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ORIGINAL STUDY

Is there any difference between the biomechanical strengths of the current fixation techniques for comminuted distal patellar fractures? (Comparison of distal patella fracture fixation techniques)

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In this biomechanical study, the strength of five different fixation techniques -anterior tension band wiring with K-wires, separate vertical wiring, headless compression screws with anterior tension band wiring, cannulated screws with tension band wiring and memory shape patellar fixator- for distal patellar fractures were compared. Forty calf knees were used for the biomechanical testing. Each specimen was pre-loaded with 10 N at 1 N/s. The distraction forces were applied consistently with the velocity of 5 mm/s. The ultimate load (N) and displacement (mm) values were recorded. The headless compression screw with anterior tension band wiring (656.9±167.9 N) and the cannulated screws with anterior tension band wiring (642.6±166.0 N) obtained significantly higher ultimate loading values compared to the other fixation methods (p<0.05). Fixation via cannulated screws with anterior tension band wiring techniques are more stabile than the patellar shape memory fixator and anterior K wire fixation.

Keywords : distal patella ; fracture ; biomechanics ; surgical treatment ; fixation.

INTRODUCTION

Patellar fractures account for about 1% of all fractures *(27)*. Patella inferior pole fractures are extra-articular and constitute 9.3-22.4% of all patellar fractures *(21)*, which are often associated with complete disruption of the extensor mechanism *(7)*. Currently there is no consensus about the optimal surgical treatment for the patella inferior pole fractures *(15)*. Internal fixation of the distal part, if possible, or excision of the small bone fragments with repair of the patellar tendon by transosseous pull-out sutures, in the extremely comminuted cases, should be performed *(17)*. However in the latter, non-absorbable synthetic sutures and partial patellectomy necessitate immobilization of the knee, which causes weakness in the quadriceps muscle *(7,14,17,30)*. Therefore, fixation of the distal patellar fractures has gained popularity over partial patellectomy.

There are various previously defined surgical fixation options for patella inferior pole fractures: anterior tension band wiring, combining screw fixation with tension band, patellotibial cerclage,

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fixed angle plate application, separate vertical wiring, basket plate and patellar shape-memory fixator applications *(7,14,17,24,30)*. Combining screw fixation with tension band wiring has been reported to be more stable than the anterior tension band wiring in terms of the achieved biomechanical strength *(2,5,6)*. However, there is no available data in the literature comparing the results of these techniques with separate vertical wiring and patellar shape-memory fixator application.

In this biomechanical study, we aimed to compare the ultimate strength of the five different fixation techniques -anterior tension band wiring with K-wires, separate vertical wiring, headless compression screws with anterior tension band wiring, cannulated screws with tension band wiring and memory shape patellar fixator- in patella inferior pole fractures. We hypothesized that the compression screw with anterior tension band wiring would result in better fixation performance than the other fixation techniques.

MATERIALS AND METHODS

Forty-five fresh and skeletally mature, left sided calf knees were obtained from a local slaughterhouse for biomechanical testing. Five knees were excluded from the study due to bone and/or cartilage degeneration, which was identified by macroscopic evaluation. After the harvesting process, each knee was placed in a separate plastic bag for storing at -20 °C.

Each specimen was scanned with computerized tomography (CT) (Toshiba, Aquillon 64, Toshiba Medical Systems, Otowara, Japan) for determination of the bone density. Axial CT images were used to obtain bone density with the OsiriX Imaging Software (Osirix Imaging Software, Osirix, Geneva, Switzerland). The region of interest for measurement was 10 mm proximal to the most distal point of the patella. Hounsfield unit (HU) was used for the evaluation of the bone density. The specimens with the appropriate bone density (mean, 588.8; standard deviation, 94.9; range, 439.4-879.2 HU) which were comparable with the range of human knees (range, 282-1411 HU) were included in the study *(11)*.

All CT measurements were performed twice by the same author (S.D.) one week apart to evaluate the reliability of the BD calculation. The intra-observer reliability for BD calculation (expressed as ICC) was 0.892 (95% confidence interval).

Forty calf knees were randomly divided into 5 groups with 8 samples in each. Randomization was performed using the MedCalc (MedCalc Software bvba, Ostend, Belgium) statistical software. All samples were thawed after 12 hours incubation in physiological saline at room (24°C) temperature prior to using. After thawing, all soft tissues were stripped excluding the patellar and quadriceps tendon. A transverse osteotomy was performed from the distal edge of the articular surface with the oscillating bone saw. A secondary osteotomy originating from the most distal point of the patella, perpendicular to the transverse osteotomy was performed to create a comminuted distal pole patellar fracture model (Fig. 1) *(24, 30)*.

