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A novel anatomical patellar plate for transverse patellar fracture – A biomechanical in-vitro study

Ahmet Karakasli [a], Nihat Acar [b,*], Fatih Ertem [c], Ramazan Ozmanevra [a], Mehmet Erduran [a]

[a] Dokuz Eylul University, Faculty of Medicine, Department of Orthopaedics and Traumatology, Izmir, Turkey
[b] Catalca Ilyas Cokay Hospital, Department of Orthopaedics and Traumatology, Istanbul, Turkey
[c] Dokuz Eylul University, Health Science Institute, Department of Biomechanics, Izmir, Turkey

A R T I C L E I N F O

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A B S T R A C T

Objective: The aim of this study was to assess the safety and stability of our novel anatomical patella plate and to compare its stability with tension band-wire technique.

Methods: A total of 12 cadaveric preserved knees (six right and six left patellae) with close patellar size were chosen to form two groups of six samples. Each group received either plate or tension band-wiring fixation for an experimentally created patella fracture. Cyclic load of an average of 350 N was applied for all specimens and after accomplishing 50 cycles the displacements of all fracture edges were recorded.

Results: After completing 50 cycles in each group, the average fracture edges displacement measured in the plate group was 1.98 ± 0.299 mm, whereas the average fracture edges displacement measured in the tension band-wire group was 2.85 ± 0.768 mm ($p = 0.016$).

Conclusion: In the operative treatment of displaced transverse patellar fractures, the strength of fixation obtained by titanium curved plates is highly stronger when compared to the fixation with a tension band-wire technique. Fixation with titanium curved plates provides satisfactory stability at the fracture site which allow withstanding the cyclic loads during the postoperative rehabilitation.

Introduction

Transverse patella fractures are commonly encountered in trauma surgery, open reduction and internal fixation are considered the gold standard treatment modality that could permit early knee motion and immediate rehabilitation.[1,2] Many fixation methods had been defined and compared to each other's in many clinical and biomechanical studies.[3–5] However, the tension band fixation method is still the most commonly used technique in patellar fracture fixation.[5,6] K-wire migration, tension band failure and surrounding soft tissue irritation are very common complications encountered in 22–30% of all cases. Consequently implant removal revision surgery may be required in 65% of cases.[7–9]

Inspired by the success of inter-fragmentary lag screw implants in various clinical applications, we introduced a double anatomical curved-plates specifically designed for fixation of patellar transverse fractures.

The goal of this study is to assess the biomechanical properties of the novel anatomical patellar plate and compare it to the most widely applied internal fixation devices, i.e. tension band-wire technique, in cadaveric patella fractures.

Material and method

After obtaining the approval of the ethical committee, resembling to previous studies,[10,11] out of 38 cadavers, 12 knees (six right and six left knees) with close patellar size were selected from our anatomy department for biomechanical examination. They were preserved in formalin based dilution for at less than 1 year. Donors were 10 men and 2 women. The selected 12 knees were divided into two groups (the right patellae were used for the titanium plate group and the left patellae were used for the tension band-wire group), each group contains six cadavers. The soft tissue was dissected leaving the knee joint capsule, ligaments, medial and lateral retinaculum and extensor mechanism intact. All patellae were horizontally osteotomized by an electrical saw to obtain a transverse patellar fracture before performing the fixation.

* Corresponding author. Catalca Ilyas Cokay Hospital, Department of Orthopaedics and Traumatology, 34540, Catalca, Istanbul, Turkey.
E-mail address: zenanacar@gmail.com (N. Acar).

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K-wire tension band technique

The classical modified anterior tension wire technique is performed with two 2.0 mm stainless steel K-wires, which were drilled into the patellae parallel to each other and perpendicular to the osteotomy line. A 1.25 mm stainless steel wire loop was inserted around the protruding superior and inferior ends of the K-wires, to form a figure-eight on the anterior surface of the patella. The wires were twisted manually and tightened until a stiff and stable fixation was achieved (Fig. 1).

