DOI: http://dx.doi.org/10.1590/1413-785220182606190551

SPRING PLATES IN DISTAL RADIO FRACTURES: "*IN VITRO*" MECHANICAL PROPERTIES

PLACA MOLA NAS FRATURAS DISTAIS DO RADIO – PROPRIEDADES MECÂNICAS "*IN VITRO*"

Ana Lécia Carneiro Leão de Araújo Lima[1], *Alex Eduardo Calderon Irusta*[1], *Alexandre Martins Portelinha*[2], *Lauro Tofollo*[1], *Antonio Carlos Shimano*[3], *Amanda Favaro Cagnolati*[1], *Nilton Mazzer*[1], *Claudio Henrique Barbieri*[1]

1. Hand Surgery Program, Hospital das Clínicas de Ribeirão Preto, Ribeirão Preto, SP, Brazil.
2. Orthopedics and Traumatology Program, Hospital das Clínicas de Ribeirão Preto, Ribeirão Preto, SP, Brazil.
3. Departamento de Biomecânica, Medicina e Reabilitação do Aparelho Locomotor (DBMRAL), Hospital das Clínicas de Ribeirão Preto, Ribeirão Preto, SP, Brazil.

ABSTRACT

Background: Distal radius fractures are one of the most common orthopedic injuries and appear in various patterns. Volar plate fixation is not always considered the gold standard treatment. Objective: To measure the resistance of a fragment-specific fixation assembly model obtained by plate fixation associated with different K-wire sizes. Method: In this original experimental study, novel II, axial compression of bone materials was tested. Results: In both groups, the maximum force supported by the fixation method in our study was ten times greater than the physiological load to which the wrist was subjected under physiological conditions. Discussion: In this study, we obtained encouraging results when compared to results reported in the literature. Our study showed that our bone fixating system was mechanically adequate for articular fractures of the intermediate column of the radius (Melone classification). The results were similar or superior to the results of pressure resistance and stiffness when data from the literature was used as reference. Conclusion: The proposed fixation method demonstrated adequate resistance for fixation of the intermediate column of the distal radius. Increasing K wire size caused augmented resistance of the fixation. ***Level of Evidence II, Prospective comparative study.***

Keywords: Fractures fixation. Frthopedics. Clinical trial.

RESUMO

Introdução: A fratura da extremidade distal do rádio é uma afecção frequente, com variedade de apresentações e nem sempre são passíveis de fixação volar única. Objetivo: Quantificar a resistência obtida no modelo experimental de fixação do fragmento específico, utilizando fio de Kirschner pré moldado, associado a fixação proximal com placa e parafuso. Métodos: Estudo experimental original, nível II, no qual foram realizados ensaios mecânicos com objetivo de avaliar a resistência a compressão axial. Resultados: Os valores de força máxima suportada pelo método de fixação foram pelo menos 10x maiores do que a carga fisiológica a qual o punho é submetido. Discussão: A fixação do tipo fragmento específico vem se mostrando útil e segura, permitindo uma mobilidade precoce segura. Os resultados analisados demonstraram que a montagem proposta em nosso estudo foi mecanicamente adequada para a fixação das fraturas articulares da borda volar ulnar (classificação de Melone) do rádio, tendo resultados semelhantes ou superiores quando comparados a literatura, avaliando a rigidez e a pressão o qual o sistema foi submetido. Conclusão: O método de fixação proposto demonstrou resistência adequada para fixação das fraturas da coluna intermediária do rádio. O aumento da espessura do fio provocou um aumento da força resistida da montagem. ***Nível de Evidência II, Estudo prospectivo comparativo.***

Descritores: *Fixação de fratura. Ortopedia. Ensaio clínico.*

Citation: Lima ALCLA, Irusta AEC, Portelinha AM, Tofollo L, Shimano AC, Cagnolati AF, Mazzer N, Barbieri CH. Spring plates in distal radio fractures: "*in vitro*" mechanical properties. Acta Ortop Bras. [online]. 2018;26(6):423-7. Available from URL: http://www.scielo.br/aob.

