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Volar locking plate osteosynthesis-the most effective treatment modality for management of unstable distal radius fractures: A clinico-radiological and functional outcome evaluation

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Abstract
Background: Fracture of distal radius is the most common fracture encountered by Orthopaedic surgeons. There is no consensus regarding optimal treatment of displaced distal radius fractures. Unstable fractures are best managed surgically and the results of volar locking plates have been promising. The aim of this study was to evaluate the clinical, radiological and functional results in patients with unstable distal radius fractures treated by open reduction and internal fixation using volar locking plate osteosynthesis.
Materials and Methods: A total of 32 patients with unstable distal radius fracture, selected between December 2018 to February 2020, were managed by using volar locking plate osteosynthesis. This was a prospective study conducted at a Tertiary care private Hospital in Kolkata, and all patients were followed up for a minimum period of 1 year. Radiological assessment was done according to the Sarmiento's modification of Lindstrom Criteria and Mayo wrist score was used to assess the functional outcomes of patients.
Results: 93.7% patients had Good to Excellent alignment of fragments on anatomic evaluation radiologically according to Sarmiento's modification of Lindstrom Criteria and 93.7% patients had Good to Excellent outcomes as per Mayo wrist score during the final follow-up. 28 (87.5%) patients did not develop any complications. At the end of 1 year, the mean Mayo wrist score was 90.31 ± 9.91. 87.5% patients had returned to their regular daily activities and pre-injury employment status by the end of final follow-up.
Conclusion: Volar locking plate fixation of unstable distal radius fracture provides a stable construct that helps in early mobilization, resulting in better clinical and radiological outcomes leading to early resumption to pre-injury functional level of an individual with minimal complications and, thereby is an upcoming method of choice for fracture distal end of radius.

Keywords: distal radius fracture, volar locking plate, functional outcome, internal fixation, mayo wrist score

Introduction
Distal radius fractures are the most common skeletal fractures, accounting for approximately 1/6th of all fractures in the human body; over 40% of these are considered unstable and require some kind of fixation [1] Intra-articular and extra-articular malalignment can lead to various complications such as post-traumatic osteoarthrosis, decreased grip strength and endurance, as well as limited motion, and carpal instability [2].
The fracture occurs most frequently due to a fall onto a hyperextended wrist, with a combination of axial load and bending forces that produce the fracture of the distal metaphyseal part of the radius. Distal radial fractures have a bimodal age distribution, consisting of a younger group who sustain a relatively high-energy trauma to the upper extremity and an elderly group who usually sustain a low energy trauma [3].
There are various treatment options for distal radius fractures including non-operative, external fixation (percutaneous pinning, bridging external fixator) and internal fixation (dorsal and volar plating, fragment specific fixation). The indications differ depending on the patient, their demands, and the type of fracture. As the prime goal of treatment is to maximize function in the hand and wrist, it is essential to consider the factors that may predict fracture instability or functional outcome, in planning treatment [4].
In spite of various new advances, closed reduction and cast immobilization has been the mainstay of treatment of these fractures but fracture malunion and subluxation/dislocation of distal radioulnar joint resulting in poor functional and cosmetic results is the usual outcome [5]. The goal of surgical fixation in the unstable distal radius fracture is to restore intra as well as extra-articular anatomic alignment. This greatly reduces the incidence of post-traumatic arthritis and also the quality of reduction that relates directly to the final outcome [6].
Open reduction and internal fixation is one of the most commonly used surgical techniques for distal radius fracture [7, 8]. Fixed angle construct provides additional strength to fixation by constructing a scaffold under the distal radial articular surface [9]. Primary stability achieved with locking screw in a plate prevents secondary displacement irrespective of the bone enabling good results in osteoporotic bones and also in young patients [10].

The development of fixed angular stable fixation techniques theoretically improves stability to maintain the reduction of fractures in osteoporotic bones and fractures considered to be unstable [11].
Volar fixed angle locking plates are an effective treatment for unstable extra-articular distal radius fractures allowing early post-operative rehabilitation [12]. Because of angular stability of locking compression plate's reduction can be maintained over times so that secondary displacement is no longer a problem [13]. The benefits of using volar locking plates include direct fracture fragment reduction, stable fixation and early post-operative rehabilitation leading to early return of range of motion and return to work [14-16].The number of complications associated with volar locking plates is relatively low as compared to dorsal plating [17]. When comparing the volar locking plate with non-locking constructs biomechanically, the former appears to be more stable and even holds the dorsally displaced fragment [18, 19].
The objective of this study was to represent our experience comprising cases of displaced and unstable distal radius fractures which were treated by open reduction and internal fixation using volar locking plate osteosynthesis to see whether the technique achieves stable fixation, good range of motion, acceptable radiological union with improved clinical and functional outcome using this easily available implant via a simple and safe surgical technique.

