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Original Research

Computer-Assisted Circular External Fixator in the Treatment of Wrist and Forearm Deformities: Functional and Radiological Outcomes

Muharrem Kanar, Yusuf Sulek, Harun Akbas, Gungor Alibakan, Bilal Gok, Raffi Armagan

Department of Orthopedics and Traumatology, University of Health Sciences Türkiye, Sisli Hamidiye Etfal Training and Research Hospital, Istanbul, Türkiye

Abstract

Objectives: Wrist and forearm deformities are usually due to congenital or post-traumatic causes. These deformities cause progressive pain and limitation of motion and impair quality of life. Acute correction with radius and/or ulna osteotomy and fixation with plate or wire can be applied in treatment, but complications such as vascular/nerve damage, malunion and inadequate correction may be encountered. Treatment with circular external fixators provides correction without residual deformity and is safer because it can provide deformity correction and gradual lengthening both intraoperatively and postoperatively. Computer-assisted circular external fixators (Ca-CEF) facilitate the correction of complex deformities by allowing postoperative deformity planning to be redone. In this study, we analyzed wrist or wrist deformities treated with Ca-CEF.

Methods: The hospital database was searched for patients who underwent surgery for wrist and forearm deformity between 2010 and 2020. Demographic data, radiographic and functional measurements of the patients were evaluated. Preoperative and postoperative forearm supination, pronation, wrist flexion and extension, Visual Analog Scale (VAS), Disabilities of the Arm, Shoulder, and Hand (DASH) score, Mayo Wrist Score and grip strength were measured. Radiological measurements of radius, ulna lengths, radial inclination and volar tilt were performed. Postoperative complications were analyzed. Preoperative and postoperative data of the patients were analyzed statistically.

Results: A total of 14 patients were included in the study. The mean age of the patients was 17.1 years (11-34), 8 were female and 6 were male. The mean follow-up period was 18.4 months (6.8-32.9). The planned anatomical correction was achieved in all patients. The mean differences between preoperative functional and radiographic data and postoperative data were 7.8 ($p=0.029$) for forearm supination, 14.64 ($p<0.001$), 6.17 kg for Grip Strength ($p=0.001$), 3.07 for VAS ($p<0.001$), 21 points for DASH Score ($p=0.003$), and 22.14 points for Mayo Wrist Score ($p=0.004$), which were statistically significantly better. No major complications were observed in any patient.

Conclusion: The study showed that Ca-CEF provides functional improvement and radiological improvement and is a safe treatment method with low complication rates. This method stands out as an effective option in the treatment of complex deformities.

Keywords: Computer-assisted, computer-assisted surgery, deformity correction, external fixators, hexapod, Madelung deformity, Taylor spatial frame, wrist joint

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Address for correspondence: Muharrem Kanar, MD. Department of Orthopedics and Traumatology, University of Health Sciences Türkiye, Sisli Hamidiye Etfal Training and Research Hospital, Istanbul, Türkiye
Phone: +90 532 510 04 18 **E-mail:** dr.kanar@hotmail.com

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Wrist and forearm deformities are generally seen as congenital malformations or pathologies that develop after trauma and cause serious functional limitations in the daily life activities of the patients and negatively affect the quality of life.[1–3] The increase in pain over time and limitation of joint movements make surgical treatment inevitable. Various approaches have been reported and conservative treatment, acute correction with osteotomy of the radius and/or ulna, fixation with plate or K-wire are commonly used methods.[4–6] However, serious complications such as vascular and nerve injury, malunion, nonunion and inadequate correction can be encountered with these methods.[7]

Circular external fixators allow correction of the deformity during and after surgery. It also provides correction of the deformity with fewer major complications.[8] Computer-assisted circular external fixators (Ca-CEF) have further improved the potential of this method and made the treatment of complex deformities safer and more effective after surgery.[9,10] The three-dimensional planning provided by Ca-CEF reduces the need for postoperative revision and the risk of postoperative complications.[8]

The aim of this study was to evaluate the functional and radiological results of patients treated with Ca-CEF for wrist and forearm deformities and to evaluate its efficacy and safety in this patient group. Our hypothesis in this study is that wrist and forearm deformities can be corrected with Ca-CEF safely and with a good functional result.

