HAND (2008) 3:96–101
DOI 10.1007/s11552-007-9074-y

Biomechanical Comparison of Different Volar Fracture Fixation Plates for Distal Radius Fractures

Kareem Sobky · Todd Baldini · Kenneth Thomas · Joel Bach · Allison Williams · Jennifer Moriatis Wolf

Received: 14 April 2007 / Accepted: 17 August 2007 / Published online: 7 September 2007

Abstract The purpose of this study was to compare the biomechanical properties of four volar fixed-angle fracture fixation plate designs in a novel sawbones model as well as in cadavers. Four volar fixed angle plating systems (Hand Innovations DVR-A, Avanta SCS/V, Wright Medical Lo-Con VLS, and Synthes stainless volar locking) were tested on sawbones models using an osteotomy gap model to simulate a distal radius fracture. Based on a power analysis, six plates from each system were tested to failure in axial compression. To simulate loads with physiologic wrist motion, six plates of each type were then tested to failure following 10,000 cycles applying 100N of compression. To compare plate failure behavior, two plates of each type were implanted in cadaver wrists and similar testing applied. All plate constructs were loaded to failure. All failed with in apex volar angulation.The Hand Innovations DVR-A plate demonstrated significantly more strength in peak load to failure and failure after fatigue cycling (p value<0.001 for single load and fatigue failure). However, there was no significant difference in stiffness among the four plates in synthetic bone. The cadaveric model demonstrated the same mode of failure as the sawbones. None of the volar plates demonstrated screw breakage or pullout, except the tine plate (Avanta SCS/V) with 1 mm of pullout in 2 of 12 plates. This study demonstrates the utility of sawbones in biomechanical testing and indicates that volar fixation of unstable distal radius fractures with a fixed angle device is a reliable means of stabilization.

Keywords Distal radius fracture · Biomechanics · Volar plate

K. Sobky · T. Baldini · K. Thomas · J. Bach · A. Williams · J. M. Wolf (✉)
Department of Orthopaedics, University of Colorado Health Sciences Center,
4200 E. 9th Avenue, B202,
Denver, CO 80262, USA
e-mail: Jennifer.Wolf@uchsc.edu

Introduction

Operative stabilization with restoration of joint congruity is the recommended treatment for unstable distal radius fractures. [10] Techniques described include Kirschner wire stabilization, external fixation, and internal fixation. [10, 25, 27] Stable fixation permits early functional rehabilitation and may improve long term outcomes. [12] Plate fixation of the distal radius fracture placed through a dorsal approach has been shown to achieve stability and joint realignment. [2, 6] However, complications including soft tissue irritation, extensor tendonitis, extensor tendon rupture, and chronic dorsal irritation requiring plate removal have been documented, particularly with π-type dorsal plates. [4, 20, 21, 24] More recent studies of lower profile dorsal plates have shown a lower rate of dorsal tissue complications, although authors have reported reoperation for extensor pollicis longus tenolysis [9] and hardware removal due to dorsal wrist pain. [26]

In an attempt to avoid the complications of dorsal plate placement, volar plating of distal radius fractures has been advocated. Volar plate designs with fixed-angle locking technology and lower profiles are thought to enhance stability and avoid soft tissue complications. [16, 17] One report with short-term follow-up showed restoration of tilt, height and inclination, with promising functional outcomes scores in patients with dorsally displaced and comminuted distal radius fractures. [22]

The biomechanical properties of both dorsal and volar plates have been evaluated to analyze plates' ability to withstand joint forces and physiologic loading. [1, 3, 7, 11, 14, 18, 19, 28] This analysis has particular relevance in the immediate post-operative period, where early motion can potentially prevent complications of stiffness and allow earlier return to activity. Based on earlier postulated forces of physiologic load, [8, 29] the majority of these studies showed that both dorsal and volar plates were capable of sustaining the forces of early active wrist motion. Only one previous study was performed in sawbones to standardize the material; this showed that the dorsal π plate had the greatest resistance to fracture gap motion, and that locked volar plates withstood loading better than unlocked volar plates. [28]

The purpose of this study was to compare the load to failure of four fixed-angle volar plates with a single static load and also after cyclical loading, simulating physiologic wrist motion. A secondary goal was to validate the use of sawbones as a distal radius fracture model, and thus, a small cadaver sample was included in our testing to evaluate the consistency and forces of modes of plate failure between sawbones and cadaver bone.