INTRODUCTION

Distal radius fracture is the most common fracture in patients presenting to emergency units, and its incidence is approximately 640 thousand per year in the USA.[1] The incidence shows a bimodal distribution, affecting predominantly young males and elderly females.[2] Approximately 57% to 66% of distal radius fractures are extra-articular, followed by complete articular fractures that affect 25% to 35% of patients and partial articular fractures that affect 9% to 16% of patients.[3]

The most frequent mechanism of injuries reported are falls from the individual's height onto an outstretched hand or high-energy trauma.[3] Fernandez and Jupiter[2] described a classification for distal radius fractures according to the mechanism of injury, subdivided into five types of injury. The AO classification considers the direction of the fracture line and the number of fragments. It is a complex and detailed classification but does not correlate with treatment options. Robert Medoff has developed a classification for intra-articular fractures based on recognition of five main fragments: the radial styloid, dorsal

All authors declare no potential conflict of interest related to this article.

Study conducted at the Hospital das Clínicas Medical School, USP, Ribeirão Preto, SP, Brazil.
Correspondence: Ana Lécia C L A Lima, Rua Martins Ribeiro, 257 Hipódromo. Recife, PE, Brazil. 51020-090. lecialima@gmail.com

Article received in 01/21/2018, approved in 08/22/2018.

wall, impacted articular fragments, dorsal-ulnar corner (die-punch fragment), and volar rim fragments.[2] These fragments may occur in isolation or in combination. For a better understanding of the fracture and surgical planning, the orthopedist must also identify the direction of deviation and the mechanism of injury. This classification is used to guide treatment in that it facilitates the choice of modular components for treating the specific fragments.[2]

Numerous options have been described for the treatment of distal radius fractures, including conservative treatment and external and internal fixations. The choice of treatment depends on the clinical profile of the patients, their demand, and the type of fracture.[3] Anatomic reduction, stable fixation, and early mobilization are the primary objectives of treatment of long-standing, complex intra-articular distal radius fractures[4,5]. The main method of internal fixation used is the locked volar plate. This method is able to satisfactorily fix articular distal radius fracture to a large degree, providing stability and facilitating early mobility. However, the surgical approach is usually not specific and complications such as irritation and tendon rupture, implant release, and secondary loss of reduction may occur.[6-9] In addition to the complications above, locked materials are costly and largely unavailable in orthopedic services in our country. The advent of computed tomography with 3D reconstruction has provided a better understanding of intra-articular distal radius fractures. This feature has allowed more efficient preoperative planning by the surgeons and more accurately define the best approach for each fracture.[10] According to Wolfe[11] there are four situations in which the isolated use of the volar plate will lead to failure: (1) complex multifragmentary disruption of the articular surface caused by shear or compressive forces; (2) fracture-dislocations (shear fractures) of the wrist; (3) carpal, radiocarpal or radioulnar instability; and (4) complex fractures with substantial metaphyseal-diaphyseal extension. In these cases, a more thorough and individualized approach is necessary to achieve better results.

Medoff and Kopylov endorsed the concept of fragment-specific fixation in distal radius fractures by individually stabilizing each fragment using a hybrid technique with plates and Kirschner (K)-wires.[12] The concept of fragment-specific fixation evolved with the perception that a single implant was not sufficient to properly fix all fracture configurations.[13] Mechanical tests demonstrated that rigid fixation of each fragment was necessary to achieve adequate stability to permit early mobilization.[14,15] Each fragment was fixed individually with low profile implants or clips, which lessened contact with adjacent tendons and thus avoided complications described in other models; it also allowed a personalized approach for each fracture, permitted the use of mini-incisions, avoided unnecessary exposures, reduced surgical aggression, and ensured stability of each fragment, ultimately allowing early mobilization.[5, 16-20]

Therefore, the objective of the present study was to evaluate the rigidity of assemblies obtained using 1.0-mm and 1.2-mm K-wires, fixed with 3.5 mm screws and 3-hole 1/3 plates, following the principles of specific fragment characteristics. A viable assembly is proposed using low cost materials widely available in orthopedics and traumatology services.

