to evaluate the differences in stability among various percutaneous Kirschner (K) wire configurations in SCF fractures.

Materials and Methods: This study was designed as an experimental, comparative biomechanical analysis using lamb bones. SCF fractures were created in 10 lamb femurs obtained from a slaughterhouse. The specimens were divided into five groups, each receiving different Kirschner wire configurations: Group 1: 2L, Group 2: 1M + 2L, Group 3: 3L, Group 4: 2M + 2L, and Group 5: 1M + 3L. K-wires of the same diameter were used across all groups. Axial compression, fatigue, and torsion tests were performed for biomechanical comparison. The minimum force and time at which the fixation began to fail, and the maximum force and time at which complete fracture occurred, were measured using a dynamometer.

Results: There was no significant difference between the groups in terms of the initial fracture force, the force at which complete fracture occurred, or the time to fracture ($p > 0.05$). Although Group 3 demonstrated higher fracture time and strength compared to the other groups, the difference was not statistically significant ($p>0.05$).

Conclusion: In this study, although the use of three lateral K-wires demonstrated the greatest mechanical stability, the difference was not statistically significant. Percutaneous K-wire fixation remains a valuable option for treating pediatric supracondylar femur fractures; however, further research is needed to determine the optimal number and configuration of wires. Although using three lateral K-wires showed the greatest mechanical stability, the difference was not statistically significant ($p>0.05$). Percutaneous K-wire fixation remains a useful option for treating pediatric supracondylar femur fractures, but more research is needed to determine the best wire number and configuration.

Keywords: Biomechanics, Kirschner wire, pediatric orthopedic surgery.

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INTRODUCTION

Pediatric femur fractures are rare compared to other pediatric fractures but are among the most common causes of pediatric trauma-related hospitalizations.[1] These fractures are more frequent in boys and tend to occur most commonly in two age groups: 2-3 years and 16-19 years.[2] Distal femur fractures are relatively uncommon in children, with diaphyseal fractures being more prevalent. While many of these injuries result from falls, traffic accidents are also a significant cause.[3] Pediatric supracondylar femur fractures (SFF) account for 12% of all femoral fractures in children. Nearly half of these fractures are displaced and require surgical intervention.[4] Treatment options for displaced supracondylar femur fractures include fixation with a spica cast, external fixator, titanium elastic nails, plate-screw systems, and percutaneous Kirschner (K) wire fixation, or a combination of these methods.[5] However, there is currently no universally accepted standard for optimal treatment. The child's age, weight, socioeconomic status, and the location of the fracture all influence the choice of fixation method. Percutaneous Kirschner wire fixation may be more advantageous in displaced SFF due to its minimally invasive nature.[6,7] K-wire osteosynthesis continues to play an important role in the treatment of pediatric fractures. Its advantages include being minimally invasive, quick to apply, and cost-effective. Its affordability, efficiency, and reliability, particularly in animal studies, make K-wire fixation an attractive option. Our hypothesis is that percutaneous K-wire fixation, as one of the treatment methods, provides optimal stability when configured using crossed K-wires. In this study, we aimed to determine which K-wire configuration offers the greatest fixation strength by performing controlled supracondylar femur fractures and subsequent fixation in intact lamb femur cadavers. No assistance from artificial intelligence or artificial intelligence-based technologies was used in the preparation of this study.

METHODS

This study was designed as an experimental, comparative biomechanical analysis using lamb bones. Ten intact lamb femurs obtained from a slaughterhouse were included in the study. Group sample sizes were determined based on power analysis. Under fluoroscopic guidance, a clean transverse fracture was created at the supracondylar region using a 3.5 cannulated drill bit (Fig. 1). Fluoroscopy was utilized to ensure the creation of standardized and uniform fractures. The diameters of all lamb bones were standardized to be the same size. All K wires used were stainless steel 316 L with a diameter of 1.8 mm. Since the bone diameters were identical, K wires of the same diameter were used throughout. K-wire configurations commonly preferred by surgeons for the fixation of pediatric supracondylar femur and humerus fractures were selected. Fixation was then performed using K wires under fluoroscopy in five groups:

Figure 1. Lamb bone with a supracondylar femur fracture.

- Group 1: Two lateral K wires,
- Group 2: One medial and two lateral K wires,
- Group 3: Three lateral K wires,
- Group 4: Two medial and two lateral K wires,
- Group 5: One medial and three lateral K wires.

Two femur specimens were used for each group.