Materials and Methods

This was a prospective study conducted in accordance with the ethical standards of the institutional review board. 32 patients with post-traumatic unstable distal radius fractures who were treated by open reduction and internal fixation using volar locking plate osteosynthesis in the Department of Orthopaedics, Peerless Hospital and B. K. Roy Research Centre, Kolkata from December 2018 to February 2020 and fulfilling the inclusion criteria were considered for this study.

Inclusion criteria

- Skeletally mature patients above 18 years of age
- Closed fractures
- Fresh injury (<3 weeks old)
- Healthy skin condition at the incision site

Exclusion criteria

- Pathological fractures
- Bilateral distal radius fractures
- Poor local soft tissue condition
- Associated neurovascular injury
- Associated other bone fracture of ipsilateral upper limb

Operative Procedure

The patients were subjected to a thorough history, clinical examination and pre-operative routine laboratory investigations, which was supplemented by radiographs in antero-posterior and lateral view of the wrist joint. CT Scan with 3D reconstruction was done in some cases. A below elbow plaster slab was applied on the affected side for temporary immobilization of fracture, pain relief and soft tissue healing until definitive surgery.
The patients were operated under General or Regional anaesthesia. Patients were positioned supine on orthopaedic table with a radiolucent operating side table. Pneumatic tourniquet was used in all cases. The surgery was done via modified Henry's approach. A 5-8 cm longitudinal incision was made along the radial border of the flexor carpi radialis tendon beginning at the wrist flexion crease and proceeding proximally depending on the extent of fracture and length of the plate. The tendon sheath was opened and it was retracted towards the ulna. The incision was deepened between flexor pollicis longus and radial artery. Care was taken to avoid damaging the radial artery on the radial side and the palmar cutaneous branch of the median nerve on the ulnar side. Blunt dissection was carried out to sweep the flexor pollicis longus muscle belly towards the ulna so as to expose the pronator quadratus muscle. The muscle was incised on its radial border and elevated using an L-shaped incision, exposing the distal radius. It was then stripped off the distal radius together with the periosteum. The pronator and flexors were retracted towards the ulnar side to reveal the fracture. All interposed soft tissues were excised and a preliminary reduction of the fracture was performed via direct or indirect means, which was accomplished by distraction and wrist flexion, and held temporarily by K-wires if necessary, under fluoroscopic guidance. Appropriate size locking plate was selected and placed over the volar surface of radius below the watershed line and temporarily fixed using cortical screw. After achieving the desired reduction, remaining screws were placed and re-confirmed under fluoroscope. Extra precaution was taken regarding dorsal penetration of screws which may lead to rupture of extensor tendons. The pronator quadratus muscle was placed over the plate and repaired using absorbable sutures. Subcutaneous tissue and skin closure was done in layers. Sterile dressings were applied to the surgical incision and the wrist was immobilized in a below elbow plaster slab.

Rehabilitation

Postoperatively, the operated limb was kept elevated in an arm pouch support. Active finger movements, forearm rotation and shoulder exercises were started on the second day. The plaster slab was removed after 2

weeks, crepe bandage applied and active exercises of wrist, elbow and shoulder were started. Lifting of heavy weight was not allowed until signs of fracture healing were radiographically confirmed.

Follow-up

The patients were regularly followed up for a minimum of 1 year at 2 weeks, 6 weeks, 12 weeks, 6 months and 1 year interval. Except for the first visit, in which only local wound condition was addressed, subsequent visits included thorough clinical and radiological assessment.

Clinical parameters evaluated were pain, swelling, tenderness, deformity, any obvious nerve palsy, compression of the level of radius and ulnar styloid process on normal and abnormal side and any complication thereof were recorded. Radiological assessment was done in terms of volar tilt or palmar inclination, radial length, radial inclination, articular step-off, radial shift and ulnar variance and the results were graded according to the Sarmiento's modification of Lindstrom Criteria. Functional assessment of the patients was done at the final follow-up as per the Mayo Wrist Score.