Materials and Methods

Left sawbone radii with white plastic cortical shell and foam cancellous core (#1105, Pacific Research Labs, Vashon, WA) were used for this study. An unstable, extra-articular fracture was simulated by making a 10 mm gap with a saw starting 20 mm proximal to the articular surface at Lister's tubercle. The cuts were made perpendicular to the long axis of the bone to allow for a consistent fracture gap on the dorsal and volar sides of the radius.

Four volar fixed-angle constructs were tested. These were (1) Hand Innovations double row DVR-A plate (Hand Innovations, Miami, FL): (2) Avanta SCS/V (San Diego, CA); (3) Wright Medical Lo-Con VLS plate (Arlington, TN); and (4) Synthes volar radius stainless locking plate (West Chester, PA). Plates from each volar fixation system were implanted in sawbones in the standard fashion. All distal fixation holes were used. Group 1 specimens were fixed with three 3.5-mm bicortical proximal screws and seven 2.0 mm terminally threaded bicortical distal locking screws. Group 2 specimens were fixed by using three 3.5-mm bicortical proximal screws and four-fixed angle tines that are part of the plate (Fig. 1). Group 3 specimens were stabilized using three 3.5 mm proximal bicortical screws and four 2.7 mm fully threaded bicortical distal locking screws. Group 4 specimens were fixed by using three 2.7 mm proximal bicortical screws and five 2.0 mm fully threaded bicortical distal locking screws.

Figure 1 Specimens fixed by using three 3.5-mm bicortical proximal screws and four-fixed angle tines.

A power analysis was performed using data from a study of biomechanical differences in sawbones humerus fixation. [23] This statistical analysis indicated that to detect a 15% difference with a 10% standard deviation while assuming a pattern of intermediate variability among plating techniques, six subjects per group were necessary to achieve power equal to 0.80, with alpha set at 0.05. [5]

Each synthetic radius model was potted in methylmethacrylate and tested in an Instron (Instron Corporation, Canton, MA) bi-axial servo-hydraulic test frame (model 1321). Six plate-radii constructs of each group of specimens were tested for load to failure by advancing a cobalt chrome sphere centered over the articular surface at a constant rate of displacement of 10 mm/min. The sphere was advanced until the construct failed or the dorsal edges of the fracture met (Fig. 2). The resultant force was defined as load to failure. Resulting angle of deformation was measured and recorded. Stiffness was also calculated from the linear portion of the load-displacement curve. Six specimens of each group were then cycled with a repeated load of 100 N for 10,000 cycles, then tested to failure as above. The choice of a 100 N load

