EARLY RESULTS OF UNSTABLE DISTAL RADIUS FRACTURES- ORIF WITH LOCKING COMPRESSION PLATE VERSUS LIGAMENTOTAXIS WITH EXTERNAL FIXATORS

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ABSTRACT

BACKGROUND

External Fixation (EF) and Open Reduction and Internal Fixation (ORIF) have been the traditional surgical modalities for unstable distal radius fractures. The Locking Compression Plates (LCP) acting as "internal external fixators" are particularly valuable in difficult situations of fractures. We undertook a study to evaluate the outcome of unstable distal radius fractures treated with ORIF with LCP versus those treated by ligamentotaxis with external fixators.

MATERIALS AND METHODS

A comparative study was carried out in a tertiary care centre with 30 cases of unstable distal radius fractures (15 cases in each group). In one group, open reduction and internal fixation with distal radius volar locking compression plate was carried out and in the other group ligamentotaxis with external fixator was done. The patients were treated and followed up over a period of one and a half year between June 2011 to November 2012. The fractures were classified according to AO classification (Arbeitsgemeinschaft für Osteosynthesefragen: German for "Association for the Study of Internal Fixation" or AO). The functional results were evaluated at the end of 6 months according to Demerit point system of Gartland and Werley modified by Sarmiento (1975) and the anatomical results as per Lindstrom criteria (1959) modified by Sarmiento (1980).

RESULTS

Overall 86.66% (13) cases had good-to-excellent anatomical results in external fixator group as compared to 93.33% (14) cases in LCP group. The functional outcome was excellent in 80% (12) and good in 13.33% (2) cases in external fixator group as compared to 66.66% (10) excellent and 26.66% (4) good in LCP group.

CONCLUSION

Both open reduction and internal fixation with locking compression plate and ligamentotaxis with external fixators are good treatment modalities for unstable distal radius fractures. However, the choice should be guided by the fracture configuration, surgeons' experience and patient's profile.

KEYWORDS

External Fixators, Locking Compression Plate, Unstable Distal Radius Fractures.

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BACKGROUND

Distal radius fractures crush the mechanical foundation of man's most elegant tool, the hand. Despite being a common injury around the wrist, it is still an intriguing problem for the orthopaedic surgeon. They are frequently intra-articular and comminuted rendering them unstable. So, the rate of secondary displacement is very high in the conventional cast immobilisation, which directly interferes in the joint functions later on. In younger individuals who demand a more functional wrist joint, these fractures occur due to high energy trauma.

There is development in operative management of these fractures with multiple pins, External Fixators (EF), Open Reduction and Internal Fixation (ORIF) with plates, etc. Anderson et al were the first to use external fixation to maintain the fracture reduction.[1] During the last three decades, numerous studies have defined the value of ligamentotaxis in maintaining the skeletal length during fracture healing. Swiss Association for the study of Internal Fixation (AO/ASIF) developed the small AO external fixator. The external fixator is a versatile tool in the treatment of intraarticular and extraarticular fractures of distal radius.[2] Vidal et al put forward the principle now known as 'ligamentotaxis.'[3]

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The recent trend is more inclined towards ORIF, as it permits accurate anatomical reduction and early mobilisation. Open reduction and internal fixation of unstable distal radius fractures with plates and screws helps in maintaining the congruity of the articular surface, restoring the Radial Length or height (RL), Volar Tilt (VT),Radial Angulation or inclination (RA) and provides stable fixation, thus reducing the incidence of post-traumatic osteoarthritis and allows early functional rehabilitation.[4] Newer implants have been developed to treat distal radius fractures which are comminuted as well as osteoporotic, where external fixators and ordinary plates screws do not provide good purchase of bone. The recent development of Locking Compression Plate (LCP) was done by combining two osteosynthesis techniques, conventional plating and locked internal fixation, into one implant as a logical and simple practical solution.[5]The new AO LCP with combination holes can be used depending on the fracture situation as a compression plate, a locked internal fixator or as an internal fixation system combining both techniques.[6] Locked plates are single-beam constructs by design, thus act as fixed-angle devices, which enhance fracture fixation in circumstances where fracture configuration or bone quality do not provide sufficient screw purchase. Fixation is further improved by the inherent angular and axial stability of locked plates.[7] In our study, we tried to compare the anatomical and functional outcome of unstable distal radius fractures when treated with open reduction and internal fixation with locking compression plate versus ligamentotaxis with external fixators.

