Intermediate-Term Outcome of 3-Dimensional Corrective Osteotomy for Malunited Distal Radius Fractures With a Mean Follow-Up of 6 Years

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Purpose Our study aimed to analyze the functional and radiological intermediate-term outcome of 3-dimensional-guided corrective osteotomies for malunited distal radius fractures and to evaluate the progression of osteoarthritis after this intervention.

Methods All patients with malunited distal radius fractures who underwent 3-dimensional-guided corrective osteotomies from October 2008 to January 2015 were included. Pre- and postoperative range of motion, grip strength, and postoperative patient-reported outcomes were assessed. Pre- and postoperative osteoarthritis grading was performed using conventional radiographs and the osteoarthritis grading system described by Knirk and Jupiter. Additionally, the evaluation of articular stepoff was performed using pre- and postoperative computed tomography.

Results Fifteen patients, with a mean follow-up of 6 years (range, 4.1−10.4 years), were included. According to rater 1, 8 cases had no postoperative osteoarthritis progression, 6 cases had progression of 1 grade, and 1 case had progression of 2 grades. According to rater 2, there was no progression in 11 cases, and there was progression of 1 grade in 2 cases and progression of 2 grades in 2 cases. Compared with before the surgery, the patients demonstrated a mean improvement of 14.8 kg (±12.6 kg) in grip strength after the surgery. At the last follow-up, the mean Patient-Rated Wrist Evaluation score was 11.8 (±12.0), the mean Disabilities of the Arm, Shoulder and Hand score was 11.1 (±11.4), and the mean residual pain score on the visual analog scale was 0.8 (±1.0).

Conclusions The intermediate-term outcome of 3-dimensional-guided corrective osteotomies for distal radius intra-articular malunions showed excellent patient-reported outcomes and no clinically relevant progression of osteoarthritis. *(J Hand Surg Am. 2022;47(7):691.e1-e10. Copyright © 2022 by the American Society for Surgery of the Hand. All rights reserved.)*

Type of study/level of evidence Therapeutic IV.

Key words 3-dimensional planning, computer-assisted surgery, corrective osteotomies, malunion, patient-specific instruments.

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Corrective osteotomies for malunited intra-articular distal radius fractures have been described as a reliable and safe method to restore articular congruency.[1–4] The surgical technique using 3-dimensional (3D) planning and navigation with patient-specific instruments (PSIs) has been described by various authors.[3–5] Despite technical challenges, several methods have been proposed, such as open approaches and arthroscopic-assisted interventions. Both result in improved range of motion (ROM), grip strength, and patient-reported outcomes.[6,7] Nevertheless, the most critical factor for reducing the progression of osteoarthritis (OA) has been shown to be the restoration of articular congruency.[8,9]

Recent developments in computer-assisted surgery have made it feasible to address these surgical challenges by using 3D planning and navigation with PSIs.[10] Using this technique, precise reduction of articular congruency is possible. Small case studies have reported excellent clinical and radiographic outcomes of such procedures for intra-articular malunions of the distal radius.[2,11] We were not able to identify reports on the long-term results of 3D planning and navigation. Therefore, the goal of this study was to review all patients who underwent corrective osteotomy using 3D planning and navigation with PSIs for the treatment of the malunion of an intra-articular distal radius fracture with respect to their clinical, radiological, and OA outcomes and, specifically, to evaluate the progression of OA over a long-term interval.

MATERIALS AND METHODS

The local ethical committee approved this retrospective study design (Zürich Cantonal Ethics Committee, BASEC-Nr. 2018-01608), and all patients gave their informed consent for their participation in, and the publication of, this study. All patients who underwent intra-articular corrective osteotomy of the distal radius using 3D planning and navigation with PSIs for the treatment of an intra-articular malunion of the distal radius from October 2008 to January 2015 at our clinic were included. The indications for corrective osteotomy were complaints of pain, stiffness, cosmetic deformity, and functional impairment due to the malunion of the distal radius. The criteria for exclusion were advanced OA, manual inactivity, and severe osteoporosis. Patients under the age of 18 years or those who refused to participate were also excluded.

Seven patients were treated nonsurgically, and 8 underwent surgery prior to our surgical intervention. Fifteen of 20 patients were included. Five patients were lost to follow-up.

A senior surgeon (N.L. or S.A.) performed the preoperative planning on a personal computer using the custom-made software application Computer Assisted Surgery Planning Application (Balgrist CARD AG). The preoperative 3D planning was performed using triangular surface models of both forearms, derived using computed tomography (CT) with a 1-mm axial resolution (120 kV, Brilliance 40 CT; Philips Healthcare).[12] The contralateral uninjured side was used as a reconstruction template. A direct bilateral comparison of the distal radius is useful to predict the normal anatomy of the injured radius.[13] Using the surgical planning software, the malunited bones were mirrored and superimposed on the bones on the healthy contralateral side as previously described.[2] Depending on the underlying malunion, the orientation of osteotomy planes was planned as previously described.[2,12,14] In general, 3 different PSIs were used: for the first PSI, a basic guide was planned, serving the registration of the preoperative planning and intraoperative situation, including drill sleeves for the placement of reference K-wires. If not included in the first PSI, a second PSI was used to perform the osteotomy, including cutting slits for the orientation of the osteotomy planes. Finally, a post-reduction guide was planned to perform a planned reduction task. Of the 15 patients, 5 required 1 osteotomy and 10 required 2 osteotomies. A plate and screws were used for internal fixation. Of the 15 fixations, 10 were performed volarly, 3 dorsally, and 2 from both sides. The surgical procedure for intra-articular corrective osteotomy using PSIs has already been described in detail.[2–5,11,12,14,15] The bone was accessed using a dorsal, volar, or combined approach. The periosteum and other soft tissues were dissected. Cutting guides were attached to the surface of the bone by drilling holes for the K-wires. The K-wires were inserted. Using a cannulated chisel, the osteotomy was performed (Fig. 1). A partial bone resection was necessary to achieve reduction in some cases. The amount of bone resection was calculated before the surgery. Anatomical reduction was achieved by shifting and rotating the fragments into their correct position using the postreduction guide (Figs. 2, 3). Four of the 15 patients needed an extra-articular osteotomy to achieve correct radial inclination and palmar tilt. After achieving the desired correction, a plate was placed for internal fixation. All