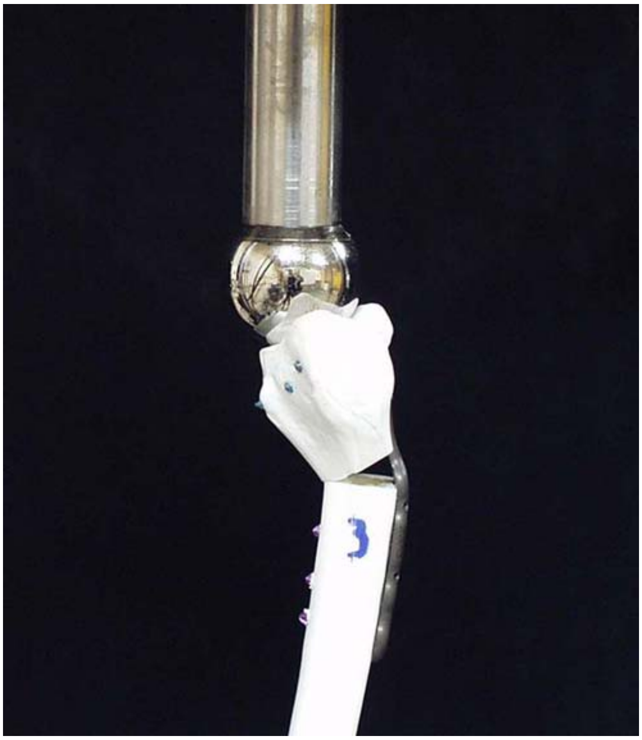

Figure 2 Six plate-radii constructs of each group of specimens were tested for load to failure by advancing a cobalt chrome sphere centered over the articular surface at a constant rate of displacement of 10 mm/min. The sphere was advanced until the construct failed or the dorsal edges of the fracture met.

was based on previously published papers estimating physiologic load across the wrist with normal motion. [8, 29]

To compare behavior in sawbones to that in human cadaveric bone, two of each plating system were implanted into fresh frozen cadaver radii. After thawing the cadaver specimens overnight, all of the soft tissues were stripped from the specimen. Using the same technique as that used in sawbones, a 20-mm fracture gap was created, and the cadavers were potted in the same manner. All eight specimens were then loaded to failure to evaluate possible differences in mode of failure and the force required for construct bending.

Load to failure, physiologic force effects on load to failure, and stiffness were calculated and compared between groups. Analysis of variance was utilized to evaluate the differences among the groups.

Table 1 Average angle (degrees) of deformation for single load to failure data.

Plate Type	DVR-A	Avanta tine	Wright Lo-Con VLS	Synthes volar stainless
	8.5	28.5	23.3	14.2
Standard deviation	5.2	5.4	3.1	3.0

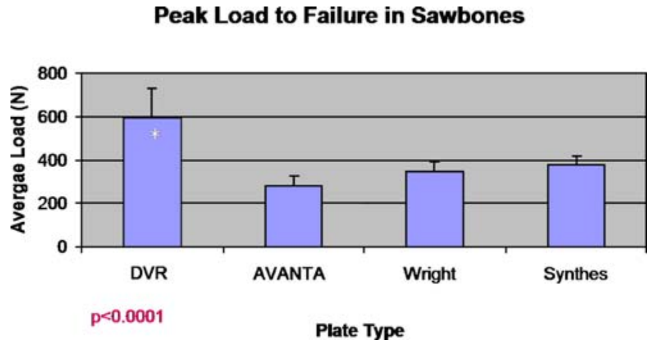

Figure 3 The Hand Innovations DVR plates showed a significantly higher load to failure than the Avanta, Lo-Con VLS locking, and the Synthes volar stainless plate.

Results

Sawbones

All plates in all groups failed with apex volar angulation at the site of the gap created in the specimens. The Hand Innovations DVR plates showed a significantly higher load to failure than the Avanta, Lo-con VLS locking, and the Synthes volar stainless plate ($p<0.001$; Fig. 3). The Synthes stainless plates showed significantly higher load to failure than the Avanta plates ($p=0.048$). There were no significant differences between any other groups. For the measured angle of deformation with failure, the DVR plate showed a significantly less resulting deformity after single load to failure than the Avanta, Lo-Con VLS, and Synthes plates ($p<0.001$). The Lo-Con VLS had a lesser angle of deformation than the Avanta tine plate ($p=0.044$), as did the Synthes plate ($p=0.007$). Comparing the Lo-Con VLS and Synthes stainless volar plates for angle of deformation showed no differences ($p=0.396$; Table 1).