Axial compression, fatigue, and torsion tests were performed for biomechanical comparison. The experiments were conducted under laboratory conditions. Five different groups were tested at 50% relative humidity (RH) and a temperature of 25°C. Biomechanical tests were carried out by placing the fixed bones in the testing device, applying force, and recording the force and time at which the fracture began and ended. A Geratech SH 5000 test system was used to apply loading at a frequency of 10 Hz at a constant compression rate of 10 mm/min from the center of motion (Fig. 2). Load and displacement values were recorded during the tests. The maximum applied load and loading rate were determined according to the ISO 7206-4 standard. The minimum force and time at which the fixated bones began to fracture, and the maximum force and time at which complete fracture occurred, were measured using a dynamometer.

Figure 2. Application of axial force to the lamb bone using the Geratech SH 5000 testing system.

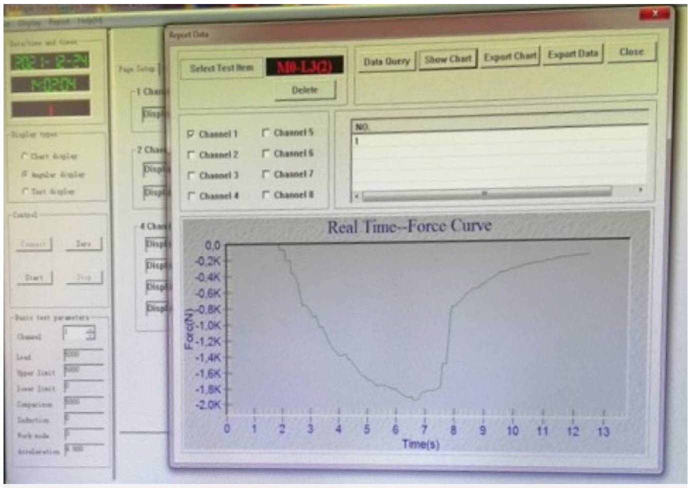

Figure 3. Dynamometer measurements recorded using the Multiple Force Gauges Testing System program.

Dynamometer measurements and data were recorded using the Multiple Force Gauges Testing System program (Fig. 3). Since our study was conducted on lamb bones, an informed consent form was not required.

Statistical Analysis

The SPSS 20.0 software package (Qiagen, Hilden, Germany) was used to evaluate the data obtained. Median (min-max) values were used for the analysis. A p value of < 0.05 was considered statistically significant. The Kruskal-Wallis test was used for group comparisons, and Dunn's multiple comparison test was applied to identify the groups showing significant differences.

Ethics Committee Approval

Ethics committee approval was not required for this study, as per the decision of the Afyon Kocatepe University Animal Experiments Local Ethics Committee (Approval Number: 49533702/04, Date: 27.01.2022).

RESULTS

In the laboratory, lamb femur bones assigned to five groups were subjected to biomechanical testing following the surgical procedure. In Group 1, the average force at the onset of fracture was 549 N, while the average force at complete fracture was 1753 N. The mean time required was 2.54 seconds. In Group 2, the mean force at fracture onset was 843.5 N, and the mean force at complete fracture was 2560 N. The mean duration was 3.13 seconds. In Group 3, the mean force at the onset of fracture was 741.5 N, and the mean force at complete fracture was 2306 N. The mean duration was 15.78 seconds (Fig. 4). In Group 4, the mean force at the onset of fracture was 626.5 N, and the mean force at complete fracture was 1927 N. The mean duration was 3.18 seconds. In Group 5, the mean force at the onset of fracture was 573.5 N, and the mean force at complete fracture was 2244 N. The mean duration was 3.70 seconds. There was no significant difference between the initial fracture force, the force at complete fracture, and the fracture duration among the groups ($p>0.05$). Although the fracture force and duration in Group 3 were higher than those in the other groups, the difference was not statistically significant ($p>0.05$) (Table 1).

DISCUSSION

Pediatric supracondylar femur fractures are rare.[4] There are various opinions regarding their treatment, and no clear consensus has been established. Surgeons typically tailor treatment options based on the patient's age, body mass index, type of fracture, and the presence of additional injuries.[8] The primary goal in treating pediatric supracondylar femur fractures is to maintain limb length and prevent translation and rotation. Ultimately, the aim is to restore full range of motion, prevent joint stiffness, and ensure the patient recovers with minimal complications. The chosen treatment approach should be suitable for both the patient and their family and should aim to minimize psychological impact.[5]