MATERIALS AND METHODS

In this prospective comparative study, 30 cases (15 cases in each group) with unstable distal radius fractures were evaluated to see the final outcome when treated with ORIF with 2.5 mm distal radius volar LCP (Sharma Surgicals) versus ligamentotaxis with AO small External Fixator with Kirschner (K) wire supplementation as and when required. The study was carried out in a tertiary care centre from June 2011 to November 2012.The inclusion criterias of this study were:- 1) Fresh fractures of distal radius (less than one week old); 2) Unstable fractures of distal radius (with angulation of the radial articular surfaces exceeding 20 degrees, articular fragment separation ≥2 mm, comminution of both volar and dorsal radial metaphyseal cortices)[8]; 3) Closed fractures; 4) Failure of obtaining reduction with closed manipulation and plaster cast. The exclusion criterias were:- Undisplaced fractures of distal radius, open fractures, epiphyseal injury, concomitant fracture of other bones or pre-existing impairment of function of the same limb and loss of followup. The initial radiographs were examined by taking anteroposterior (AP) and lateral views of the affected wrist and the fracture was classified according to AO classification. One group was treated with ORIF with volar LCP and the other by ligamentotaxis with a unilateral uniplanar AO small External Fixator frame along with percutaneous Kirschner wires supplementation as required. There was an average delay of three days in both the groups. The operations were performed by three experienced surgeons, employing surgical techniques described by the AO/ASIF group. Post-operative radiographs were examined to assess the accuracy of reduction and technical quality of fixation. The patients were followed up clinico-radiographically at 1 week, 2 weeks, 6 weeks, 12 weeks and then every 3 months. During visits emphasis was laid upon active finger movements, Range of Motion (ROM) exercises of elbow and shoulder joint along with cleaning of pin- skin interface in external fixator group. In the ORIF with LCP group, a protective Plaster of Paris (POP) slab was applied for 2 weeks, after which intensive physiotherapy was started and paraffin wax bath was advised if required.

The functional results were evaluated at the end of 6 months according to Demerit Point System of Gartland and Werley (modified by Sarmiento et al 1975).[9,10] The outcome of each fracture was graded as excellent, good, fair or poor. The magnitude of grip strength was measured by using a handheld dynamometer. The contralateral uninjured wrist of the patients was chosen as the control wrist. The percentage of grip strength was recorded on the injured limb in comparison to the normal hand. Three parameters were used in the evaluation of anatomical results: volar tilt, radial angulation and radial length, all of which were measured on the roentgenogram by an experienced radiologist. For comparison, x-ray films were not made of the uninjured extremity, normal values were taken as average 23 degrees of radial angulation, 11 degrees of volar tilt and 12 mm of radial length[11] (Figure 1).