Statistical analysis

The data was collected in Microsoft Excel (Windows 10; version 2016) and the statistical software SPSS version 20 was used for analysis. Categorical variables were expressed as number of patients and percentage of patients and compared across the groups using Fisher's Exact Test. Continuous variables were expressed as mean, median and standard deviation and compared across the groups using Kruskal Wallis Test. An alpha level of 5% was taken, i.e., if any p value was less than 0.05 it was considered to be significant.

Results

Age Distribution

Overall, 81.3% patients were between the age group of 20-50 years. The mean age in this study was 41.28 ± 11.82 years. The youngest patient was 21 years old and the eldest patient was 67 years old. It might be because of growing incidence of unstable distal radius fractures in younger adults related to high energy injuries rather than simple fall secondary to motor vehicle accidents and sports.

Table 1: Age Distribution

Age (years)	No. of Patients	Percentage (%)
20-30	6	18.8
31-40	9	28.1
41-50	11	34.4
51-60	4	12.5
61-70	2	6.2
Total	32	100.0

Sex Distribution

22 patients (68.8%) were male and 10 patient was female (31.2%). Majority of patients were Male which may be because of more outdoor and sports related activities makes them more vulnerable to accidents and trauma.

Side of Injury Distribution

Number of Right wrist involvement was 14 (43.8%) which was almost comparable to Left wrist involvement which was 18 (56.2%). Dominant hand was involved in 17 (53.1%) patients.

Mode of Injury Distribution

In this study, 15 (46.9%) patients were involved in road traffic accident, 13 (40.6%) suffered a fall, and 4 (12.5%) sustained a direct blow to the injured wrist.

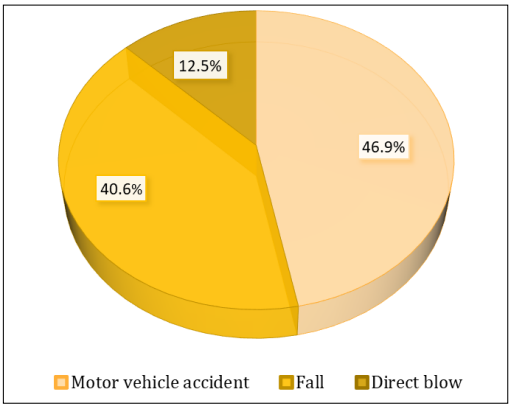

Fig 1: Mode of Injury Distribution

Fracture type Distribution
The distal radius fractures were selected and classified as per the Frykman classification.

Table 2: Frykman classification Distribution

Frykman Type	No. of patients	Percentage (%)
II	4	12.5
IV	3	9.4
VII	5	15.6
VIII	20	62.5
Total	32	100.0

Radiological Evaluation
Dorsal tilt
As compared to normal hand, the volar tilt (from a neutral of 0^0) of the distal radial articular surface varied from 4^0 to 26^0, average being 12^0. The tilt decreased from an average of 13^0 dorsal pre-operatively to an average of 7.72 ± 5.18^0 volar at the final follow up evaluation.
Post-operatively, the dorsal tilt was corrected to the anatomical palmar tilt or at least a neutral angle in 28 patients (87.5%) while in 4 patients (12.5%) the dorsal tilt could not be restored even to a neutral angle.
At the final follow up, 1 patient (3.1%) had some loss of correction of dorsal tilt. In 96.9% of the patients the correction of tilt achieved at surgery was maintained till healing.

Radial length
The average loss of radial length was 11 mm pre-operatively which decreased to an average of 1.13 ± 1.93 mm loss at the final follow up.
In 1 patient (3.1%) there was 4 mm of collapse of radial length from the immediate post-operative to the final follow up period. 96.9% of the fractures maintained the post-operative radial length till union.

Radial inclination
The loss of radial inclination varied from 0^0 to 10^0. The average loss of radial inclination was 12.1^0 pre-operatively which decreased to an average loss of 2 ± 2.57^0 at the final follow up. In 1 (3.1%) patient there was a loss of 3^0 correction of radial inclination.