The anterior tension band wiring was used in the first group. In the second group, fixation was performed with two 4.5 mm cannulated screws (AAP implants, Berlin, Germany) sent from distal

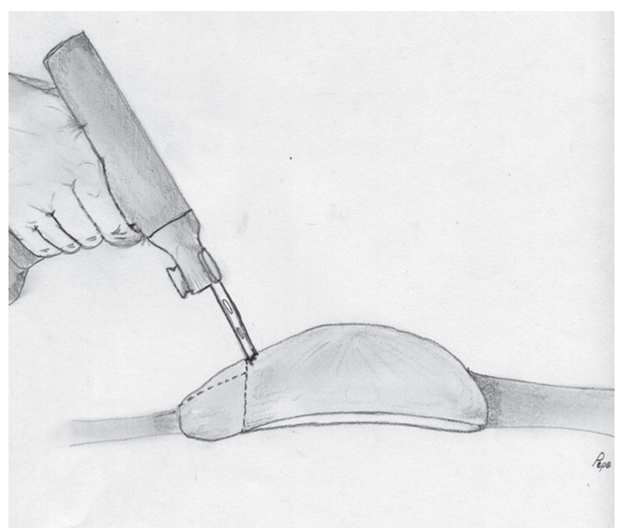

Fig 1.—Creation of distal patellar fracture model

to proximal, which were combined with the anterior tension band wiring. Fracture fragments in the third group were fixed by 2-separated vertical wiring. Fixation with 4.5 mm headless compression screws (Argemed Medical Devices, Ankara, Turkey) with anterior tension band wiring was used in the fourth group. Patellar memory shape fixator (Xin Chang Memory Alloy Tech Co., Ltd.; Shanghai, China) was used to stabilize the fracture fragments in the fifth group. Throughout the study, 2.00 mm K-wires and 1.25 mm cerclage wires were used (Fig 2a-e).

Biomechanical testing was performed with a mechanical testing system (Testometric Micro 500; Testometric Company Ltd., Rochdale, Lancashire, UK). The accuracy of the testing machine was 0.5 N for force measurement and 0.01 mm for measurement of displacement. The maximum payload of the machine was 30 kN and the maximum displacement was 940 mm. Patellar and quadriceps tendons were inserted into testing device via custom made clamps (Fig. 3). The applied load was parallel to the long axis of the patella. It was pre-loaded with 10 N at 1 N/s and this was continued for 5 seconds by the machine. Then the distraction force was applied consistently with the velocity of 5 mm/s *(6)*. Ultimate load (N) and ultimate displacement (mm) were recorded. Ultimate load was defined as the maximum endured load during testing and ultimate displacement (mm) was defined as the distance between the fracture lines at the moment of the ultimate loading. The test was stopped when the fixation was disrupted or the patellar ligament was lacerated *(15)*.

Statistical analysis was performed using the SPSS 20 for Mac (SPSS Inc., Chicago, IL, USA) software. The distribution between the groups was found to be normal with the Kolmogorov-Smirnov test. The test data was seen to be non-homogeneously distributed ($p < 0.05$) in the Levene test. Thus, non-parametric tests were used for the statistical evaluation. Kruskal – Wallis test was used to compare the ultimate loading and ultimate displacement values of the groups. When the Kruskal-Wallis test was statistically significant, the Dunn test was used as a post hoc analysis. A p value <0.05 (2-tailed) was considered to be statistically significant.

Fig. 3.— Biomechanical testing machine setup

RESULTS

The mean ± SD ultimate loading value in all groups was 488.5 ± 195.5 N. The highest and the