Methods

Study Design

This retrospective comparative study was performed under approval of the institutional ethical review board (approval no: 4502; date: 20/08/2024) in accordance with the Declaration of Helsinki all patients provided informed consent prior to participation.

Setting

Patients treated for wrist and forearm deformity between 2010 and 2020 with Ca-CEF (Spider Frame-Tasarımmed, Istanbul, Türkiye), a circular external fixator consisting of two rings connected by six telescopic rods and allowing simultaneous deformity correction around a virtual hinge axis through computer-assisted six-axis deformity analysis, were retrospectively analyzed through our medical records.

Patients aged 10-30 years with radius deformity treated with Ca-CEF were included in the study (Fig. 1). In cases accompanied by ulna deformity, a mini monolateral fixator was incorporated into the Ca-CEF system for additional stabilization of the ulna (Fig. 2).

In patients with deformity at the Centre of Rotation of Angulation level close to the radiocarpal joint, the radiocarpal joint was bridged to increase system stability (Fig. 3). For this purpose, one or two shanz screws were applied to the second or third metacarpal bones. The bridging procedure was terminated after a maximum of 6 weeks when the deformity was completely corrected. In cases requiring lengthening, the lengthening process was performed gradually at a rate of 0.75 mm per day.

In all patients, the fixator system was removed after correction of the deformity and radiological consolidation. The patients were retrospectively evaluated in terms of the localization of the deformity, the necessity of the radiocarpal joint bridge and the results of the methods used. The surgical methods chosen were determined for each patient considering the severity of the deformity and biomechanical requirements.

All included patients had complete medical records, ra-

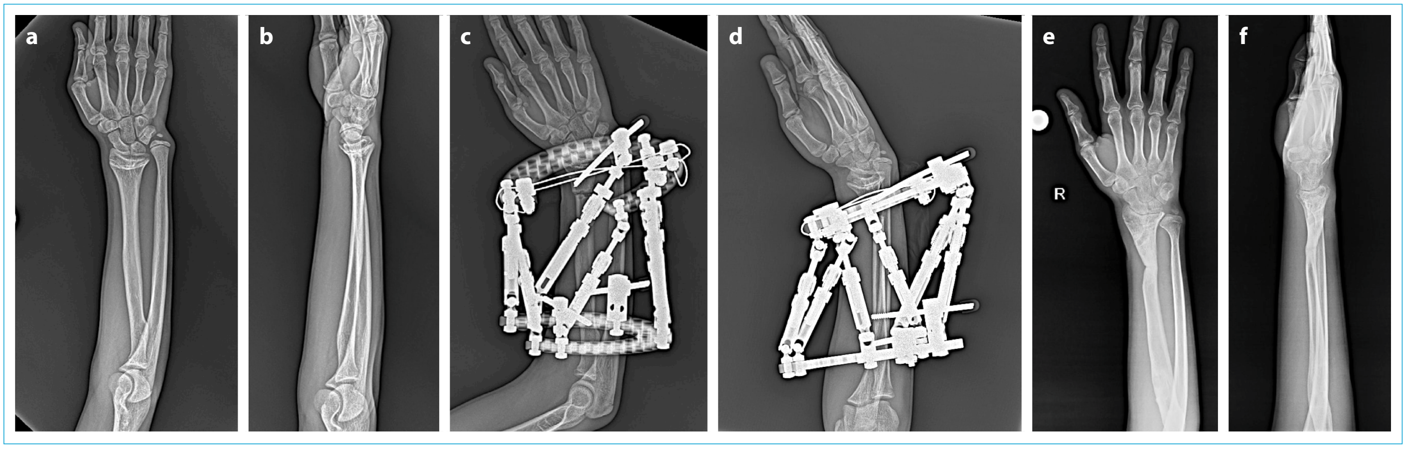

Figure 1. Preoperative wrist radiographs in anterior-posterior **(a)** and lateral **(b)** views, and postoperative wrist radiographs in anterior-posterior **(c, e)** and lateral **(d, f)** views, demonstrating deformity correction using the Computer-Assisted Circular External Fixator (Ca-CEF).