Anatomical curved-plate technique

The 3.5 mm titanium anatomical curved plate (TIPSAN CO. Company, Izmir-Turkey) has a 1 mm body thickness, 1 cm body width and two hook-like blocks at both ends. The anatomical patellar plate is available in eight variable lengths ranging from 25 mm to 60 mm, which were specifically designed to fit on the patellar anterior surface. One hole is present on each hook-like end blocks of the plate, the proximal hole of the plate is not threaded, designed to receive the screw head, whereas the distal hole is threaded to receive the threaded part of the screw. The plate is prebent in a semicircular shape to anatomically fit the anterior patellar surface. When the screw is introduced through the proximal non-threaded block, it passes to the distal threaded block, where the screw can exert its lag effect. The flexible nature of the plate allows lag effect compression of the screw which happens between the head of the screw settled in the non-threaded proximal block and the threaded distal block. Additionally it maintains the reduction by buttressing the anterior surface of the patella against deforming forces. After reduction of the transverse fracture, two 1.6 mm guide K-wires are placed parallel to each other's to stabilize the fracture. A 3.2 mm canulated drill pit is used to open the tract for screw entrance, then a 3.5 mm tap is used to prepare the tract for lag screw insertion. After getting the appropriate plate and screw sizes, the proximal part of the plate is placed through the guide wire, whereas the distal part is inserted through the distal part of the guide wire to rest on the anterior surface of the patella to prepare for screw insertion (Fig. 2). A 1/3 threaded canulated cancellous 3.5 mm screw can then be advanced through the guide wire till it meets the threaded distal end of the plate to exert it's inter-fragmentary compression (Fig. 3).

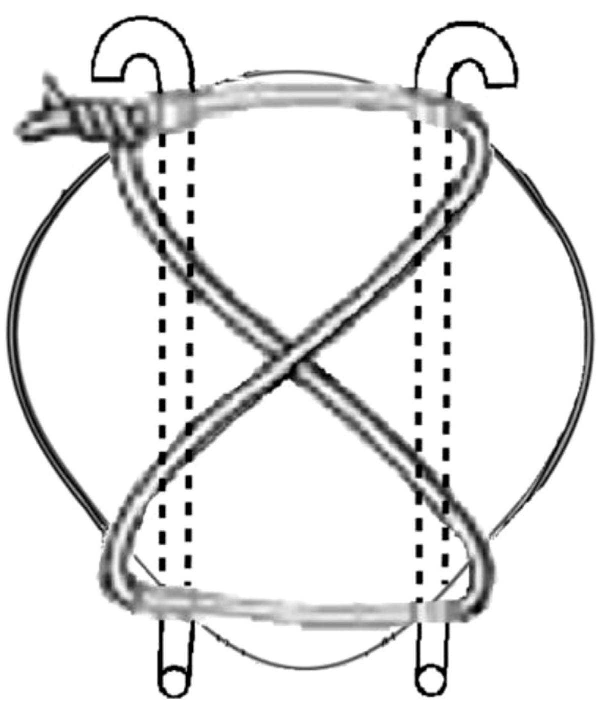

Fig. 1. The classical modified anterior tension band-wire technique.

Mechanical testing

All samples were tested by exerting a knee motion from full extension to 90° flexion by applying traction to the quadriceps tendon (Fig. 4). Due to the different contracture conditions between the cadaveric knee joints, it was not possible to use the same traction load to obtain a full extension in each joint. The fracture gap before starting the test was 0 mm for all specimens and this indicates a successful anatomic reduction of the patella fractures. The testing protocol composed of two parts, the first part consisted of a multiple cyclic loading, composed of 50 cycles for each sample, whereas the second part consisted of loading to failure trial. In each sample a 70 N preload was applied to the steel-sling in order to keep it completely tensioned. A tractional load was applied in each cycle with a speed of 200 mm/min till a full extension takes place. Cyclic loading composed of 50 cycles between 275 N and 420 N at a speed of 200 mm/min. At the end of the 50 cycles the fracture edges displacement in each sample was recorded.

For the statistical analysis the Man Whitney-U test was conducted. Statistical significance level was set at $p = 0.05$.

Results

An average load of 350 N was applied to the quadriceps tendon to obtain a full extension in all knees, the maximum load applied was 420 N, whereas the minimum load applied was 275 N. The load versus displacement for the two techniques were shown in Fig. 5 (Fig. 5).

The fracture gap measurements increased with the load applied up to a point and subsequently decreased. The peak in the fracture gap occurred at the middle of the range of flexion.

In order to obtain the same range of motion (from 90° flexion to full extension) in every sample every test cycle was controlled by the crossbar's travel distance required to simulate the desired range-of-motion. In spite of the anatomical differences between the specimens, the required average load in the plate group was 354.16 N and in the tension band-wire group was 345.83 N, they did not differ significantly ($p = 0.84$) (Table 1). In the first part of the trial, after completing the 50 cycle in each group, the average fracture edges displacement measured at the middle range of flexion in the plate group was 1.98 ± 0.299 mm, whereas the average fracture edges displacement measured at the middle range of flexion in the tension band-wire group was 2.85 ± 0.768 which was statistically significant than the first group with a P value of 0.016.