MATERIAL AND METHODS

As this was a purely biomechanical study, not involving living specimens, the study did not require ethics committee approval.

Specimens

Anatomic synthetic bones such as right radius (model 3011) produced by the National Bone Industry were used as test samples. The radius bones were cut transversely 12 cm from the distal articular surface inserted in an acrylic block (colorless self-polymerizing acrylic – JET) suitable for the test machine. A demarcation was created to simulate the volar rim fragment, as described by Melone[2]. The fragment originating from the osteotomy had an area of approximately 1.5 cm^2. Two holes were made 7 mm from each center, with an orientation perpendicular to the proposed fracture line. Samples were divided into 2 groups: in Group 1 (1.0-mm assembly) the radius bones were drilled with a 1.2 mm drill bit. In Group 2 (1.2-mm assembly) the radius bones were drilled with a 1.5 mm drill bit. After the perforation, osteotomies were performed according to previously established protocol.

All cuts, osteotomies, and perforations were performed at the Precision Laboratory of the USP - Ribeirão Preto Campus.

Implants

The implants were prepared from pre-molding of 1.0-mm and 1.2-mm K-wires according to the conformations shown in Figure 1. The fractures were fixed using molded K-wires inserted into pre-established holes and fixed proximally with plate and screws, the final configuration thus forming a three-point fixation (Figures 2 and 3).

Experimental Groups

Destructive axial compression tests were performed for the two experimental groups comprising four specimens each. Group 1 consisted of assemblies using K-wires having a 1.0-mm diameter and Group 2 consisted assemblies using K-wires of 1.2 mm diameter.

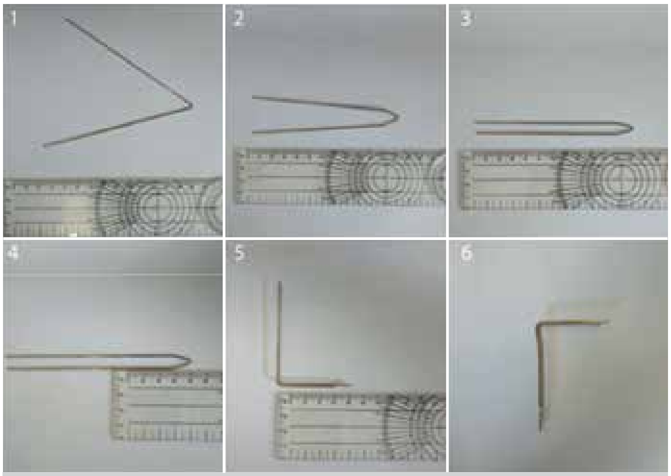

Figure 1. Molding of 1.0-mm and 1.2-mm Kirschner (K)-wires.

Figure 2. Examples of Kirschner (K)-wires inserted into pre-established holes.

Figure 3. Examples of final fixation with the 3-point configuration.

Mechanical tests

The tests were carried out using a universal test machine (UTM), EMIC DL10000 (INSTRON EMIC, São José dos Pinhais, PR, 83020, Brazil) available at the Bioengineering Laboratory of the Ribeirão Preto Medical School (USP), connected to a computer equipped with software controlling the applied loads and storage and interpretation of the obtained data. Both the control condition and the measurements of the applied loads and the deformations produced were carried out using the TESC v. 1.10 program.

Destructive tests (maximum load) were performed on the UTM, with axial compression. Initially three pilot runs were carried out for standardization; the results of these runs were not included in the analysis. Eight destructive tests were performed, four for each group. The obtained values were analyzed and submitted to statistical analysis. The maximum force at which the material could be subjected without rupture and the rigidity of the assembly were analyzed.