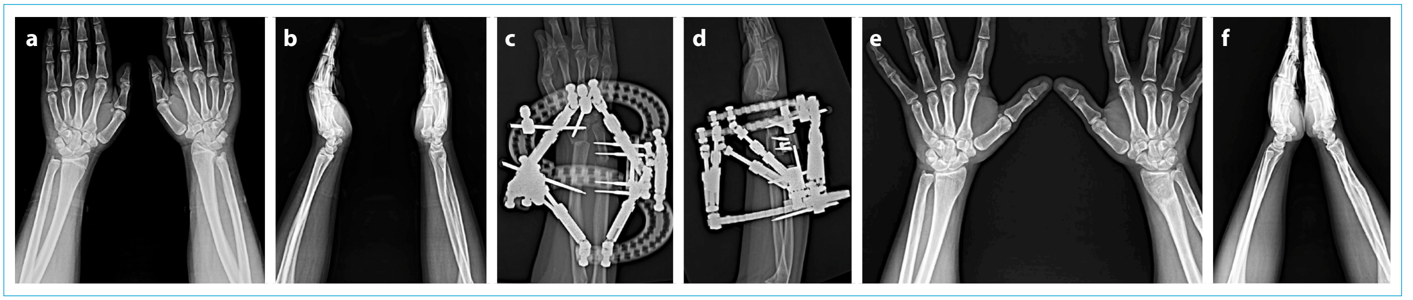

Figure 2. Preoperative wrist radiographs in anterior-posterior **(a)** and lateral **(b)** views, and postoperative wrist radiographs in anterior-posterior **(c, e)** and lateral **(d, f)** views, demonstrating the inclusion of a mini monolateral fixator in the Computer-Assisted Circular External Fixator (Ca-CEF) system for additional stabilization of the ulna in cases accompanied by ulna deformity.

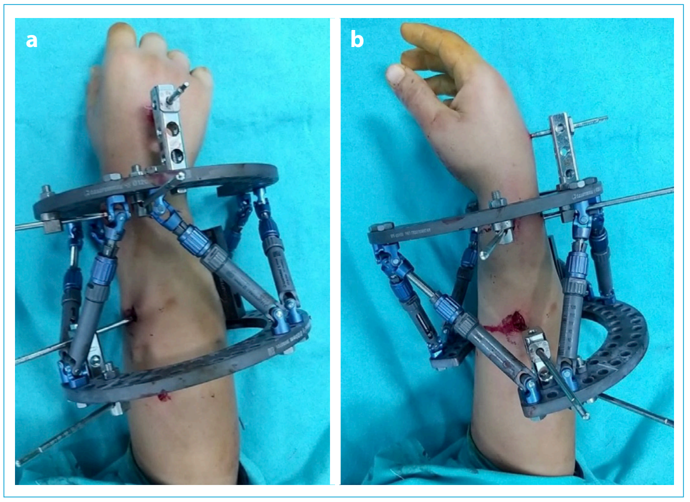

Figure 3. Anterior **(a)** and lateral **(b)** views of the wrist in a patient with a radiocarpal joint bridge applied to enhance stability during deformity correction using the Computer-Assisted Circular External Fixator (Ca-CEF).

diographs suitable for evaluation, and a minimum follow-up period of 6 months after treatment with Ca-CEF. Patients with incomplete medical data, radiographs not suitable for evaluation, and a follow-up period of less than 6 months after treatment with Ca-CEF were excluded from the study.

Variables

The primary variables were radiological and functional results. Preoperative and postoperative demographic data, radiological and functional measurements were evaluated. Functional assessment included range of motion (forearm supination, pronation and wrist flexion and extension), Disabilities of the Arm, Shoulder, and Hand (DASH) Score, Mayo Wrist Score and Grip Strength. Pain status of the patients was assessed using a Visual Analogue Scale (VAS) (Fig. 4). Radiological measurements of radius, ulna lengths, radial inclination and tilt were performed by two orthopedic specialists at 1-month intervals. Intraoperative and postoperative complications were analyzed. Furthermore, functional scores were assessed using standardized scales to ensure uniformity in the evaluation process. The study size was determined by the number of patients who met the inclusion criteria during the defined study period (2010-2020).