Anatomical evaluation by Sarmiento's modification of Lindstrom Criteria
Anatomically 26 patients (81.2%) had Excellent, 4 patients (12.5%) had Good and 2 had Fair (6.3%) restoration of anatomy. Poor anatomic restoration was not seen in any of the patients. Thus, 93.7% patients had good to excellent alignment of fragments.

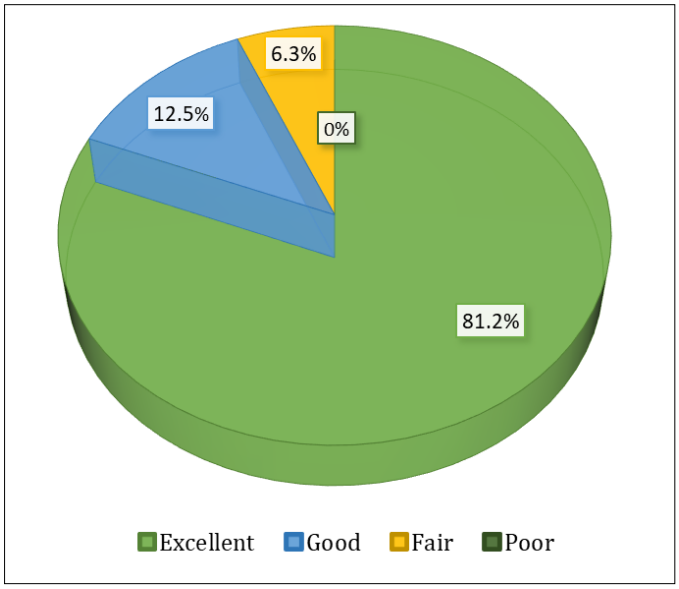

Fig 2: Anatomical evaluation by Sarmiento's modification of Lindstrom Criteria

Functional Evaluation
Range of Motion
The mean dorsiflexion at final follow up in our study was 57.19 ± 10.33^0 ranging from $30\text{-}65^0$ whereas the mean palmar flexion was 59.78 ± 9.73^0 with a range of $30\text{-}70^0$.

Mean radial deviation was 14.03 ± 3.06^0 [range: 8-18^0] and mean ulnar deviation was 24.66 ± 5.53^0 [range:10-33^0].
The average pronation and supination were 68.63 ± 6.69^0 [range: 50-80^0] and 76.28 ± 9.66^0 [range: 50-85^0] respectively.
21 (65.6%) patients had >120^0, 9 (28.1%) had 90^0-120^0 and 2 (6.3%) had 60^0-90^0 arc of motion. In none there was <60^0 arc of movement by the end of 1 year follow up.

Grip strength
The mean grip strength on the injured side as compared to the other side at the last follow up was 91.09 ± 9.31% with a range between 70-100%. 13 patients regained full grip strength.

Mayo Wrist Score
At the end of final follow-up, the average Mayo wrist score for 32 patients was 90.31 ± 9.91.

Mayo Wrist Score Outcome
25 (78.1%) patients showed Excellent and 5 (15.6%) patients had Good results. 2 (6.3%) patients demonstrated Satisfactory whereas none had Poor result post-operatively at the end of 1 year follow up.