In the second part of the trial, gradual loading to failure was applied to both groups. In the tension band-wire group only two cadaveric samples completed 100 cycles. Four cadaveric knees failed before completing the 100 cycles at an average of 78 cycles with a minimum load of 480 N and a maximum load of 650 N. The remaining two cadaveric samples which completed the 100 cycles, failed at 685 N and 720 N. Whereas in the plate group, implant failure took place in one cadaveric sample after 85 cycles with a load of 570 N. Two cadaveric samples failure took place after 100 cycles with loads of 650 N and 735 N, three samples completed the 100 cycles and further loading up to 800–850 N leaded to a rupture of the quadriceps tendon at the steel-sling apparatus (Table 2). The results of loading to failure were not comparable due to the rupture of the quadriceps tendons.

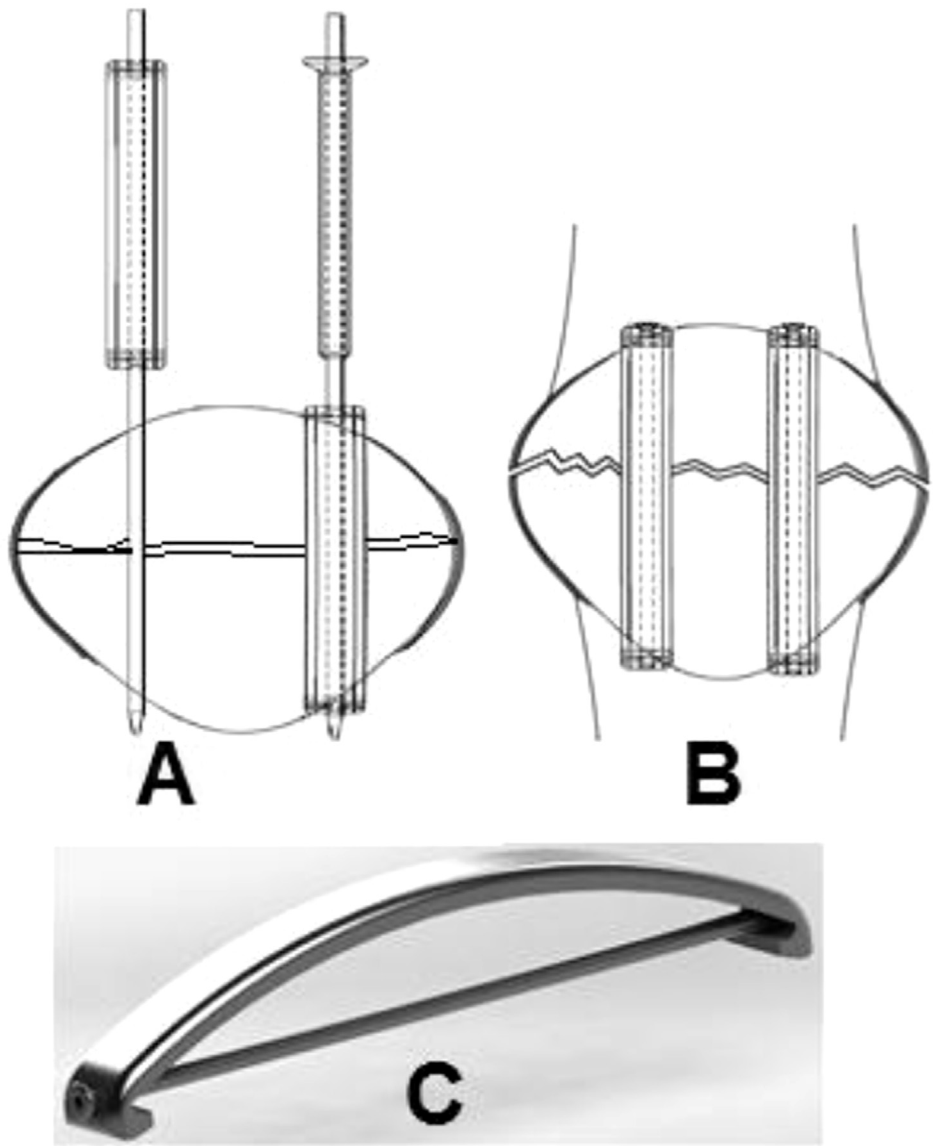

Fig. 2. The technique of anatomical plate application, (A) K-wire insertion after anatomical reduction, (B) Replacement of the anatomical patellar plate through the K-wires, then placement of the canulated cortical screw through the K-wire. (C) The anatomical patellar plate.