Statistical Analysis

The statistical analysis of this study was performed by using SPSS Statistics software, version 27 (Armonk, New York: IBM Corp.). Descriptive variables were expressed as number, percentage, mean value, mean value (range; minimum-maximum) and mean±standard deviation. Preoperative and postoperative radiological and func-

Figure 4. Comparison of preoperative and postoperative range of motion in wrist extension **(a)**, and flexion **(b)**, forearm pronation **(c)**, and supination **(d)**.

tional evaluation data were compared. Shapiro-Wilk test was used to evaluate the normal distribution of the preoperative and postoperative difference. Preoperative and postoperative differences were also subjected to a power analysis. The effect size was calculated as 0.8 using Cohen's d method, and based on 80% power and a significance level of 0.05, 12 patients were determined to be sufficient. Variables conforming to normal distribution were analyzed by independent samples t-test; variables not conforming to normal distribution were evaluated by Mann-Whitney U test. In all analyses, a Type-1 error (α) of 5% and a p-value <0.05 were accepted as the limit of statistical significance.

Results

Demographic Outcome

A total of 14 patients who met the inclusion and exclusion criteria were included in the study. Only 2 patients were excluded because they dropped out of the postoperative follow-up. The mean age of the patients was 17.1 years (range 11 to 34 years), 8 were female and 6 were male. The mean follow-up period was 18.4 months (range 6.8 to 32.9) (Table 1). The planned anatomical correction was achieved in all patients.

The mean differences between preoperative functional and radiographic data and postoperative data were 7.68 for forearm supination (p<0.05), 14.64 for wrist flexion (p<0.001), 6.17 kg for grip strength (p=0. 001), 3.07 for VAS (p<0.001), 21 points for DASH score (p=0.003), and 22.14 points for Mayo Wrist Score (p=0.004), which were statistically significantly better (Table 2) (Figs. 5, 6).

The preoperative and postoperative radius and ulna length, inclination, volar tilt data of the patients are shown in Table 3 and only statistically significant difference in radius length was found between preoperative and postoperative (Fig. 7) (p=0.023). No major complications were observed in any patients. Pin site infections were managed successfully with appropriate pin site care.

Discussion

In this study, it was shown that computer-assisted circular external fixators can be used successfully and safely, especially in the treatment of complex wrist and forearm deformities. Significant improvements in the postoperative joint clinical results and functional scores of the patients support the effectiveness of Ca-CEF. Our findings support our hypothesis that Ca-CEF can be used to correct wrist and forearm deformities safely and with good functional results.

Many patients with wrist deformities present with mild or asymptomatic cases, and conservative treatment is indicated for such patients.[11,12] In symptomatic cases, treatment is planned according to deformity, symptoms and etiology. If surgical treatment is required, corrective osteotomy and various fixation methods can be used.

In the literature, it has been reported that good anatomy is a predictor of improvement in clinical outcomes with restoration.[13–15] However, although all methods applied can improve the deformity, it is not clear which method is more effective. In patients with painful and progressive Madelung deformities, radius osteotomy and Ilizarov technique have been reported to be a successful method for correction of the deformity.[10,16] In addition, Ca-CEF has been shown to be successful in correcting wrist and forearm deformities. In a study in which 8 wrists of 7 patients with Madelung deformity were evaluated with the Ilizarov method, a change in mean radial inclination from 45° to 30°, a change in mean volar inclination from 25° to 11°, and an average increase in radial length of 12 mm were observed.[17] In our study, it was observed that similar anatomical restoration could be

Table 1. Patient characteristics

Characteristics	Preoperative
Mean age (years)	17.1±8.4
Gender	
Women	8
Men	6
Etiology	
Posttraumatic	4
Congenital	10
Duration of Ca-CEF (days)	99.6±26.7
Follow-up periods (month)	18.4±8.4

Ca-CEF: Computer-Assisted Circular External Fixator.