RESULTS

Statistical analysis was performed separately for the 4 samples from Group 1 (1.2-mm K-wires) and for the 4 samples from Group 2 (1.0-mm K-wires). Group 1 assembly presented a mean maximum force of 660.8 N (± 28.23) and mean rigidity of 210 N/mm (± 20.98). Group 2 (1-mm) assembly exhibited a mean maximum force of 512.1 N (± 59.03) and mean rigidity of 258.0 N/mm (± 44.58). Other descriptive variables such as minimum, median, maximum, mean, standard deviation and coefficient of variation of both maximum force and rigidity are reported in Tables 1 and 2 and also in Figures 4 and 5.

Comparison of Group 1 and 2 (1.2-mm × 1-mm) assemblies

Maximum Force

To compare force and rigidity variables between the groups, the student t-test was used. A statistically significant difference was observed in the maximum force variable, between the 1.2-mm and 1-mm groups (p = 0.003) (Figure 6).

Increasing the diameter of the K-wires used in the assembly resulted in a higher load carrying capacity. The 1.2-mm group was able to withstand loads 29% higher than the 1.0-mm group, on average.

The values of the maximum force supported by the assemblies in our tests in both groups were higher than the physiological load to which the wrist is subjected by muscle tension, which is 50 N.[21,22] The assembly in which the 1.2-mm K-wires were used was able to withstand up to an average 12-fold higher load than

Table 1. Group 1.2-mm Assembly. Descriptive variables of the test samples.

	Maximum force (N)	Rigidity (N.mm)
Number of samples	4	4
Minimum	621.9	179.8
Median	660.8	218.8
Maximum	690.2	224.1
Mean	658.4	210.4
Standard Deviation	28.23	20.98
Coefficient of variation	4.29%	9.97%

Table 2. Group 1-mm Assembly. Descriptive variables of the test samples.

	Maximum force (N)	Rigidity (N.mm)
Number of samples	4	4
Minimum	423.4	210.2
Median	512.1	258.0
Maximum	564.9	304.6
Mean	503.1	257.7
Standard Deviation	59.03	44.58
Coefficient of variation	11.73%	17.30%

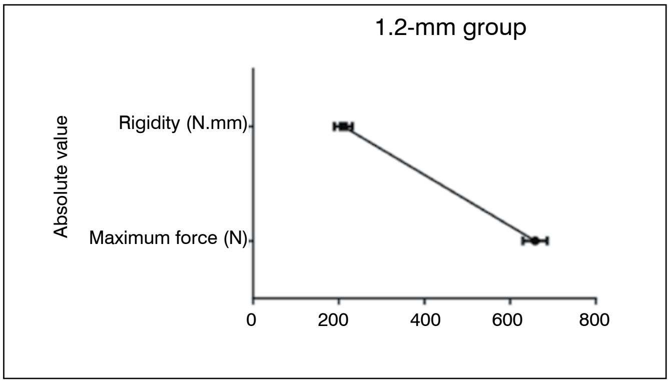

Figure 4. Graphical representation of the absolute values of the variables maximum force and rigidity of the 1.2-mm group.

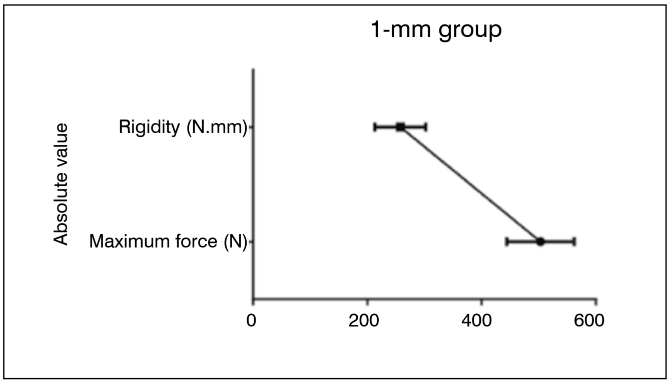

Figure 5. Graphical representation of the absolute values of the variables maximum force and rigidity of the 1-mm group.

that exposed to physiologically. The Group using the 1.0-mm K-wires supported on average about a 10-fold higher load than under physiological conditions.