The DVR plate showed a significantly higher load to failure after fatigue loading (10,000 cycles of 100N force then load to failure) than the Avanta tine plate ($p<0.001$), Lo-Con VLS ($p<0.001$), and Synthes volar plate ($p=0.012$; Fig. 4). There were no significant differences when

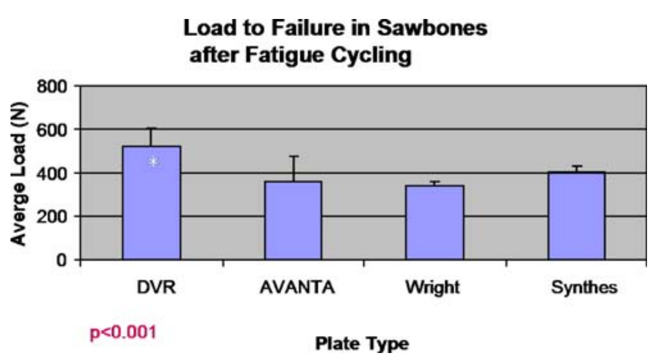

Figure 4 The DVR plate showed a significantly higher load to failure after fatigue loading than the other plates.

Table 2 Average angle (degrees) of deformation for fatigue failure data.

Plate Type	DVR-A	Avanta tine	Wright Lo-Con VLS	Synthes volar stainless
	5.6	34.4	25.3	19.0
Standard deviation	3.9	2.7	3.9	2.5

comparing the Avanta plate to the Lo-Con VLS (p=0.643), Avanta to Synthes plate (p=0.335), and Lo-Con VLS to Synthes volar plate (p=0.161). In the measurement of bending angle with failure, the DVR plate again showed significantly less resulting deformity after fatigue failure than the Avanta, Lo-Con VLS, and Synthes plates ($p<0.001$, $p<0.001$, p=0.021, respectively). Analysis showed no differences between the Avanta and Wright Lo-Con plate (p=0.836), Avanta and Synthes plate (p=0.153), and between the Lo-Con VLS and Synthes stainless plate (p= 0.106; Table 2).

The stiffness of each plate was calculated by fitting a straight line to the linear portion of the load vs deflection curve. The slope of the line represented the stiffness of the plate and the R2 value was noted. ANOVA single factor data analysis was performed to determine if there was a significant difference ($p<0.05$) in stiffness between the four plate designs tested for single load to failure or fatigue pretesting before being loaded to failure. All R2 values were greater than 0.97 showing that the curves could be fit well with a straight line. The DVR plate showed the highest stiffness in single loading to failure at 162 N/mm, but was not significantly stiffer than any of the other three plates (Fig. 5). The Lo-Con VLS plate demonstrated the highest stiffness after fatigue loading, but again, this showed no statistical difference when compared to other groups. There were no significant differences among the four plate groups in either load to failure or physiologic load testing ($p>0.05$).

There were two plates of 12 in the Avanta tine group that had 1 mm of tine pull out of the distal fragment. There were no failures of the proximal fixation and no other evidence of cut out or screw/tine bending or failure in these constructs. There was no plate breakage across the groups.

Cadavers

Cadaver testing was performed with a single load to failure, with the identical technique used in the synthetic bone models. The purpose was to evaluate the mode of plate failure as compared to the sawbones model. All plates failed with apex volar angulation, similar to plates in synthetic bone. Peak load to failure was higher in cadaver bone, with an average of 549 N required for failure in cadavers and 398 N seen with synthetic bone failure (Fig. 6). There was no plate or screw breakage of the cadaver-plate constructs under loading, and no pullout of either proximal or distal fixation.