Fig. 3. (A) The anatomical patellar plate with a two hook-like edges. (B) Plate application on cadaveric patella sample after anatomical reduction.

Discussion

The tension band-wire fixation method is a widely accepted technique for all types of patella fractures.[7,9] However, many reports documented that tension wire system may not offer strong compression and may lead later on to a fracture displacement during active knee movements postoperatively.[1,12,13] Many biomechanical studies had investigated and compared variant fixation methods that can be used for patella fractures.[13,14] The combination of cannulated lag screws with anterior tension band has been used as a common alternative, since in some biomechanical studies it showed higher load-bearing capacity and offered greater initial stability.[1,14] The applied lag screws and tension bands apply a strong compression at the fracture site during knee flexion and extension, even during episodes of higher load-bearing capacity,[7] however, tension wires may lose their tension in vivo due to soft tissue

Fig. 4. All samples were tested by exerting a knee motion from 90° flexion to full extension by applying traction to the quadriceps tendon through a steel-sling.

atrophy, which could lead to secondary fracture gap dehiscence.[7,14] Maquet,[15] in a letter to the editor, remarked that in his experience, the tension band principle worked even without addition of interfragmentary screws or k-wires. He proposed that placement of screws through the fragments would diminish the tension band effect such that simultaneous use of inter-fragmentary fixation and the tension band effect would be contradictory. In order to avoid wires usage the idea of anterior curved plate emerged to replace the tension wire use and to offer a stronger and stable fixation that can withstand active knee flexion, extension and high cyclic loads.

Several attempts have been already made to fix fractures of the patella with plates like Basket plates, which have been successfully used in clinical practice for specially fractures of the distal pole. However, they are inherently unstable and suitable only for distal pole fractures of the patella.[16] The angle-stable plate system have demonstrated excellent biomechanical properties and superior stability,[17,18] however such a plate design, since it is applied on both sides of the patella, may disturb the retinacular system and negatively affect the blood supply of the patella. In addition to that, angled plate system contains large number of screws which most of the time do not cross the fracture line perpendicularly to exert the optimum inter-fragmentary effect.

The novel anatomical patellar plate is designed to fix transverse patellar fractures which make up the majority of patellar fractures 34%.[19] The anatomical plate can be manipulated easily to allow a perpendicular introduction of the lag screws on the fracture line, which in term permits an optimum inter-fragmentary compression. However, the novel plate design makes it not suitable to be used in comminuted fractures and detached small fragments.

In this study, we tested the initial fixation properties of two different methods that can be used for internal fixation of transverse patella fractures. We aimed to compare the biomechanical characteristics of the two fixation techniques.

As an alternative to stainless steel wire, titanium curved plates offer several advantages when compared with other materials.[6,8] Titanium curved plates are mechanically superior to other implants and wires in vitro, combining properties of high stiffness and high ultimate tensile strength. At the same time, titanium curved plates appear to maintain its mechanical characteristics in vivo. Titanium curved plates are biocompatible and has a minimal tissue reaction compared to other metals.[8,9] Recent works has demonstrated that postoperative symptoms and complications related to implants after surgical treatment of patella fractures are potentially less likely with the use of titanium plates.[6,8,9]

Although the novel anatomical plate is still not used in current practice, however, in vitro-biomechanical conditions it offered a stable compression when compared to the traditional tension band-wire technique. The curved plate with the inter-fragmentary screws offer a stable strong fixation for patella transverse fractures that may allow early and safe postoperative rehabilitation.

Some studies demonstrated that, formalin alters the mechanical properties of bone tissue.[20] However, other studies showed similar mechanical properties and elastic energy absorption for formalin-fixed and fresh-frozen bone, whereas plastic energy absorption is highly decreased for formalin-fixed samples.[21,22] It is documented