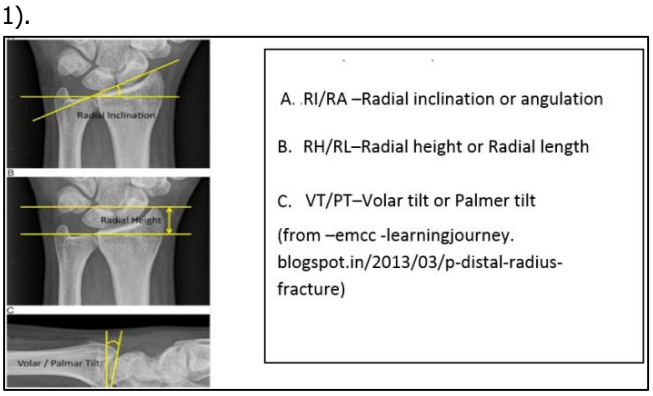

Figure 1. The Anatomical Parameters to Assess the Distal Radius Fractures

The findings were then critically evaluated using the criteria proposed by Lindstrom (1959), which is modified by Augusto Sarmiento et al (1980).[12] Measurements of each fractures were taken: pre-reduction, immediate postoperative period, after removal of fixator (in external fixator group only) and at the end of 6 months. The range of motion was evaluated after 6 months with the help of a goniometer. The percentage of ROM was evaluated by comparing with the uninjured side. The degree of arthritis in the radiocarpal and radioulnar joint is evaluated by the grading as proposed by Knirk et al (1986).[13]

The statistical analysis were made using the software GraphPad InStat for Windows. Differences were considered significant when the p value was <0.05.

RESULTS

There were 19 males (63.33%) and 11 females (36.66%) with average age of 39.66 years (range 21 to 65 years). 60% of cases in our study were due to high velocity trauma. The patients in external fixator group had their fixators removed at 6 weeks after clinico-radiographical assessment of union. The patients were followed up for minimum period of 6 months. According to AO classification, the highest number of fractures were of the type C category, 26 cases (86.66%) as most of the injuries occurred due to high energy trauma(Table 1).

Type of Fracture	External Fixator	LCP
A1	0	0
A2	0	0
A3	1(6.66%)	3(20%)
B1	0	0
B2	0	0
B3	0	0
C1	5(33.33%)	9(60%)
C2	3(20%)	1(6.66%)
C3	6(40%)	2(13.33%)
Total	**15**	**15**

Table 1. Type of Fracture

In the final analysis of the anatomical results at 6 months, the loss of radial length was 2.46±2.26 mm, the radial angulationwas 17.93±3.45 degrees andvolar tilt was 2.46±4.79 degrees in the external fixator group. In the LCP group, the loss of radial length was 0.5± 0.88 mm, the radial angulation was 21±2.72 degrees and volar tilt was 6±1.85 degrees. Anatomical reduction and its maintenance up to fracture union was better in ORIF with LCP group, which was found to be statistically significant (p<0.05 paired sample 't' test) in all three parameters. We hadresidual deformity in the form of prominent ulnar styloid in 2 (13.33%) cases and residual dorsal tilt in 1(6.66%) case in the external fixator group, because of the loss of reduction. In LCP group, residual deformity in the form of prominent ulnar styloid was found in 2 (13.33%) cases. The overall anatomical results at six months assessed according to criterias proposed by Lindstorm (1959) modified by Sarmiento, 13 (86.66%) cases had good-to-excellent result in external fixator group as compared to 14 (93.33%) cases in LCP group(Table 2).

Anatomical Results	Ext. Fixator	LCP
Excellent	8 (53.33%)	12(80%)
Good	5(33.33%)	2(13.33%)
Fair	2(13.33%)	1(6.66%)
Poor	0	0
Total	15	15

Table 2. Anatomical Results at 6 Months

The range of movements of the injured wrist and forearm were measured after 6 months in both groups and were compared (Table 3). There was no statistically significant difference found in the range of motion in between the two groups (p value 0.702); however, there was decreased range of radial deviation in the LCP group (p value 0.015), which may be due to mechanical disadvantage of the lateral end of the T plate. In the external fixator group, the range of pronation and supination movements were found to be less; this might be due to the external fixator pins causing obstructions in the early initiation of such movements in postoperative period.

Range of Motion	Range (In Degrees)		Mean and Standard Deviation (In Degrees)	
	External Fixator	LCP	External Fixator	LCP
Dorsiflexion	47-72	45-80	61±7.28	60±9.63
Palmar flexion	42-72	40-75	60.4±7.57	58.33±9.57
Pronation	46-75	45-80	62.4±8.59	70±8.66
Supination	42-75	45-85	63.06±8.65	75±9.45
Radial deviation	8-20	5-20	14.53±4.79	10±3.91
Ulnar deviation	11-27	15-30	20.46±5.04	23±3.82

Table 3. Range of Motion on Injured Side at 6 Months

The percentage of range of motion in the affected wrist was evaluated by calculating the average range of motion of the uninjured wrist, in each study group (Table 4).