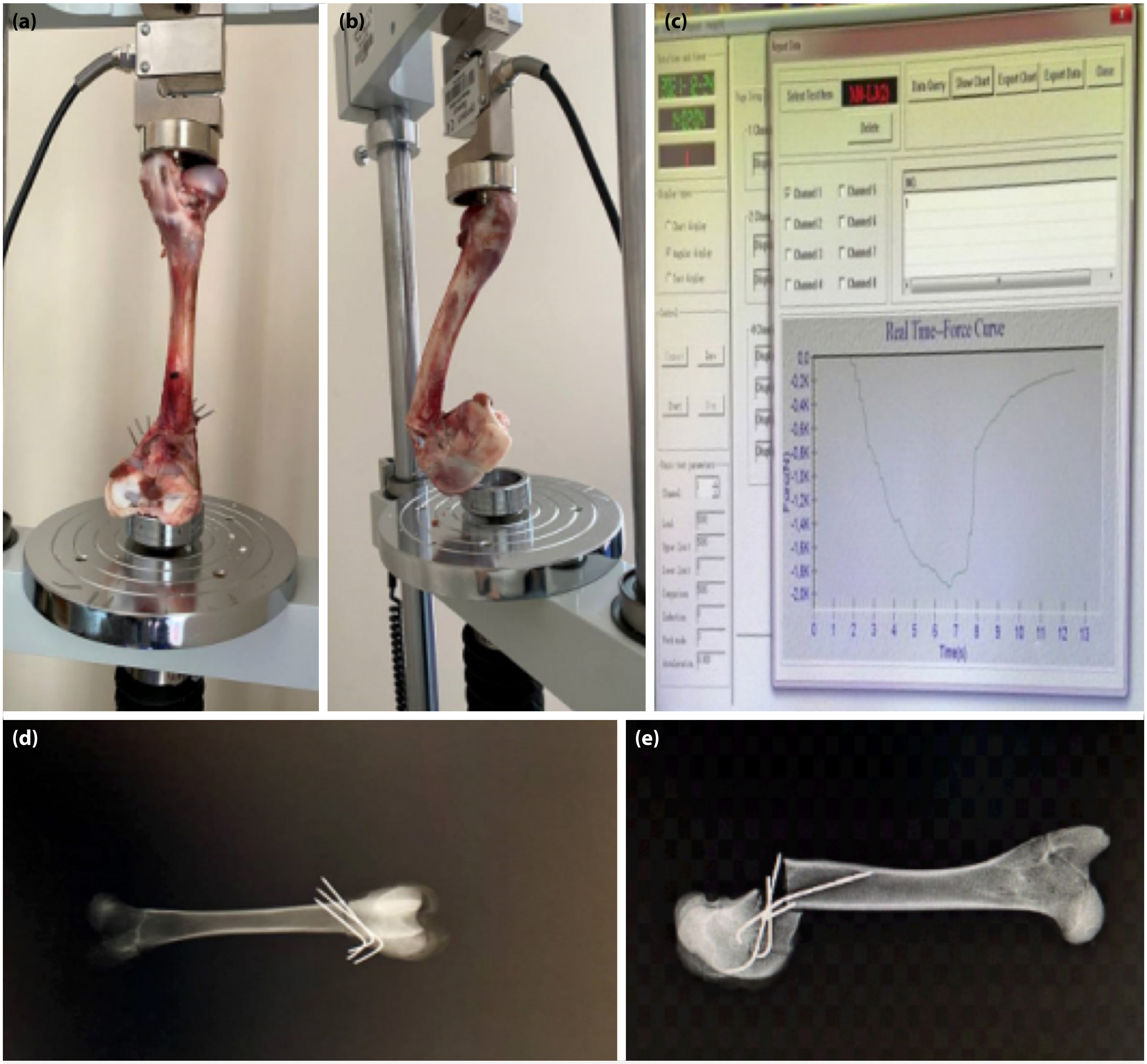

Figure 4. Mechanical testing and radiographic evaluation of Group 3 before and after the procedure. **(a)** Image of the lamb femur fixed with three K-wires prior to testing. **(b)** Image of the fracture following compression. **(c)** Dynamometer measurement recorded with the Multiple Force Gauges Testing System program. **(d)** Radiograph showing lateral fixation with three K-wires before testing. **(e)** Radiographs of bones fixed with three lateral K-wires after the procedure.