Similar differences between the groups were not observed on evaluation of the rigidity variable, p = 0.103 (Figure 7). Increasing the thickness of the K-wire did not result in a significant increase in the assembly's rigidity.

DISCUSSION

The clinical usefulness and versatility of fragment-specific fixations lies in the ability to anatomically adjust the rigidity of the fractures that cannot be properly fixed using a single implant or with external fixation.[5,23,24]

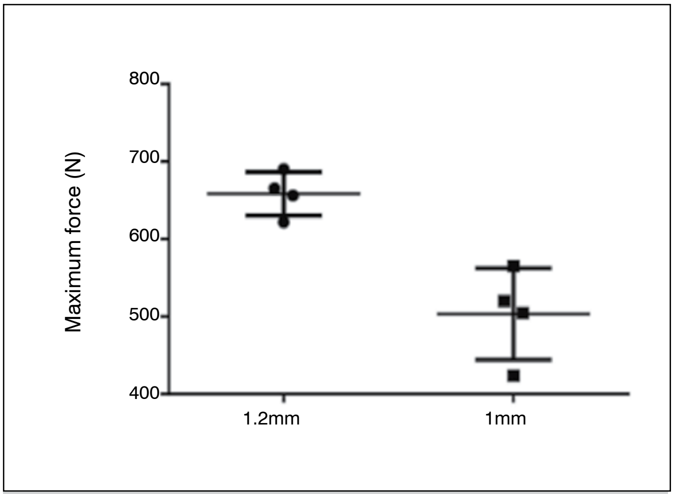

Figure 6. Mean and standard deviation of the comparison of the maximum force between the groups, after the application of the Student's *t*-test .

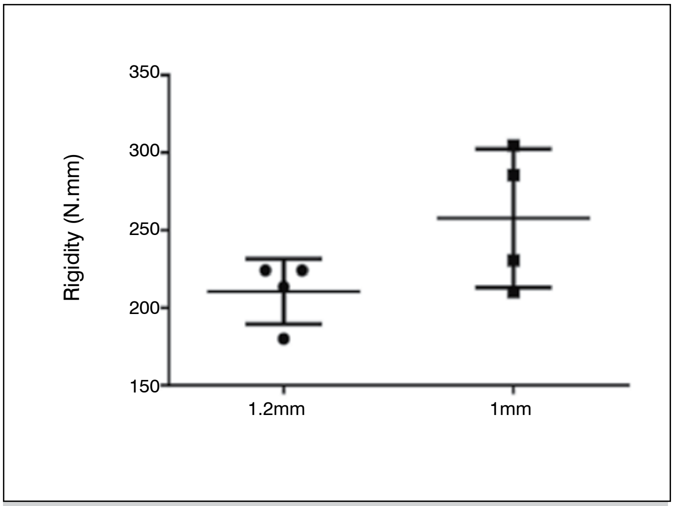

Figure 7. Mean and standard deviation of the rigidity between the groups (by the Student's *t*-test).

Positive results have been obtained in several studies, with good and excellent results in 85% of treated C2 and C3 fractures (AO classification).[25] Benson et al.[26] showed that the technique of fragment-specific fixation guaranteed sufficient stability to allow use of the hand after the third postoperative day without increasing the risk of soft tissue injury or secondary loss of reduction. When compared to the volar plate, the fragment-specific fixation technique provided a significant increase in early mobility, early return to work and activities of daily living, significantly reducing the risk of early joint rigidity, but the results of these two techniques (volar plate and fragment-specific fixation) occurred tardively, and were similar in the above-mentioned conditions.[21]

The versatility of the association of the K-wires with the plates and screws is based on their modest profile and their widespread availability, which makes them good candidates for fragment-specific fixation. In our study, we developed an assembly to fix fragments of the intermediate column and tested its safety as a fixation method through destructive biomechanical tests.

Our results were encouraging, both with in terms of the comparison of compressive forces exerted on a normal resting wrist caused by muscle tension,[21,22] and in terms results from other mechanical studies.