Range of Motion	External Fixator	LCP
Dorsiflexion	89.05%	87.27%
Palmar flexion	84.18%	82.74%
Pronation	73.76%	82.35%
Supination	73.32%	86.20%
Radial deviation	55.35%	38.83%
Ulnar deviation	57.23%	66.19%

Table 4.Percentage of Range of Motion at 6 Months

In our study, we graded articular incongruity as proposed by Knirk et al (19 86).[13] 11(73.33%) cases had grade '0' articular incongruity in external fixator group as compared to 14(93%) cases in LCP group. Restoration of articular congruity was better seen in LCP group, which was statistically insignificant (p value 0.34).

14 cases (93.33%) had grip strength more than 60% as compared to the opposite hand in external fixator group, whereas in LCP group there were 13 cases (86.66%) with similar findings (p value 0.109). The traumatic arthritis was assessed radiologically in late followup and evaluated as per the criteria proposed by Knirk et al (1986).[13]In our study we found more cases with Grade 0 type arthritis, because of the short followup of 6months. There were 12(80%) cases with grade 0 traumatic arthritis in external fixator group and 11 (73%) cases in LCP group.

The overall functional results were evaluated as shown in Table 5.

Grade	External Fixator	LCP
Excellent	12 (80%)	10 (66.66%)
Good	2(13.33%)	4(26.66%)
Fair	1(6.66%)	1(6.66%)
Poor	0	0

Table 5. Functional Outcome at 6 Months

The functional outcome after the followup of six months and according to demerit point system of Gartland and Werley (modified by Sarmiento, 1975)[9,10] were excellent in 80% (12) cases, good in 13.33% (2) cases, fair in 6.66%(1) case in external fixator group; 66.66% (10) cases had excellent functional outcome in LCP group followed by 26.66% (4) good, 6.66% (1) fair results. Overall, 93.33% (14) of cases had good-to-excellent functional results in both the study groups.

The commonest complication in external fixator group was loss of reduction, seen in 9 (60%) cases followed by pin tract infection in 4 (26.66%) cases, traumatic arthritis and residual deformity in 3 (20%). Loss of reduction was seen in (60%) cases in external fixator group, which was due to the fact that most of the fractures were of Type C group, out of which 6 (40%) cases were of Type C3. Since additional bone grafting was not done in any of the cases, external fixator alone was not adequate enough to maintain the reduction. In one case with C3 fracture we used additional K-wires along with external fixator, which helped in maintaining the reduction. Only four cases (26.66%) in external fixator group could be convinced to undergo remanipulation for loss of reduction. The pin tract infections were managed conservatively with oral antibiotics and antiseptic dressing. There were no cases of pin loosening in our study as we were using converging pins and taking care to avoid unicortical pin placement, which were important causes of pin loosening.

In LCP group, commonest complication was traumatic arthritis in 4 (26.66%) cases followed by hypertrophic scar in 3 (20%) cases. The hypertrophic scars occurred probably due to early mobilisation by 2 weeks. These were managed conservatively with local steroid injections. There was 1(6.66%) case of penetration of screws into joint, this occurred during the early part of our study. After that we took utmost care while putting the distal screws and started with ulnar side first, since it is at most risk for intraarticular penetration. This patient was operated again for removal of the offending screw, as it hindered in postoperative physiotherapy. There was 1(6.66%) case of median nerve neuropathy. The neuropathy responded well to conservative treatment. There were no cases of wound dehiscence or tendon rupture in our study.

DISCUSSION

Fractures of the distal radius are one of the most common injuries in orthopaedics. In cases of displaced, intra-articular fractures, repair focuses on precise anatomical reduction and articular alignment. Restoration of the anatomy and articular surface may prevent the onset of arthritis and improve function.[14] Therefore, there is need for studies that substantiate specific treatment protocols to ensure that surgeons have the necessary information to effectively restore function to their patients.