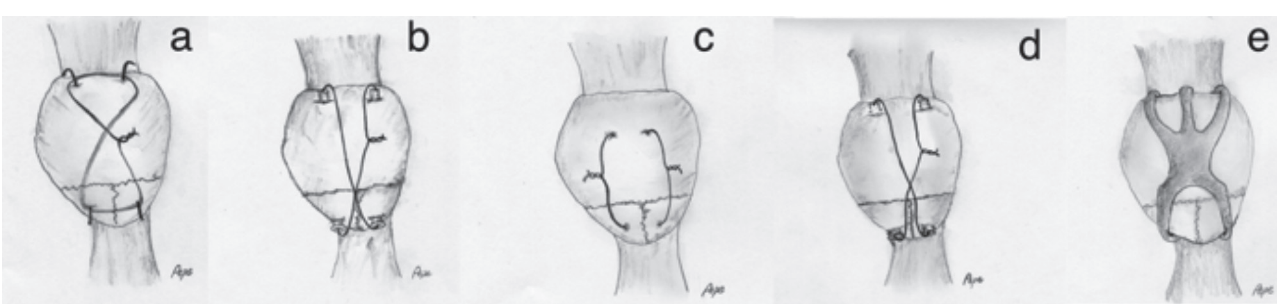

Fig 2.— Schematic drawings of the fixation techniques (a anterior tension band wiring; b cannulated screws with tension band wiring; c separate vertical wiring; d headless compression screw with tension band wiring; e memory shape patellar fixator)

lowest mean ultimate loading values were obtained in the headless compression screw with anterior tension band wiring group (656.9 ± 167.9) and the memory shape patellar fixator group (328.2 ± 37.9) respectively. The headless compression screw with anterior tension band wiring and the cannulated screws with tension band wiring groups obtained significantly higher values compared to the other fixation techniques ($p<0.05$) (Fig 4).

The mean ± SD ultimate elongation value was 26.8 ± 4.3 mm in all groups. The highest and the lowest mean ultimate elongation values were obtained in the separate vertical wiring group

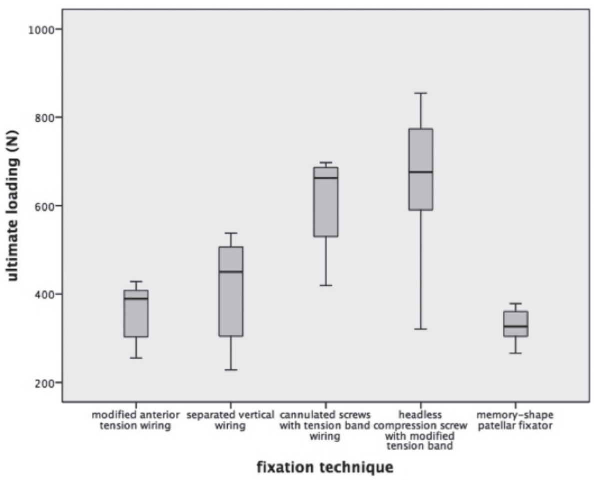

Fig. 4.— Ultimate loading values of the groups: (95% confidence interval)

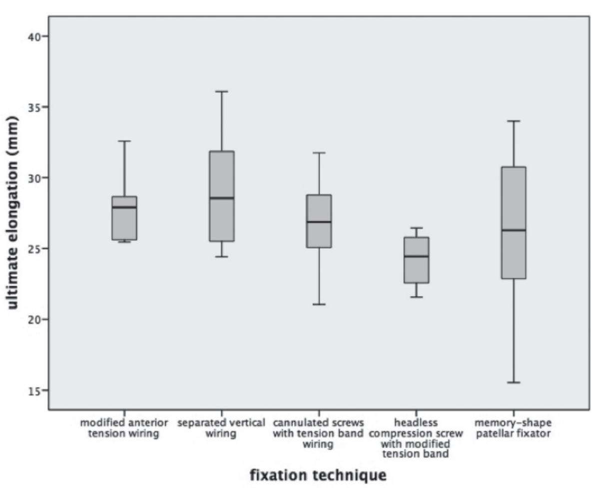

Fig. 5.— Ultimate elongation values of the groups: (95% confidence interval)

(29.0 ± 4.1) and the headless compression screw with anterior tension band wiring group (25.1 ± 3.9) respectively. There was no statistically significant difference between the groups in terms of ultimate elongation values ($p=0.29$) (Fig 5). The biomechanical test results are presented in Tables 1 and 2.

The post-hoc power analysis was performed using the G*Power 3.1 statistical analysis program. Alpha error probability, effect size f value and statistical power of the study (1-beta) were 0.05, 0.706 and 0.93 respectively.

DISCUSSION

The strength of five different fixation methods for patella inferior pole fractures was compared in this biomechanical study, which is the first one in the literature that compares all of these fixation techniques simultaneously. The main finding of this study was that the headless compression screws with anterior tension band wiring and cannulated screws with anterior tension band wiring obtained higher ultimate loading values compared to patellar shape memory fixator and anterior tension band wiring with two K-wires.