Table 2. Functional and radiological outcomes (Mean±SD)

Items	Preoperative (Mean±SD)	Postoperative (Mean±SD)	p
Grip Strength (kg/F)	15.5±4.2	21.7±4.7	<0.001
Range of motion (degrees)			
Supination	68.6±9.5	76.4±8.4	0.029
Pronation	69.6±12.4	74.3±10.1	0.352
Wrist Extension	47.5±15.5	71±9	0.137
Wrist Flexion	56.4±11.3	57.1±18.6	<0.001
VAS pain score	6.6±1.3	3.6±1	<0.001
Mayo Wrist Score	56.8±21.1	78.9±9	0.004
DASH	39.3±20.9	18.4±11.6	0.003

VAS: Visual Analog Scale; DASH: Disabilities of the arm, shoulder, and hand.

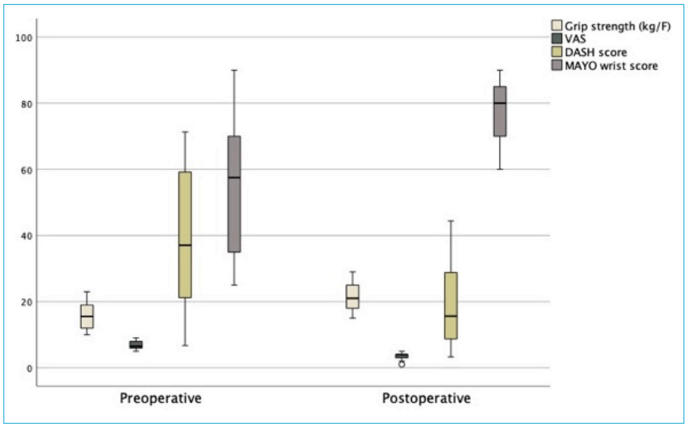

Figure 5. Preoperative and postoperative functional scores: grip strength, VAS, DASH, and Mayo Wrist Score.

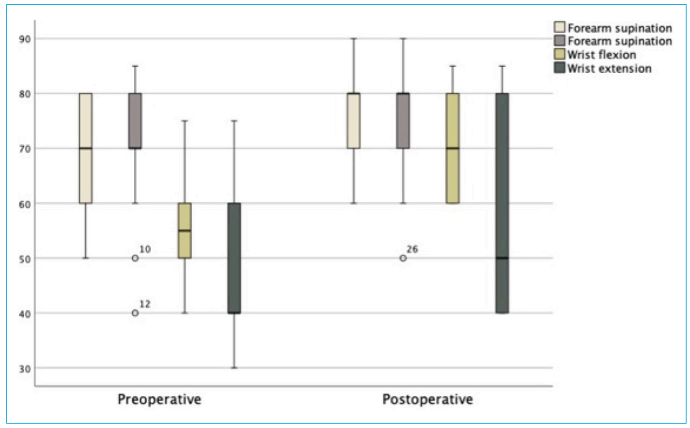

Figure 6. Preoperative and postoperative range of motion in forearm supination, wrist flexion, and wrist extension, demonstrating significant ımprovements after Ca-CEF treatment.

Table 3. Radiographic measurements

Items	Preoperative (Mean±SD)	Postoperative (Mean±SD)	Percentage of change (%)	p
Radius lenght (mm)	184.1±25.9	209.4±29.2	14.0	0.023
Ulna lenght (mm)	190±43.2	212±38.4	11.6	0.114
İnklination (degrees)	31±14.8	21.5±4.7	-30.6	0.052
Volar tilt (degrees)	18.8±18.2	12±15.5	-36.2	0.3

achieved with the Ca-CEF method.

The findings of our study show that Ca-CEF provides success in the correction of wrist and forearm deformities. According to the results obtained, there was a significant improvement in the range of motion after surgery. Especially the increase observed in supination and flexion movements supports that Ca-CEF is an effective method in wrist and forearm deformities in terms of providing an appropriate range of motion. These findings are consistent with similar studies in the literature and suggest that Ca-CEF may be a preferable surgical method option in complex wrist and forearm deformities.[16–20] At the same time, significant improvements in functional scores suggest that patients treated with Ca-CEF can return to their activities of daily living more quickly and independently and have a significant improvement in their quality of life.