McKenna J et al treated 48 patients for distal radial fractures with an (AO) construct showing excellent or good functional results in 90% cases and radiographically 95% had an excellent or good result.[15] Huang TL et al did retrospective group study of the small AO external fixator in the management of acute intra-articular fractures of the distal radius. The overall clinical and functional outcomes showed that 22 patients (31.4%) had excellent results, 36 (51.4%) had good results, 9 (12.9%) had fair results and 3 (4.3%) had poor results.[16]

Though external fixation is a popular method for treating distal radius fractures, but it cannot assure maintenance of the reduction. Supplementing external fixation with intramedullary Kirschner wires can improve retention of fracture reduction during healing, resulting in better functional results. Use of external fixator has pit-falls like loosening of fixators in osteoporotic bones, loss of reduction, pin tract infection and stiffness of wrist. Treatment of displaced intraarticular fractures of the distal radius by open reduction and plate fixation produce acceptable results, although the complication rates can be high.[4] The problems associated with the methods of internal fixation have recently been addressed by the use of low profile plates or fixed angled plates.[6] Jorge L. Orbay et al[17]treated patients with dorsally displaced, unstable distal radial fractures with a new fixed-angle internal fixation device using a volar approach to avoid the soft tissue problems associated with dorsal plating. The combination of stable internal fixation with the preservation of the dorsal soft tissues resulted in rapid fracture healing, reduced need for bone grafting and decreased the incidence of tendon problems.[17] Leung F et al[18] in their biomechanic cadaveric study of an AO type C2 fracture of distal radius established the superiority of the palmar locking compression T-plate over conventional palmar or dorsal T-plates. Christoph Sommer et al[19] found that locked plates preserved periosteal blood supply, promote more rapid bone healing and decreased the incidence of infection, bone resorption, delayed union, nonunion and secondary loss of reduction. They are particularly valuable in difficult situations like osteoporosis, complex joint fractures or juxta-articular fractures. Douglas S. Musgrave et al[20] used a new volar fixed-angle plate system for successful stabilisation of dorsally unstable distal radius fractures allowing early mobilisation of wrist. Wong KK et al[21] concluded volar locking plates as a safe and effective treatment for unstable fractures of the distal radius with acceptable complication rates.

There are studies comparing the results of ORIF with LCP to that of ligamentotaxis to find out which is superior. The literature offers no conclusive evidence in this regard.[22,23,24,25] Kapoor H et al[26] in a randomised control

study of 90 patients recommended that displaced severely comminuted intra-articular distal radius fractures should be treated with an external fixator. Thomas W. Wright et al[27] concluded ORIF with a volar fixed-angle implant in comparison to external fixator, resulted in stable fixation of the distal articular fragments allowing early postsurgical wrist motion. The functional outcome scores for the groups were equivalent, whereas intra-articular step-off, volar tilt and radial length were better in the ORIF group. In our study, anatomical reduction and its maintenance up to fracture union was better in ORIF with LCP group, which was found to be statistically significant ($p< 0.05$ paired sample 't' test) in all three parameters as compared to external fixator group. The overall anatomical result at the end of the study, 86.66% (13) of cases had good-to-excellent result in external fixator group as compared to 93.33% (14) case in LCP group. Restoration of articular congruity was also better seen in LCP group. In our study, we have found traumatic arthritis of grade I and II in most of the patients who had step off > 2 mm. Articular step off more than 2 mm is significant and leads to traumatic arthritis, so restoration of articular congruity is very important to get a satisfactory functional result.[13] The functional outcome after the end of the study period and according to demerit point system of Gartland and Werley (modified by Sarmiento, 1975), overall 93.33% (14) of cases had good-to-excellent functional result in both the study groups. Even though anatomical reduction of the fracture was comparatively better in LCP group, the final functional outcome was equally good in both the study groups. Marco Rizzo et al[28] too had similar findings in their study. Zamzuri Z et al[29] treated 26 patients with closed unstable comminuted intra-articular fracture distal end of the radius with two different methods of treatment to compare their anatomical and functional results. The anatomical results at six months and one year showed that the internal fixation was more effective in maintaining the reduction compared to the external fixation group. The radial height, volar tilt and radial inclination were well maintained. However, the functional results at six months and one year showed no differences between these two types of fixation. The complication rate was higher in external fixation group. A good functional outcome can be achieved by even with partial degree of anatomical deformity. Our results reinforce their findings.