There is no consensus regarding the ideal treatment of patella inferior pole fractures *(2,4,15)*. Currently, new surgical approaches for the optimal management are still under development *(18,22,25)*. The aim of such surgical treatment is to achieve stable fixation with restoration of the patellar tendon length, which permits early postoperative motion *(12,24)*. Internal fixation of the distal part by a compression screw with anterior tension band wiring, if possible, or the excision of the small bone fragments with repair of the patellar tendon by transosseous pull-out sutures, in extreme cases, are the preferred surgical options of the current authors. The loss of reduction after fixation is still a major problem *(10,28)*. Early rehabilitation and strong stability are key factors in determining the technique for fixation *(27)*. Tension-band wiring resists tensile forces through the fracture line and converts them to compressive forces at the articular surface during knee flexion *(19)*. The main advantage of this tension band wiring technique

Table I.— Ultimate loading and elongation values

Group	Ultimate Loading (N)	Ultimate Elongation (mm)
Anterior tension band wiring	360.4 ± 66.2 (255,5 - 428,1)	26.9 ± 4.1 (18.3-32.5)
Separate vertical wiring	454.3 ± 205.7 (228,2 - 884,8)	29.0 ± 4.1 (24.2.3-36.0)
Cannulated screws with tension band wiring	642.6 ± 166.0 (419.5 - 963,6)	26.9 ± 4.1 (21.0-31.7)
Headless compression screw with tension band wiring	656.9 ± 167.9 (320.7 – 854.7)	25.1 ± 3.9 (21.5-34.0)
Memory shape patellar fixator	328,2 ± 37.9 (265.8 - 378,4)	26.1 ± 6.0 (15.5-33.9)
All groups	488.5 ± 195.5 (228.2 – 963.6)	26.8 ± 4.3 (15.5-36.0)

Values are expressed as mean ± standard deviation, with the range in parentheses.

is that it allows full weight bearing and early physiotherapy without the necessity for external splint fixation *(7)*. In contrast, the excision of the small bone fragments with the repair of the patellar tendon by transosseous pull-out sutures requires approximately 6 weeks of immobilization of the knee joint, which leads to quadriceps atrophy *(13)*. Thus, the surgical technique used affects the length of immobilization after surgery

The traditional fixation method of the distal patellar fracture is anterior tension band wiring with Kirschner wire. Tension band wiring method base on the principles of translation of the tensile strength in the non-articular surface to the compressive forces in the articular surface *(10)*. Tension band fixation with K wires has potential issues such as implant irritation and thus limitation of movement, loss of reduction and separation of cerclage wire's from the K wire *(7,10,14)*. Literature data presents up to 22% incidence of reduction loss and fracture opening by traditional TBW technique with two parallel K-wires (10). In our study, the patellar memory shape fixator and anterior tension band wiring with K wire had the lowest ultimate loading values.

Cannulated screws with anterior tension band wiring gained popularity in the treatment of patella inferior pole fractures due to easy implantation, achievement of stable fixation, security and minimal tissue irritation *(3,7,8)*. Carpenter et al. reported the superiority of this method to the anterior tension band wiring with Kirschner wires in terms of biomechanical strength *(5)*. Similar results were found in another study comparing the method of anterior tension band wiring with cannulated screw and anterior tension band wiring with two K wires in the transverse patellar fractures *(2)*. In the same study, there was no difference between the cannulated and headless compression screws in terms of the biomechanical strength. Our study revealed that cannulated screws with anterior tension band wiring had biomechanically more stable fixation capability than memory shape patellar fixator and anterior tension band wiring with two K-wires. Our study also showed that there was no difference between cannulated and headless compression screws in terms of the ultimate loading values.