Hara et al.[27] quantified the distribution of forces through the wrist in a mechanical test detailing the peak pressure in each region under a load of 10 kg. The value was higher in the scaphoid fossa, 2.4 MPa, followed by the lunate fossa with 1.5 MPa, and smaller in the triangular fibrocartilage, which supported 1.1 MPa. Considering the maximum force obtained in our tests and converting this to Pascal units, the maximum pressure supported by our assembly was 4.40 MPa in the 1.2-mm wire Group and 3.41 MPa in the 1.0-mm wire Group. These values indicate that our assemblies were capable of supporting loads up to 3-fold higher than those demonstrated in the study by Hara et al.[27]

Our fixation method was able to withstand a pressure 10-fold higher than that supported by the percutaneous fixation with K-wire described by Naidu.[15] We believe this was due to the configuration of our fixation assembly, composed of K-wires associated with plates and screws, which increased the rigidity of the assembly.

The present study demonstrated that the proposed assembly was mechanically adequate for fixation of articular fractures in the intermediate column of the radius and exerts sufficient resistance to counteract the physiological forces of the wrist at rest and even support small loads (up to 10 kg).

When compared to results of other studies in the literature, our results were satisfactory, and we encourage the use of such fixation method in clinical practice.

CONCLUSIONS

The proposed assemblies show adequate resistance for fixing fractures of the intermediate column of the radius and supported loads of up to 10 kg. Increasing the thickness of the K-wire of the assembly produced an increased resistance of the maximum force.

AUTHORS' CONTRIBUTIONS: Each author contributed individually and significantly to the preparation of the manuscript. ALCLAL (0000-0001-9676-8003)*, AMP (0000-0003-1971-9923)* and LT (0000-0003-1735-377X)* were the main contributors to the writing of the manuscript. ALCLAL, AECI (0000-0002-0756-6432)* and ACS (0000-0002-3119-2362)* conducted the biomechanical tests and gathered clinical data. AFC (0000-0002-8760-6325)*, AECI and AMP evaluated the data of the statistical analysis. ALCLAL and AMP did the bibliographic research. NM (0000-0002-1239-7602)* and CHB (0000-0003-3858-602X)* reviewed the manuscript and contributed to the intellectual concept of the study. *ORCID (Open Researcher and Contributor ID).