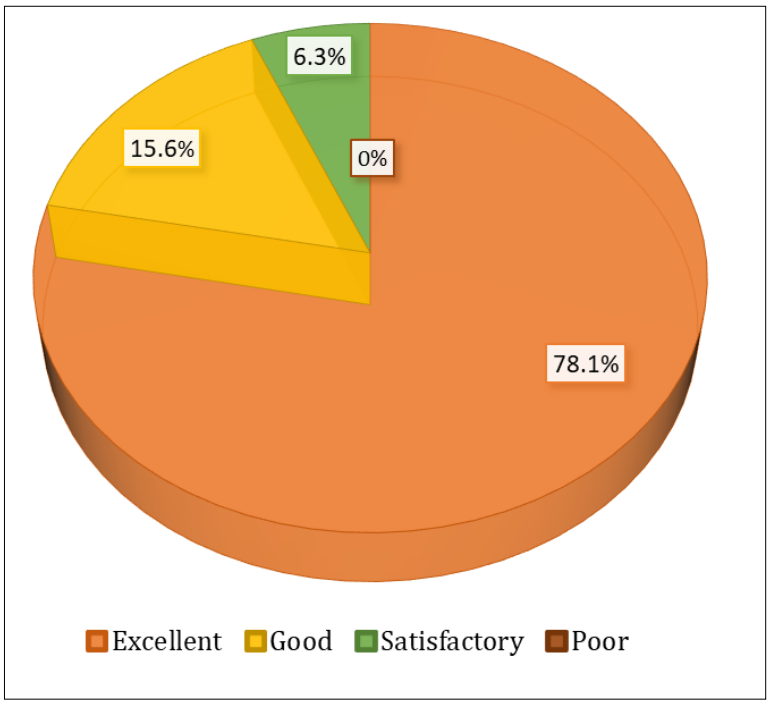

Fig 3: Mayo Wrist Score Outcome

Complications
28 (87.5%) patients did not have any complications. 4 patients (12.5%) had mild occasional pain out of which 3 patients (9.4%) had a significant loss of grip strength. These 4 patients (12.5%) were on restricted employment due to pain, restriction of movement and decreased grip strength. Otherwise, rest all of the patients returned to their regular daily activities and pre-injury employment status. Other complications such as infection, non-union, instability, finger stiffness, carpal tunnel syndrome, complex regional pain syndrome and loss of reduction were not seen. No patient had to undergo implant removal for hardware related problems. Majority of patients (93.7%), presented within 1 week of injury. The average time to radiological union was observed to be around 12 weeks. No intraoperative complications such as excessive bleeding, iatrogenic fracture, tendon rupture or neurovascular damage were encountered during the surgical procedure.

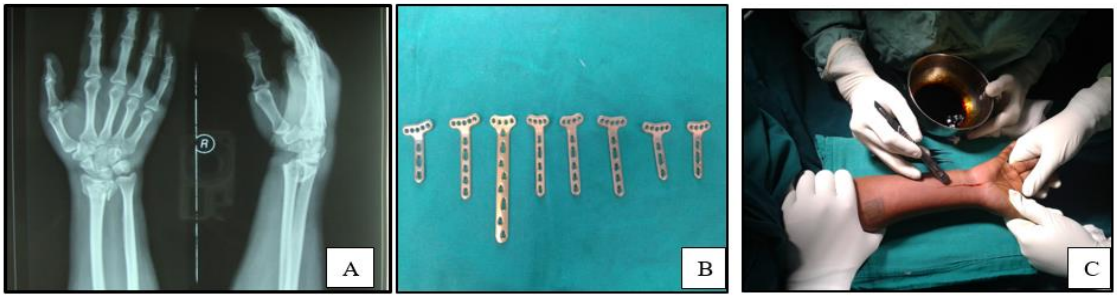

Fig 4: (A) Pre-op X-ray showing an unstable distal radius fracture; (B) Volar locking plates of various size; (C) Intra-op marking of incision site; (D) Intra-op view showing plate placement with appropriate screw combination; (E) Intra-operative lateral fluoroscopic view of wrist post fracture reduction and plate-screw placement; (F) Intra-operative antero-posterior fluoroscopic view of wrist post fracture reduction and plate-screw placement; (G) Post-operative healed surgical scar; (H) Antero-posterior radiograph showing anatomical fracture reduction status with plate and screws in situ at final follow-up; (I) Lateral radiograph showing anatomical fracture reduction status with plate and screws in situ at final follow-up; (J) Palmar flexion at final follow-up; (K) Dorsiflexion at final follow-up; (L) Supination at final follow-up; (M) Pronation at final follow-up

Discussion

Distal end radius fractures are the most frequently seen upper extremity fractures. They can present with a wide array of fracture patterns, with variations in the extent of displacement, degree of articular disruption, and the stability and reducibility of fragments.

The goal of surgery for unstable distal radius fracture is to obtain and maintain an anatomical reduction and to allow restoration of function [20]. Achieving fracture stability is a pre-requisite for attaining a satisfactory outcome. Unstable fractures are at increased risk of loss of reduction and subsequent malunion.[21] Malalignment can potentially lead to a poor functional outcome with residual pain, loss of motion, decreased endurance and grip strength, midcarpal instability, and post-traumatic arthritis [22].