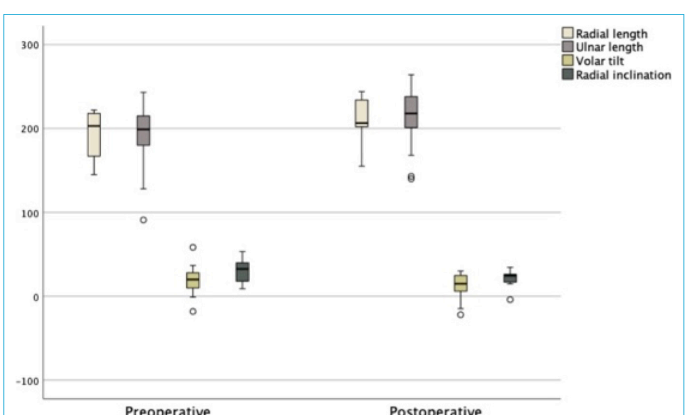

Figure 7. Preoperative and postoperative radiological measurements: radial length, ulnar length, volar tilt, and radial inclination.

The decision for surgical treatment of wrist and forearm deformities is primarily based on the degree of pain reduction and improvement in functional status. Improvements in pain and functional status of patients depend on the success of surgery. In order to restore the anatomy and function of the wrist and forearm in deformities, even 3D computer planning and patient-specific intraoperative guidelines have been attempted.[15] The reduction in pain levels shown in our study is another important result of Ca-CEF treatment. The decrease in the VAS scores of the patients in the postoperative period is an indication that they had a more comfortable recovery period after treatment with less pain. In addition, the possibility of gradual correction provided by Ca-CEF may contribute to the reduction of pain levels by optimizing tissue compliance. In this context, improvements in VAS scores indicate that Ca-CEF is a reliable option for pain management.

Ca-CEF provides safe postoperative treatment with gradual deformity correction, but as a disadvantage, it causes a long duration of treatment. In a study with 7 case series in the literature, a mean duration of Ca-CEF was reported to be 86.1 days and this duration was 99.6 days in our study.[18] This may cause some comfort and psychological problems in adolescent patients.

The functional improvement obtained with Ca-CEF was not only limited to range of motion but also included a significant increase in grip strength. Grip strength is an important parameter for many activities in daily life, and improvement in this area significantly increases the functional capacity of patients.[15,18,19] This has a direct positive effect on patients' independence and quality of life.[21] This increase in grip strength shows that Ca-CEF is a valuable surgical method in terms of deformity correction and restoration of musculoskeletal system functions when used with the correct application principles in the treatment process.

The fact that no major complications were observed in any patient during the study period supports the prominence of Ca-CEF as a safe treatment method. While the risk of vascular and nerve injury may be relatively high with traditional osteotomy and plate/wire fixation methods, the progressive correction of Ca-CEF reduces this risk.[2,4,6,7,12,19,22] Furthermore, the potential of this device to minimize postoperative complications is also an important issue. This finding suggests that Ca-CEF offers a relatively minimally invasive and safe option for the treatment of complex deformities.

This study has some limitations. Firstly, the retrospective nature of the study creates certain limitations in the data collection process. In addition, the relatively small number of patients limits the generalization of the results to large populations and the comparison of results with different surgical methods. However, the fact that a homogeneous patient group was included in the study and all patients were managed with similar treatment protocols increases the reliability and comparability of the data obtained.

Conclusion

In conclusion, this study demonstrated that Ca-CEF is an effective and reliable treatment modality in the treatment of wrist and forearm deformities. It provides remarkable advantages compared to conventional methods, especially in terms of high patient satisfaction, low complication rate and functional improvement. With these features, Ca-CEF provides surgeons with a reliable treatment option for managing complex wrist and forearm deformities.

Disclosures

Ethics Committee Approval: The study was approved by the Sisli Hamidiye Etfal Training and Research Hospital Clinical Research Ethics Committee (date: 20.08.2024), no: 4502).

Conflict of Interest: No conflict of interest was declared by the authors.

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Use of AI for Writing Assistance: The authors declared that this study utilized an AI-supported language program solely for the purpose of enhancing the clarity and quality of the writing.

Informed consent: All patients provided written informed consent prior to their inclusion in the study.

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