Discussion

One of the purported advantages of volar plating for distal radius fractures has been the ability to allow patients to perform early postoperative motion. Evaluation of the strength and stiffness of volar plates, through biomechanical simulation of the forces across the wrist, tests this hypothesis. Recent biomechanical investigations have shown that multiple plating systems appear strong enough to withstand physiologic force. [11, 13, 15, 18, 19, 28]

The most comprehensive study of distal radius volar plate biomechanics to date compared the failure properties and stiffness of ten volar plates, [11] which included three of the four plate systems used in this study. The majority of the biomechanical testing was performed using a wedge

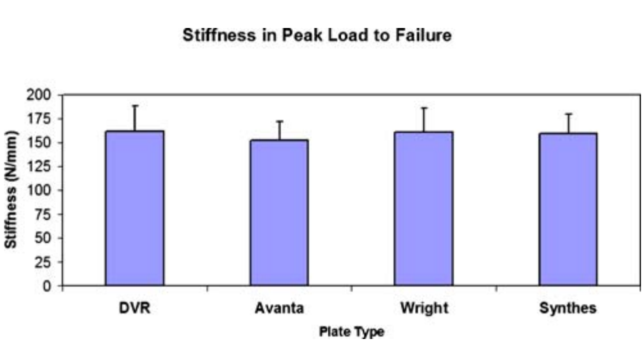

Figure 5 There were no significant differences in stiffness among the four plate types.

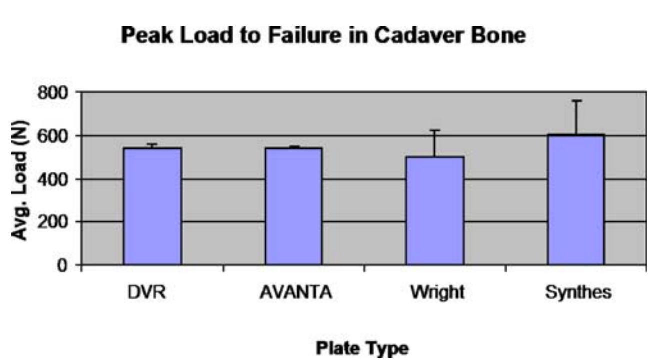

Figure 6 Peak load to failure was higher in cadaver bone compared to synthetic bone.

osteotomy model, with a small comparison group of eight segmental resection. This study showed that stainless steel plates were stiffer than titanium plates, and that in the segmental resection model, distal fixation failure was common. All plates in all groups failed with plate bending.

Willis et al. have published the only study to date comparing the behavior of volar plates using a sawbones model. [28] In this study, four volar plates were compared to the Synthes π dorsal plate system. Two of the volar plates were locking plates (Hand Innovations DVR, and Synthes volar locking plate), but only the DVR used distal locking technology. This study showed that the Synthes π plate was significantly stiffer than the volar plates in a wedge compression radius fracture model, and that the DVR and volar locking plates were more stiff than the nonlocking volar plates.

In our study, the use of a sawbones model to test volar plates in a gap resection construct is novel. Synthetic sawbones felt to simulate real bone most closely were chosen to standardize the biomechanical protocol; sawbones also offer a cost-efficient model for implant trials. Quantitative analysis of the angle of deformation confirmed that the DVR plate had a significantly lower degree of bending at failure than the Synthes, Wright, and Avanta plates. Of the four plates tested, the DVR plate had a significantly higher peak load at failure but did not differ in stiffness when compared to the other three plates. In clinical applications, these data would suggest that the DVR can tolerate higher sustained force through the wrist before failing. However, the stiffness data are likely more clinically relevant since the measured forces replicate physiologic loading more accurately. The similarities in stiffness across the four plate systems support the idea that since all four plates performed similarly during gradually increasing load, with the same degree of displacement, all provide sufficient fixation to tolerate physiologic forces during healing. Compared to Koh's study, only one of the plate types showed any distal fixation failure, specifically tine pullout in the Avanta plate.

To validate the sawbones model, a small cadaver study was also performed. Cadaver specimens were not standardized by densitometry, age, sex, or size. Cadaver construct behavior was compared to synthetic bone and showed the same mode of failure and comparable peak loads to failure. This cadaver model, as a control measure, supports the use of sawbones for future use in biomechanical studies.