Zvi Margaliot et al[30] did a meta-analysis of outcomes of external fixation versus plate osteosynthesis for unstable distal radius fractures and found no clinically or statistically significant differences in pooled grip strength, wrist range of motion, radiographic alignment, pain and physician-rated outcomes between the 2 treatment modalities. There were higher rates of infection, hardware failure and neuritis with external fixation and higher rates of tendon complications and early hardware removal with internal fixation.

CONCLUSION

ORIF with LCP and ligamentotaxis with external fixator, both are good treatment modalities for treating unstable fractures of distal radius. Which one to choose should be guided by the fracture configuration, surgeons' experience and patient's profile. ORIF with LCP is comparatively better option for obtaining good anatomical reduction, as it helps in preventing development of traumatic arthritis later on. Intensive physiotherapy in postoperative period is a must to achieve good functional outcome. Good functional outcome can be achieved even with partial degree of anatomical deformity, but wherever possible attempt should be made for anatomical reduction. No single treatment modality for treating unstable fractures of distal radius fractures can be called the best. Each case should be dealt on merit. To prevent loss of reduction and restoration of palmar tilt by uniplanar ligamentotaxis is difficult in comminuted fractures. In severely comminuted fracture, wherever possible bone grafting should be done or additional stabilisation with 'K' wire may be of great value.

Limitations and Recommendation

It was very difficult to compare the results of both groups in such a small series of 15 cases in each group with an average followup of only six months. Either of the treatment protocol, external fixation or ORIF with LCP may be followed to achieve better functional results, only their judicious application is required. Combination of bone grafting in both groups may produce early and better consolidation of fracture and hence may help in early mobilisation and better functional outcome. Patient's better acceptability of ORIF with LCP in comparison to external fixation inspires us to recommend ORIF with LCP of distal radius fractures wherever adequate facilities exists. Further studies with long duration of followup is desired, as it may reveal statistically significant data later on.

REFERENCES

[1] Anderson R, O' Neil. Comminuted fractures of distal end of the radius. Surg Gyne Obst 1944;78:434-440.
[2] Rikli DA, Kupfer K, Bodoky A. Long–terms results of the external fixation of distal radius fractures. J of Trauma 1998;44(6):970-976.
[3] Vidal J, Buscayret C, Connes H. Treatment of articular fractures by ligamentotaxis with external fixation. In: Brooker AF, Edwards CC, eds. External fixation, the current state of the art. Baltimore: Williams & Wilkins1979:75-81.
[4] Campbell DA. Open reduction and internal fixation of intraarticular and unstable fractures of the distal radius using AO distal radius plate. J Hand Surg Br 2000;25(6):528-534.
[5] Frigg R.Locking Compression Plate (LCP). An osteosynthesis plate based on the dynamic compression plate and the point contact fixator (PC – Fix). Injury 2001;32(Suppl 2):63-66.