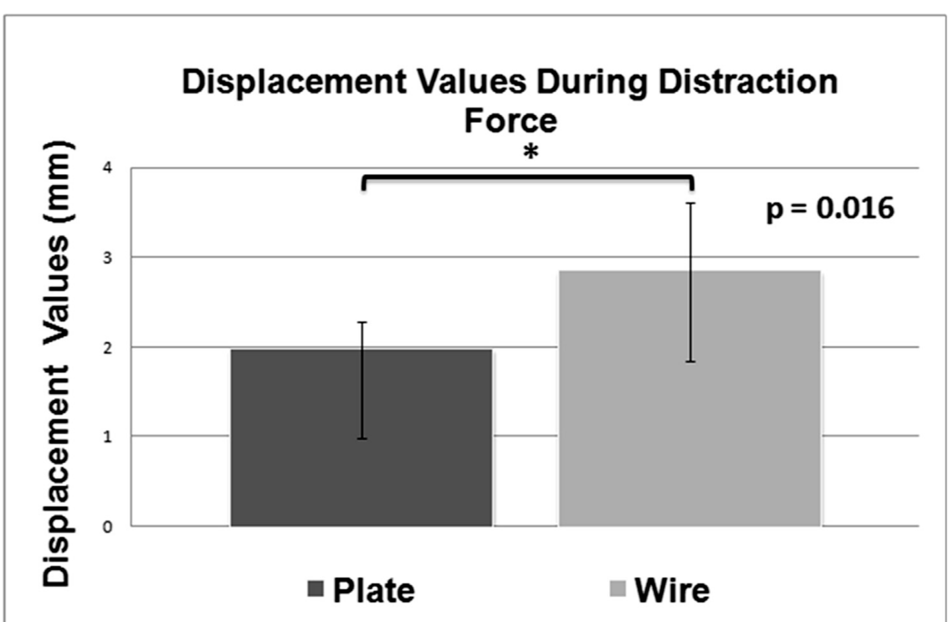

Fig. 5. The load versus displacement for the two techniques.

Table 1
A demonstration of the loads required for full extension in the two groups and the displacement of the fracture gap after 50 cycles of loading.

	Load applied for full extension (plate group) (N)	Plate fixation fracture displacement in (mm)	Load applied for full extension (band group) (N)	Tension band-wire fixation fracture Displacement in (mm)	P value
Cadaver (1)	390	1.52	360	2.51	
Cadaver (2)	420	1.84	315	1.98	
Cadaver (3)	290	2.01	385	3.26	
Cadaver (4)	305	2.24	410	2.41	
Cadaver (5)	370	1.92	275	2.78	
Cadaver (6)	350	2.36	330	4.16	
Average displacement (mm)		1.98 ± 0.299		2.85 ± 0.768	0.016
Average load (N)	354.16		345.83		0.84

Table 2
Results of the loading to failure trial in the two groups.

Loading to failure trial	Tension band-wire group (n = 8)	Plate group (n = 8)
Specimens did not complete 100 cycles (n)	4	1
Specimens completed 100 cycles (n)	2	5
Minimal load of failure (Newton)	480 N	570 N
Maximum load of failure (Newton)	720 N	850 N
Rupture of the quadriceps tendon at the steel-sling apparatus due to extreme force (n)	0	3

that, as a reactive electrophilic chemical, formalin usually react by cross-linking functional groups in tissue proteins, polysaccharides, and nucleic acid and this in term creates an irreversible methylene crosslinks which disturbs the mechanical properties of the muscles,[23] and this led in the quadriceps muscle rupture in the second part of the trial. The work with formalin-embalmed samples is considered always a limitation. However, working with formalin-embalmed cadavers should be accepted as fresh frozen samples could not be available in adequate numbers.

We have several weakness regarding our work, the cadaveric samples were small in number and not fresh, which in term affected the loading process required to obtain a full extension in each sample. Working with preserved cadaveric specimens affected the soft tissue tensile strength which resulted in tendon ruptures, which in term didn't allow loading to failure comparison between the two groups.

Conclusions

The findings of this study show that, the biomechanical properties of anatomical patellar plate are superior to the traditional tension band-wire technique in transverse patella fractures. Fixation with titanium curved plates provides satisfactory stability at the fracture site to withstand cyclic loads which maybe encountered during the postoperative rehabilitation. Titanium curved plates are a biomechanically suitable alternative to tension band-wire technique for fixation of transverse patella fractures.

Conflicts of interest

All authors declare that, there is no conflict of interest regarding this work.

Ethical approval

Hospital ethics of research committee reference number is 2014/14-05.