Locking plates and screws can be used for fixation. However, the reduction of displaced supracondylar femur fractures, whether open or closed, can be difficult. Especially in pathologic fractures, Bor et al.[9] reported that fixation with plate screws becomes easier following intraoperative application of an external fixator, which they removed during the same procedure after achieving permanent fixation. Studies have shown that the fracture line often needs to be exposed for plate screw application, and this may lead to circulatory problems in the region, particularly in the physis and epiphysis. Complications such as nonunion, infection, and delayed healing may also ocur.[7]

Table 1. Force and time measurements at the onset of fracture and at complete fracture in five groups following supracondylar femur fracture fixation with K-wires

	Force at Fracture Onset				Force at Complete Fracture				Time to Fracture			
	Min*	Max**	Median	p	Min*	Max**	Median	p	Min*	Max**	Median	p
Group 1	68	1030	549	0.102	702	2084	1753	0.203	2.54	2.55	2.55	0.998
Group 2	579	1108	843.5	0.641	2210	2911	2560.5	0.910	2.65	3.61	3.13	0.895
Group 3	161	1322	741.5	0.553	879	3734	2306.5	0.459	2.43	29.14	15.78	0.07
Group 4	96	1157	626.5	0.549	340	3514	1927	0.108	0.94	5.42	3.18	0.238
Group 5	425	722	573.5	0.874	1493	2995	2244	0.911	2.23	5.17	3.70	0.728
p	0.913				0.928				0.943			

*Min: Minimum; **Max: Maximum.

Although elastic titanium nails are a good option for the surgical treatment of supracondylar femur fractures, studies have shown that they are inadequate in preventing rotation and can cause soft tissue damage at the nail entry sites.[10] Additionally, research has indicated that elastic nails are not ideal for supracondylar femur fractures due to their insufficient stability.[11]

External fixators have gained popularity in the treatment of pediatric supracondylar femur fractures because of their ease of use and versatility. However, percutaneous K-wire fixation increases stability and supports safe surgical procedures.[12,13] Although external fixators offer advantages in terms of ease of use, they also have disadvantages, including pin-site infections, development of joint stiffness, prolonged hospitalization, and the need for a second surgery for removal.[14] When external fixators and percutaneous K-wire applications were compared in supracondylar femur fractures, K-wire fixation was reported to be more advantageous, as the external fixator (EF) group experienced greater blood loss, longer hospital stays, and longer operation times.[7]

Closed reduction and K-wire fixation in pediatric supracondylar femur fractures is often preferred by surgeons due to its minimally invasive nature. However, it also has drawbacks, such as pin-site infection, re-fracture, delayed union, nonunion, and implant failure. Despite these risks, K-wire fixation remains widely favored because it is easy to learn and apply. Radiologic and clinical outcomes have been reported to be very good in patients aged 4-10 years with supracondylar femur fractures who underwent K-wire fixation. However, due to subjective concerns about the stability of K-wire fixation, surgeons often applied a spica cast in addition.[15] Studies have also been conducted on cases in which K-wire fixation was used in children under 4 years of age, and both functional and radiologic results were reported to be very good.[7]

In percutaneous K-wire fixation, since there is a risk of growth arrest if the wires cross the physis, they should be positioned to avoid crossing the physis whenever possible.[16] In pediatric supracondylar femur fractures, although avoiding the physis is ideal, crossing it may be necessary depending on the nature of the fracture and the fixation technique. However, this may lead to future complications such as limb length discrepancies or deformities.

In our literature review, we did not find any studies examining the biomechanical or cellular differences in osteotomy and fixation of lamb bones obtained from slaughterhouses. Additionally, we found no studies comparing K-wire fixation in animal experiments. Animal experimental models are widely used in all areas of health research and are particularly common in orthopedic studies, especially those focusing on bone healing. Although lamb femur bones and human femur bones may not exhibit identical biomechanical responses, no studies in the literature have addressed this comparison directly. However, examining the different biomechanical responses of lamb bones to various types of fixation may still offer valuable insights into how different fixation methods might perform in human bones.

In our study, while investigating the stability of K wires applied in different configurations, we found that the most stable setup involved three K wires inserted laterally. Nonetheless, mechanical stability was also satisfactory in the other configurations, with no statistically significant differences observed. Since only two lamb femurs were used per group, the statistical power was limited. Future studies with a larger number of specimens may yield different results. The main limitations of this study include the small number of specimens and the limited clinical relevance, as lamb bones do not perfectly replicate the biomechanics of the human pediatric femur.

CONCLUSION

In this study, we conducted a biomechanical analysis using lamb bones to evaluate the durability and stability of percutaneous K-wire applications in various configurations for pediatric supracondylar femur fractures. Initially, we hypothesized that the most mechanically stable and durable configuration would consist of one medial and three lateral K-wires. However, our results showed that the most mechanically stable configuration was three lateral K-wires alone. Nonetheless, no statistically significant difference was observed (p>0.05). In conclusion, percutaneous K-wire fixation is a favorable option in the surgical treatment of pediatric supracondylar femur fractures. However, given the lack of consensus regarding the optimal number and configurations of K-wires, further comprehensive studies are needed.

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