Excision of the distal fragment followed by reattachment of the patellar tendon is one of the traditional treatment methods in patella inferior pole fractures *(1)*. Particularly, this option might be preferred in the presence of excessive fragmentation of the distal pole into small parts, which interferes with fracture fixation *(16)*. Repair of the extensor mechanism can be done with transosseous sutures or anchors *(1)*. This technique

Table 2.— Intergroup comparisons of the ultimate loading values

	P value
Memory shape patellar fixator vs Anterior tension band wiring †	0.48
Memory shape patellar fixator vs Separate vertical wiring †	0.10
Memory shape patellar fixator vs Headless compression screw with tension band wiring†	**<0.001***
Memory shape patellar fixator vs Cannulated screws with tension band wiring †	**<0.001***
Anterior tension band wiring vs Separate vertical wiring †	0.35
Anterior tension band wiring vs Headless compression screw with anterior tension band wiring †	**0.006***
Anterior tension band wiring vs Cannulated screws with tension band wiring †	**0.005***
Separate vertical wiring vs Headless compression screw with tension band wiring †	0.06
Separate vertical wiring vs Cannulated screws with tension band wiring †	0.06
Headless compression screw with tension band wiring vs Cannulated screws with tension band wiring †	0.96

† Represents the greater ultimate loading values
* Represents the statistically significant difference. Dunn test was used for the comparisons between groups.

has many disadvantages such as anterior knee pain and prolonged immobilization resulting in quadriceps atrophy *(14)*. In addition, anchor usage is not recommended in patients with excessive comminuted fragments due to the requirement of strong bone stock *(7)*.

The intraosseous bone wire suture technique was developed as an alternative approach to excision of the bone fragments and later on it was modified by Yang, who described the separate vertical wiring technique *(30)*. Yang detected that the separate vertical wiring technique had higher ultimate load failure than the pull out suture technique in his study evaluating the biomechanics of distal pole excision and transosseous suture techniques. Kim et al. reported that 16 of the 18 patients treated with this method had excellent and the rest had good functional results *(14)*. To the best of our knowledge, this study is the first to compare the separate vertical wiring techniques with other fixation techniques in terms of biomechanical aspects.

Patellar shape memory fixator (PSMF) is another treatment option for comminuted patella inferior pole fractures. In the treatment of patellar fractures, shape-memory alloys alter shape with changes in temperature and they are used as an internal fixator *(10,29)*. Shape memory systems, which are composed of Nickel-Titanium (NiTi) alloys and used in the treatment of patellar fractures, are also used in the treatment of acetabular fractures, humerus shaft fractures, treatment of scaphoid nonunions, vertebral surgery, rib fracture surgeries, cardiovascular surgery and maxillofacial surgery *(10,23,29)*. PSMF allows early knee rehabilitation, relatively short operation time, minimal blood loss, suitable corrosion resistance and acceptable biocompatibility advantages *(10)*. Liu et al. reported that 24 of the 25 patients treated with this method in distal pole fractures had excellent and the other one had good functional outcomes *(17)*. However, this system has potential disadvantages such as implant irritation, implant related cartilage damage and loss of reduction due to bone-implant incompatibility *(29)*. In our study, we obtained lower ultimate loading values in PMSF than the values obtained in cannulated screws with tension band wiring.

The basket plate is another fixation method for the treatment of distal patellar fractures *(13,26)*. Compared with partial patellectomy, it is reported to be related with better joint movement, muscular strength, mobility and pain control advantages*(13,20)*. However, there are some disadvantages such as patellar tendon injury, soft tissue irritation, retaining the position of the basket plate due to considerable slippage, risk of implant failure, patella baja, and prolonged surgical time *(7,10,15)*. Due to its unavailability in local market, it has not been tested in our study.

The patellotibial cerclage technique has potential problems such as difficulty in adjusting the length of the patellar tendon, of the necessity for implant removal and anterior knee pain *(7,30)*. In our study, the patellotibial cerclage technique was not used due to our testing protocol, which inserts the specimen to the testing machine from the patellar tendon instead of the tibia.

In this study we investigated the biomechanical aspects of the currently used fixation techniques of patella inferior pole fractures. To our knowledge this study is the first in the literature comparing the five different fixation techniques synchronously. One of the potential weaknesses of the current study is the utilization of the calf knees instead of human cadavers. However, we performed the testing with the calf knees, which had bone density equivalent to that of human knees and there are available biomechanical studies in the literature related to fracture models of calf knees *(2,6,9)*. Another limitation is the evaluation of the biomechanical behavior of the fixation methods in the extension position. However, the effect of knee flexion may result in different loading patterns on the fixation than the extended position.

In conclusion, cannulated screw with anterior tension band wiring and headless compression screw with anterior tension band wiring obtain a higher ultimate loading values in the surgical treatment of distal patellar fractures compared to patellar shape memory fixator and anterior tension band wiring with K wires.

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