There were several limitations in this study. A different number of distal fixation points were used with each plating system, as all possible distal fixation holes were filled. While this reproduces the actual clinical scenario, the difference in screw number is a weakness of nonexact comparison. The comparative cadaver study was small and thus not amenable to statistical analysis or comparison of the plate constructs, and the specimens were not standardized.

This study evaluated four volar plates in peak load to failure with constant compression and fatigue preloading, as well as for stiffness of the implants. Our results showed a significantly higher peak loading force required to deform the DVR plating system with sustained compressive force and after physiologic force application. However, there were minimal differences in stiffness between the DVR, Lo-Con VLS, Synthes stainless, and the Avanta tine plates. There was no proximal fixation failure in any of the plates, and only two of the Avanta plates showed distal fixation failure. These results indicate that all of these plates can withstand physiologic loading to allow early wrist range of motion after surgery for distal radius fractures.

Acknowledgements The authors would like to acknowledge Hand Innovations, Avanta, Wright Medical, and Synthes for donating the plating systems tested. This work was supported by a grant from the Dept. of Orthopaedics, UCHSC.

References

1. Blythe M, Stoffel K, Jarrett P, Kuster M. Volar versus dorsal locking plates with and without radial styloid locking plates for the fixation of dorsally comminuted distal radius fractures: A biomechanical study in cadavers. J Hand Surg [Am] 2006;31 (10):1587–93.
2. Campbell DA. Open reduction and internal fixation of intra articular and unstable fractures of the distal radius using the AO distal radius plate. J Hand Surg [Br] 2000;25(6):528–34.
3. Cheng HY, Lin CL, Lin YH, Chen AC. Biomechanical evaluation of the modified double-plating fixation for the distal radius fracture. Clin Biomech (Bristol, Avon) 2007.
4. Chiang PP, Roach S, Baratz ME. Failure of a retinacular flap to prevent dorsal wrist pain after titanium Pi plate fixation of distal radius fractures. J Hand Surg [Am] 2002;27(4):724–8.
5. Cohen J. Statistical power analysis for the behavioral sciences. Hillsdale, NJ: Lawrence Erlbaum Associates; 1988.
6. Fitoussi F, Ip WY, Chow SP. Treatment of displaced intra-articular fractures of the distal end of the radius with plates. J Bone Joint Surg Am 1997;79(9):1303–12.
7. Grindel SI, Wang M, Gerlach M, McGrady LM, Brown S. Biomechanical comparison of fixed-angle volar plate versus fixed-angle volar plate plus fragment-specific fixation in a cadaveric distal radius fracture model. J Hand Surg [Am] 2007;32(2):194–9.
8. Horii E, Garcia-Elias M, Bishop AT, Cooney WP, Linscheid RL, Chao EY. Effect on force transmission across the carpus in procedures used to treat Kienbock's disease. J Hand Surg [Am] 1990;15(3):393–400.
9. Kamath AF, Zurakowski D, Day CS. Low-profile dorsal plating for dorsally angulated distal radius fractures: an outcomes study. J Hand Surg [Am] 2006;31(7):1061–7.
10. Knirk JL, Jupiter JB. Intra-articular fractures of the distal end of the radius in young adults. J Bone Joint Surg Am 1986;68(5):647–59.
11. Koh S, Morris RP, Patterson RM, Kearney JP, Buford WL, Jr., Viegas SF. Volar fixation for dorsally angulated extra-articular