As far as the treatment of these fractures are concerned, it is one of the most challenging type. The management of distal radius fracture has undergone changes owing to the advances in technology. Improved imaging methods provide better understanding of fractures and elucidation of the effects of the injury type on fracture formation and factors that lead to instability. The desired fixation method is the one that can not only maintain satisfactory reduction, but also allow early motion to avoid joint stiffness and disuse atrophy [10]. Open reduction and internal fixation performed via volar approach using a locking plate osteosynthesis is now a days considered as the treatment of choice for unstable distal radius fractures.

Internal stabilization of distal radius fractures, especially with a volar locking plate, provides a better restoration of radiographic parameters such as radial height, radial inclination and volar tilt as compared to other treatment modalities for such injuries. It also provides a better technique to fix osteoporotic bone [23]. The biomechanical results show that locking volar plates provide significantly greater resistance to fracture gap motion compared to standard volar plates in a dorsally comminuted distal radius fractures [14]. Biomechanical studies comparing volar fixed angle fixation plates with conventional dorsal implants report that the former plates are stronger [18]. Fixed-angle volar plates prove stronger under cyclical loading tests than dorsal implants as the implant-bone interface is the limiting factor [18]. In a locking screw system, the threaded screw head locks in the threaded screw hole of the plate to attain stability. Consequently, axial forces in the bone are transmitted to the plate rather than the screw, and no screw toggle can occur. Because stability with a locking screw does not require compression between the bone and the plate, the periosteal blood supply under the plate is preserved [24].

In the volar approach, the volar anatomy of the wrist presents an advantage over the dorsal aspect because there is more space between the volar cortex and the flexor tendons. The pronator quadratus can also sometime act as a hedge to prevent soft tissue complications. The palmar cortex is relatively flat, and the plate is better contoured for application from this aspect rather than on the dorsal cortex of the distal radius [25]. Anatomical reductions of palmar cortex may avoid the shortening of the radius, which is important for its restoration. The volar plate system used in our study was a locking plate system and this might be one of the reasons for retaining good anatomical reduction.

In multifragmentary comminuted fracture of distal radius, fragment specific or column specific fixation may be required (Three column theory – radial, ulnar and intermediate). The variable angle volar locking plate plays an important role in this scenario as it has been designed to address complex fracture patterns. The two columns – radial and intermediate; can be stabilized adequately using a single plate. Fragment specific fixation also becomes possible through multiple distal holes by multidirectional screw placement. Moreover, fixed-angle plate designs minimize screw loosening in the distal fragments due to the 'toggling effect' and thereby reduce the danger of secondary displacement [26]. Extraarticular plate was used specially in those cases without intraarticular involvement. Periarticular plate was used mainly in intraarticular fracture where much distal placement of the plate can be done for its distal screw orientation. Juxtaarticular plate was not used in any case because of in built torsion of this high-profile plate resulting in mismatch and difficulty in plate fixation in our population.

Surgical approach, fracture reduction, and volar plating techniques are easier than dorsal plating. Vascularity of dorsal distal radius is not hampered with volar plating. Extensor tendon handling in dorsal approach may injure these structures which is preserved by palmar approach. Closure of the wound preceded by well coverage of healthy pronator quadratus breasting over volar plate is also an additional advantage [27].

In our study population, demographic factors such as age, sex, handedness, and dominance of the injured hand had no significant bearing on the functional or radiological outcome. The fracture type, i.e., extra-articular, partial articular, or intra-articular, including its subtypes, did not show any significant effect on the outcome at any interval. Though less favourable outcomes were more frequent in the intra-articular fractures, this was not found to be statistically significant. The mechanism of injury (high or low velocity) and time duration till surgery also did not have any significant influence.

Table 3: Correlation of Sarmiento's modification of Lindstrom Criteria with continuous variables (Mean ± SD)

	Sarmiento's modification of Lindstrom Criteria			
	Excellent	**Good**	**Satisfactory**	**P value**
Age (years)	40.64 ± 10.61	43.60 ± 13.61	43.50 ± 28.99	0.848
Volar tilt (^{0})	9.80 ± 3.73	0.40 ± 0.89	0.00 ± 0.00	<0.001
Radial shortening (mm)	0.28 ± 0.61	3.60 ± 1.34	5.50 ± 3.54	<0.001
Loss of radial inclination (^{0})	1.04 ± 1.27	4.00 ± 2.35	9.00 ± 1.41	0.002
Dorsiflexion (^{0})	62.20 ± 2.16	43.00 ± 4.47	30.00 ± 0.00	<0.001
Palmar flexion (^{0})	64.12 ± 3.32	48.00 ± 7.58	35.00 ± 7.07	<0.001
Arc of Movement (^{0})	126.64 ± 4.83	93.00 ± 4.47	65.00 ± 7.07	<0.001
Radial deviation (^{0})	15.16 ± 2.34	10.80 ± 0.84	8.00 ± 0.00	0.001
Ulnar deviation (^{0})	26.56 ± 3.44	20.00 ± 6.28	12.50 ± 3.54	0.005