References

1. Carpenter JE, Kasman RA, Patel N, Lee ML, Goldstein SA. Biomechanical evaluation of current patella fracture fixation techniques. *J Orthop Trauma*. 1997 Jul;11(5):351–356.
2. Scilaris TA, Grantham JL, Prayson MJ, et al. Biomechanical comparison of fixation methods in transverse patella fractures. *J Orthop Trauma*. 1998 Jun–Jul;12(5):356–359.
3. Baran O, Manisali M, Cecen B. Anatomical and biomechanical evaluation of the tension band technique in patellar fractures. *Int Orthop*. 2009 Aug;33(4):1113–1117.
4. Lefaivre KA, O'Brien PJ, Broekhuyse HM, Guy P, Blachut PA. Modified tension band technique for patella fractures. *Orthop Traumatol Surg Res*. 2010 Sep;96(5):579–582.
5. Muller ME, Allgower M, Schneider R, Willenegger H. *Manual of Internal Fixation: Techniques Recommended by the AO Group*. 2nd ed. Berlin: Springer-Verlag; 1979:248–253.
6. Weber MJ, Janecki CJ, McLeod P, Nelson CL, Thompson JA. Efficacy of various forms of fixation of transverse fractures of the patella. *J Bone Jt Surg Am*. 1980 Mar;62(2):215–220.
7. Hung LK, Chan KM, Chow YN, Leung PC. Fractured patella: operative treatment using the tension band principle. *Injury*. 1985 Mar;16(5):343–347.
8. Torchia ME, Lewallen DG. Open fractures of the patella. *J Orthop Trauma*. 1996 Jan;10(6):403–409.
9. Wild M, Eichler C, Thelen S, Jungbluth P, Windolf J, Hakimi M. Fixed-angle plate osteosynthesis of the patella—an alternative to tension wiring? *Clin Biomech (Bristol Avon)*. 2010 May;25(4):341–347.
10. Thelen S, Schneppendahl J, Jopen E, et al. Biomechanical cadaver testing of a fixed-angle plate in comparison to tension wiring and screw fixation in transverse patella fractures. *Injury*. 2012 Aug;43(8):1290–1295.
11. Karakasli A, Acar N, Basci O, Karaarslan A, Erduran M, Kaya E. Iatrogenic lateral meniscus anterior horn injury in different tibial tunnel placement techniques in ACL reconstruction surgery – a cadaveric study. *Acta Orthop Traumatol Turc*. 2016 Oct;50(5):514–518.
12. Fortis AP, Milis Z, Kostopoulos V, et al. Experimental investigation of the tension band in fractures of the patella. *Injury*. 2002 Jul;33(6):489–493.
13. Burvant JG, Thomas KA, Alexander R, Harris MB. Evaluation of methods of internal fixation of transverse patella fractures: a biomechanical study. *J Orthop Trauma*. 1994;8(2):147–153.
14. Benjamin J, Bried J, Dohm M, McMurtry M. Biomechanical evaluation of various forms of fixation of transverse patellar fractures. *J Orthop Trauma*. 1987;1(3):219–222.
15. Maquet P. Fractures of the patella. *J Bone Joint Surg Am*. 1994 Oct;76A(10):1594.
16. Matejcic A, Smiljanic B, Bekavac-Beslin M, Iedinsky M, Puljiz Z. The basket plate in the osteosynthesis of comminuted fractures of distal pole of the patella. *Injury*. 2006 Jun;37(6):525–530.
17. Egol Ka, Kubiak En, Fulkerson E, Kummer FJ, Koval KJ. Biomechanics of locked plates and screws. *J Orthop trauma*. 2004 Sep;18(8):488–493.
18. Haidukewych GJ. Innovations in locking plate technology. *J Am Acad Orthop Surg*. 2004 Jul–Aug;12(4):205–212.
19. Bostrom A. Fracture of the patella. A study of 422 patellar fractures. *Acta Orthop Scand Suppl*. 1972;143:1–80.
20. Comert A, Kokat AM, Akkocaoglu M, Tekdemir I, Akca K, Cehreli MC. Fresh-frozen vs. embalmed bone: is it possible to use formalin-fixed human bone for biomechanical experiments on implants? *Clin Oral Implants Res*. 2009 May;20(5):521–525.
21. Unger S, Blauth M, Schmoelz W. Effects of three different preservation methods on the mechanical properties of human and bovine cortical bone. *Bone*. 2010 Dec;47(6):1048–1053.
22. Van Haaren EH, van der Zwaard BC, van der Veen AJ, Heyligers IC, Wuisman PI, Smit TH. Effect of long-term preservation on the mechanical properties of cortical bone in goats. *Acta Orthop*. 2008 Oct;79(5):708–716.
23. Fox CH, Johnson FB, Whiting J, Roller PP. Formaldehyde fixation. *J Histochem Cytochem*. 1985 Aug;33(8):845–853.