REFERENCES

1. Chung KC, Spilson SV. The frequency and epidemiology of hand and forearm fractures in the United States. J Hand Surg Am . 2001;26:908-15.
2. Wolfe S. Distal Radius Fractures. In: Wolfe SW, Pederson WC, Hotchkiss RN, Kozin SH, Cohen MS. Green's Operative Hand Surgery. Philadelphia: Elsevier/ Churchill Livingstone, 2016. p. 552-7.
3. Rockwood CA, Green DP. Fractures of the Distal Radius and Ulna. In: Rockwood CA, Bucholz RW, Court-Brown CM, Heckman JD, Tornetta P. Rockwood and Green's Fractures in Adults. Philadelphia: Lippincott Williams & Wilkins, 2010. p. 1059.
4. Trumble TE, Schmitt SR, Vedder NB. Factors affecting functional outcome of displaced intra-articular distal radius fractures. J Hand Surg AM. 1994;19(2):325–40.
5. Dodds SD, Cornelissen S, Jossan S, Wolfe SW. A biomechanical comparison of fragment-specific fixation and augmented external fixation for intra-articular distal radius fractures. J Hand Surg Am. 2002,27(6):953–64.
6. Harness NG, Jupiter JB, Orbay JL, Raskin KB, Fernandez DL. Loss of fixation of the volar lunate facet fragment in fractures of the distal part of the radius. J Bone Joint Surg Am. 2004;86-A(9):1900-8.
7. Cross AW, Schmidt CC. Flexor tendon injuries following locked volar plating of distal radius fractures. J Hand Surg Am. 2008;33(2):164-7.
8. Lucas GL, Fejfar ST. Complications in internal fixation of the distal radius. J Hand Surg. 1998;23(6):1117.
9. Lowry KJ, Gainor BJ, Hoskins JS. Extensor tendon rupture secondary to the AO/ ASIF titanium distal radius plate without associated plate failure. Am J Orthop (Belle Mead NJ). 2000;29(10):789–91.
10. Harness NG, Ring D, Zurakowski D, Harris GJ, Jupiter JB. The influence of three-dimensional computed tomography reconstructions on the characterization and treatment of distal radial fractures. J Bone Joint Surg Am. 2006;88(6):1315-23.
11. Lam J, Wolfe SW. Distal radius fractures: what cannot be fixed with a volar plate? The role of fragment-specific fixation in modern fracture treatment. Op Tech Sports Med. 2010;18(3):181-8.
12. Medoff RJ, Kopylov P. Immediate internal fixation and motion of comminuted distal radius fractures using a new fragment-specific system. Orthop Trans. 1998;22:165.
13. Lam F, Jaysekera N, Karmani S, Jupiter JB. What's new in the treatment of distal radius fractures? Curr Orthop. 2006;20(3):208–11.
14. Rikli D, Regazzoni P. Fractures of the distal end of the radius treated by internal fixation and early function: a preliminary report of 20 cases. J Bone Joint Surg Br. 1996;78(4):588–92.
15. Naidu SH, Capo JT, Moulton M, Ciccone W 2nd, Radin A. Percutaneous pinning of distal radius fractures: a biomechanical study. J Hand Surg (Am). 1997;22(2):252–7.
16. Konrath GA, Bahler S. Open reduction and internal fixation of unstable distal radius fractures: results using the trimed fixation system. J Orthop Trauma. 2002;16(8):578–85.
17. Geissler WB, Fernandez DL. Percutaneous and limited open reduction of the articular surface of the distal radius. J Orthop Trauma. 1991;5(3):255–64.
18. Swigart CR, Wolfe SW. Limited incision open techniques for distal radius fracture management. Orthop Clin North Am. 2001;32(2):317–27.
19. Schumer ED, Leslie BM. Fragment-specific fixation of distal radius fractures using the trimmed device. Tech Hand Up Extrem Surg. 2005;9(2):74-83.
20. Peine R, Rikli DA, Hoffmann R, Duda G, Regazzoni P. Comparison of three different plating techniques for the dorsum of the distal radius: a biomechanical study. J Hand Surg. 2000;25(1):29–33.
21. Chang HC, Poh SY, Seah SC, Chua DT, Cha BK, Low CO. Fragment- specific fracture fixation and double-column plating of unstable distal radial fractures using AO mini-fragment implants and Kirschner wires. Injury. 2007;38(11):1259–67.
22. Leslie BM, Medoff RJ. Fracture specific fixation of distal radius fractures. Tech Orthop. 2000;15(4):336-52.
23. Protomstri PD, Price JS, Schumer E, Korris M, Leslie B, et al. Initial outcome of distal radius fractures treated with the Trimed Wrist Fixation System. In: Presented at the 56th Annual Meeting of the American Society for Surgery of the Hand, Baltimore, MD, October 2001.
24. Benson LS, Minihane KP, Stern LD, Eller E, Seshadri R. The outcome of intra--articular distal radius fractures treated with fragment-specific fixation. J Hand Surg Am. 2006,31(8):1333–9.
25. Taylor KF, Parks BG, Segalman KA. Biomechanical stability of a fixed-angle volar plate versus fragment-specific fixation system: cyclic testing in a C2-type distal radius cadaver fracture model. J Hand Surg Am. 2006;31(3):373–81.
26. Ruby LK, Cooney WP, An KN, Linscheid RL, Chao EYS. Relative motion of selected carpal bones: a kinematic analysis of the normal wrist. J Hand Surg Am. 1988;13(1):1–10.
27. Hara T, Horii E, An K-N, Cooney WP, Linscheid RL, Chao EYS. Force distribution across wrist joint: application of pressure-sensitive conductive rubber. J Hand Surg Am. 1992;17(2):339–47.