Pronation (^{0})	71.04 ± 4.77	63.00 ± 1.41	52.50 ± 3.54	0.002
Supination (^{0})	80.20 ± 5.41	67.20 ± 1.64	50.00 ± 0.00	0.001
Grip strength (%)	93.00 ± 7.22	90.00 ± 10.61	70.00 ± 0.00	0.042
Mayo Wrist Score	94.40 ± 5.07	81.00 ± 2.24	62.50 ± 3.54	<0.001

No significant difference was observed in the various radiological parameters at the last follow up, as compared to immediate post-operative period and at 3 months; indicating that the fracture fixation was rigid in the present study and no further significant collapse of the fracture occurred post-surgery. Sarmiento's modification of Lindstrom Criteria at the last follow up showed good to excellent result in 93.7% of patients in our study. Jose et al[28] reported Lindstrom score to be good to excellent in 86.8% of the cases; while Kotian P et al[29] observed the same in 75% of the studied participants.

Concerning functional outcome in our study, we achieved in 93.7% of cases a good to excellent outcome, and satisfactory outcome in 6.3% of cases according to the Mayo wrist scores, comparable to studies conducted by other authors such as Kenny K et al[30] who showed excellent outcome in 88% of cases and good outcome in 8% of cases, Sugun et al[31] who reported excellent scores in 14 of their patients, good in 11, satisfactory in 20 and poor in 1 patient. Agarwala et al[32] reported excellent/good result in 88% and satisfactory result in 12% of patients and similar results were obtained in the study done by Chavhan et al[33] in which functionally 16 patients (46%) had excellent, 15 well (43%) and 4 patients (11%) had satisfactory restoration of functions.

Results obtained in the present study are similar and comparable to the results reported in the literature in terms of union, anatomical parameters and functions with special feature of minimal complications.

It is proven from this study that restoration of anatomical reduction and stable fixation results in good to excellent functional outcome as per the Mayo wrist score.

Table 4: Correlation of Mayo Wrist Outcome with Sarmiento's modification of Lindstrom Criteria

		Mayo Wrist Outcome			**Total**	**P value**
		Excellent	**Good**	**Satisfactory**		
Sarmiento's modification of Lindstrom Criteria	Excellent	24 (96)	2 (40)	0 (0)	26 (81.3)	0.001
	Good	1 (4)	2 (40)	1 (50)	4 (12.5)	
	Satisfactory	0 (0)	1 (20)	1 (50)	2 (6.2)	
Total		25 (100)	5 (100)	2 (100)	32 (100)	

Proper understanding of fracture and fracture pattern is equally important which has become easier now a days due to advancement of recent technology and investigations. Operative skill, advance instruments, availability of various type of implants and assistance backup are other mentionable determining factors. Proper post-op rehabilitation is an important factor from the patient's side for which follow up at regular interval with proper guidance is very essential. In overall, a good effort from the surgeons team as well as from the patients side is crucial for better clinical and functional outcome.

Limitations of our study include single institution bias, small group of patients, short follow-up period and a lack of control group. A multicentre study with more patients is essential to substantiate benefits of this treatment method.

Conclusion

Despite the multiple treatment options and approaches available for managing unstable distal radius fractures, locking plate fixation through the volar approach seems to be the 'gold standard' in terms of decreased complication, stable reduction and fracture fixation, and association with good functional outcome in these fractures. The technique emphasizes that open reduction and internal fixation using volar locking plate osteosynthesis provides good-to-excellent clinical, radiological and functional results and is effective in the correction and maintenance of distal radius anatomy as it avoids bridging the radiocarpal joint and allows for early joint movement, owing to its fixation strength. This procedure is applicable for all unstable fractures of the distal radius, in young patients with a good bone stock as well as in elderly osteoporotic patients.

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