fractures of the distal radius: a biomechanical study. J Hand Surg [Am] 2006;31(5):771–9.
12. Kreder HJ, Agel J, McKee MD, Schemitsch EH, Stephen D, Hanel DP. A randomized, controlled trial of distal radius fractures with metaphyseal displacement but without joint incongruity: closed reduction and casting versus closed reduction, spanning external fixation, and optional percutaneous K-wires. J Orthop Trauma 2006;20(2):115–21.
13. Leung F, Zhu L, Ho H, Lu WW, Chow SP. Palmar plate fixation of AO type C2 fracture of distal radius using a locking compression plate—a biomechanical study in a cadaveric model. J Hand Surg [Br] 2003;28(3):263–6.
14. Liporace FA, Gupta S, Jeong GK, Stracher M, Kummer F, Egol KA, Koval KJ. A biomechanical comparison of a dorsal 3.5-mm T-plate and a volar fixed-angle plate in a model of dorsally unstable distal radius fractures. J Orthop Trauma 2005;19(3):187–91.
15. Liporace FA, Kubiak EN, Jeong GK, Iesaka K, Egol KA, Koval KJ. A biomechanical comparison of two volar locked plates in a dorsally unstable distal radius fracture model. J Trauma 2006;61(3):668–72.
16. Orbay JL, Fernandez DL. Volar fixation for dorsally displaced fractures of the distal radius: a preliminary report. J Hand Surg [Am] 2002;27(2):205–15.
17. Orbay JL, Touhami A. Current concepts in volar fixed-angle fixation of unstable distal radius fractures. Clin Orthop Relat Res 2006;445:58–67.
18. Osada D, Fujita S, Tamai K, Iwamoto A, Tomizawa K, Saotome K. Biomechanics in uniaxial compression of three distal radius volar plates. J Hand Surg [Am] 2004;29(3):446–51.
19. Osada D, Viegas SF, Shah MA, Morris RP, Patterson RM. Comparison of different distal radius dorsal and volar fracture fixation plates: a biomechanical study. J Hand Surg [Am] 2003;28(1):94–104.
20. Ring D, Jupiter JB, Brennwald J, Buchler U, Hastings H, 2nd. Prospective multicenter trial of a plate for dorsal fixation of distal radius fractures. J Hand Surg [Am] 1997;22(5):777–84.
21. Rozental TD, Beredjiklian PK, Bozentka DJ. Functional outcome and complications following two types of dorsal plating for unstable fractures of the distal part of the radius. J Bone Joint Surg Am 2003;85-A(10):1956–60.
22. Rozental TD, Blazar PE. Functional outcome and complications after volar plating for dorsally displaced, unstable fractures of the distal radius. J Hand Surg [Am] 2006;31(3):359–65.
23. Rubel IF, Kloen P, Campbell D, Schwartz M, Liew A, Myers E, Helfet DL. Open reduction and internal fixation of humeral nonunions : a biomechanical and clinical study. J Bone Joint Surg Am 2002;84-A(8):1315–22.
24. Schnur DP, Chang B. Extensor tendon rupture after internal fixation of a distal radius fracture using a dorsally placed AO/ASIF titanium pi plate. Arbeitsgemeinschaft fur Osteosynthesefragen/Association for the Study of Internal Fixation. Ann Plast Surg 2000;44(5):564–6.
25. Sennwald GR, Della Santa D. Unstable fracture of the distal radius and its treatment: comparison of three techniques: external fixation, intramedullary pinning and AO plates. Chir Main 2001;20(3):218–25.
26. Simic PM, Robison J, Gardner MJ, Gelberman RH, Weiland AJ, Boyer MI. Treatment of distal radius fractures with a low-profile dorsal plating system: an outcomes assessment. J Hand Surg [Am] 2006;31(3):382–6.
27. Trumble TE, Culp RW, Hanel DP, Geissler WB, Berger RA. Intra-articular fractures of the distal aspect of the radius. Instr Course Lect 1999;48:465–80.
28. Willis AA, Kutsumi K, Zobitz ME, Cooney WP, 3rd. Internal fixation of dorsally displaced fractures of the distal part of the radius. A biomechanical analysis of volar plate fracture stability. J Bone Joint Surg Am 2006;88(11):2411–7.
29. Wolfe SW, Swigart CR, Grauer J, Slade JF, 3rd, Panjabi MM. Augmented external fixation of distal radius fractures: a biomechanical analysis. J Hand Surg [Am] 1998;23(1):127–34.