[6] Wagner M. General principles for the clinical use of the LCP. Injury 2003;34(Suppl 2):B31-42.
[7] Egol KA, Kubiak EN, Fulkerson E, et al. Biomechanics of locked plates and screws. J Orthop Trauma 2004;18(8):488-493.
[8] Cooney WP, Linschied RL, Dobyns JH. External pin fixation for unstableColles' fractures. JBJS 1979;61A(6):840-845.
[9] Gartland JJ, Werley CW. Evaluation of healed Colles' fractures. JBJSA 1951;33A(4):895-907.
[10] Sarmiento A, Pratt GW, Berry NC,et al. Colles' fracture. Functional bracing in supination. JBJS 1975;57(3):311-317.
[11] Weber SC, Szabo RM. Severely comminuted distal radius fracture as an unsolved problem: complications associated with external fixation and pins and plaster techniques. J Hand Surgery 1986;11(2):157-165.
[12] Sarmiento A, Zagorski JB, Sinclair WF. Functional bracing of Colles' fractures: a prospective study of immobilization in supination versus pronation. Clinical Orthopaedics and Related Research 1980;146:174-183.
[13] Knirk JL, Jupiter JB. Intra-articular fractures of distal end of theradius in young adults. JBJS 1986;68(5):647-659.
[14] Jakob RP, Fernandez DL. The treatment of wrist fractures with the small AO external fixation device. In: Uhthoff HK, Stahl E, ed. Current concepts of external fixation of fractures. Berlin: Springer-Verlag1982:307-314.
[15] McKenna J, Harte M, Lunn J. External fixation of distal radial fractures. Injury 2000;31(8):613-616.
[16] Huang TL, Huang CK, Yu JK, et al. Operative treatment of intra-articular distal radius fractures using the small AO external fixation device. J Chin Med Assoc 2005;68(10):474-478.
[17] Orbay JL, Fernandez DL, Fernandez MD. Volar fixation fordorsally displaced fractures of the distal radius: a preliminary report. The Journal of Hand Surgery 2002;27(2):205-215.
[18] Leung F, Zhu L, Ho H, et al. 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):263-266.
[19] Sommer C, Gautier E, Müller M, et al. First clinical results of locking compression plate (LCP). Injury 2003;34(Suppl 2):B43-54.
[20] Musgrave DS, Idler RS. Volar fixation of dorsally displaced distal radius fractures using the 2.4-mm locking compression plates. J Hand Surg Am 2005;30(4):743-749.
[21] Wong KK, Chan KW, Kwok TK, et al. Volar fixation of dorsally displaced distal radial fracture using locking compression plate. J Orthop Surg (Hong Kong) 2005;13(2):153-157.
[22] Margaliot Z, Haase SC, Kotsis SV, et al. A meta-analysis of outcomes of external fixation versus plate osteosynthesis for unstable distal radius fractures. J Hand Surg [Am] 2005;30(6):1185-1199.
[23] Jeudy J. Treatment of complex fractures of the distal radius: a prospective randomised comparison of external fixation versus locked volar plating. Injury 2012;43(2):174-179.
[24] Esposito J, Schemitsch EH, Saccone M, et al.External fixation versus open reduction with plate fixation for distal radius fractures: a meta-analysis of randomised controlled trials. Injury 2013;44(4):409-416.
[25] Franceschi F, Franceschetti E, Paciotti M, et al. Volar locking plates versus K-wire/pin fixation for the treatment of distal radial fractures: a systematic review and quantitative synthesis. Br Med Bull 2015;115(1):91-110.
[26] Kapoor H, Agarwal A, Dhaon BK. Displaced intra-articular fractures of distal radius: a comparative evaluation of results following closed reduction, external fixation and open reduction with internal fixation. Injury 2000;31(2):75-79.
[27] Wright TW, Horodyski M,Smith DW. Functional outcome of unstable distal radius fractures: ORIF with a volar fixed-angle tine plate versus external fixation. J Hand Surgery 2005;30(2):289-299.
[28] Rizzo M, Katt BA, Carothers JT. Comparison of locked volar plating versus pinning and external fixation in the treatment of unstable intraarticular distal radius fractures. Hand 2008;3(2):111-117.
[29] Zamzuri Z, Yusof M, Hyzan MY. External fixation versus internal fixation for closed unstable intra-articular fracture of the distal radius. Early results from a prospective study. Med J Malaysia 2004;59(1):15-19.
[30] Margaliot Z, Haase SC, Kotsis SV, et al. A meta-analysis of outcomes of external fixation versus plate osteosynthesis for unstable distal radius fractures. J Hand Surg Am 2005;30(6):1185-1199.