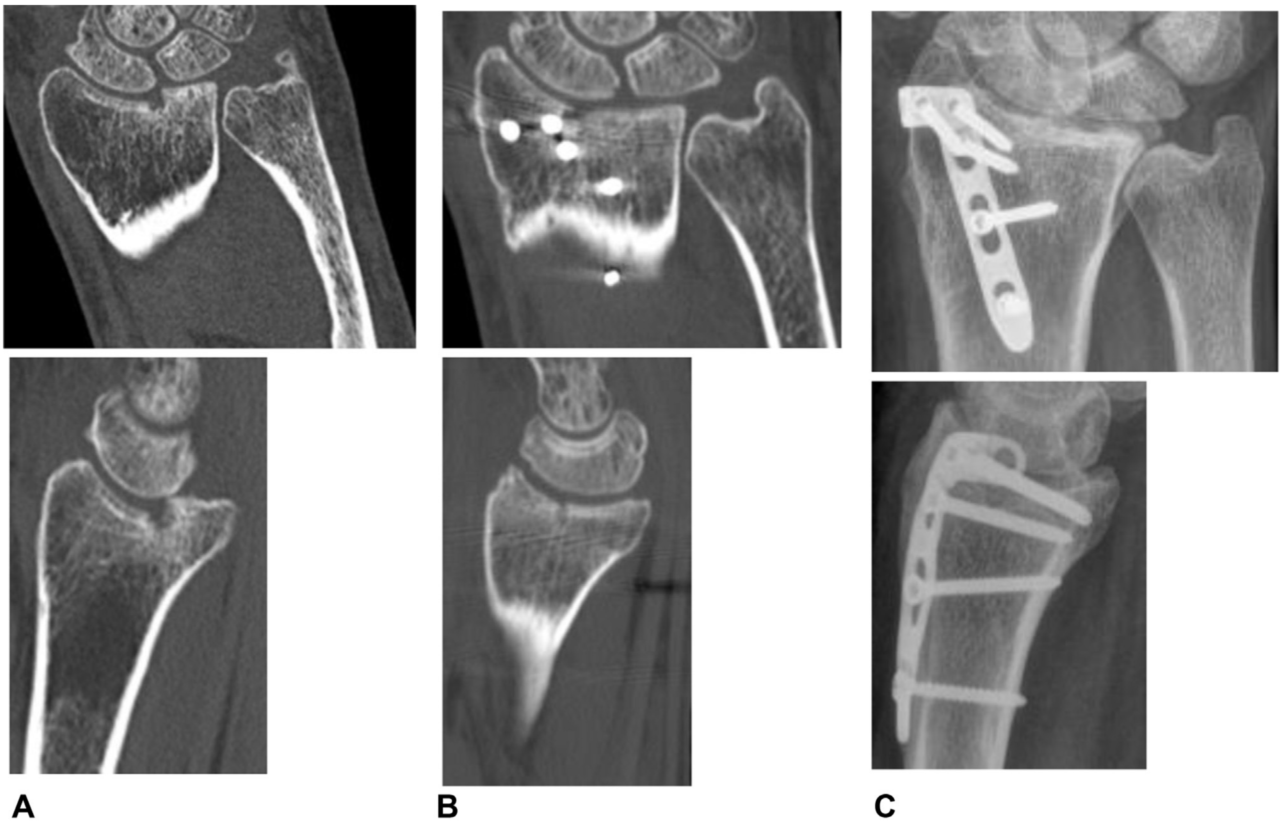

FIGURE 1: Patient 1 was a 63-year-old patient with a volar-radial to dorsal ulnar fracture line, and a proximal shift of nearly 3 mm of the scaphoid fossa was present. The correct position of the fragment was restored by shifting it distally along the osteotomy surface. The fixation was performed with a 2.4-mm locking compression plate. **A** Preoperative CT in the posteroanterior and sagittal views. **B** Postoperative CT in the posteroanterior and sagittal views. **C** Radiograph in the posteroanterior and sagittal views after a follow-up of 10.4 years.

the surgeries were performed by a senior surgeon (N.L. or S.A.).

Clinical results were evaluated by assessing pre- and postoperative pain using the visual analog scale, grip strength, and ROM (flexion, extension, pronation, supination, and ulnar and radial deviations). Additionally, patient-reported outcomes, comprising Disabilities of Arm, Shoulder and Hand and Patient-Rated Wrist Evaluation scores, were collected after the surgery.[16]

Gilbart and Gerber[17] described subjective shoulder value as an easily applied, responsive, and valid measure of shoulder function. They asked their patient the following question: "What is the overall percent value of your shoulder if a completely normal shoulder represents 100%?" They defined the subjective shoulder value as a patient's subjective shoulder assessment result expressed as the percentage of an entirely normal shoulder that would score 100%. In the same manner, we defined the subjective hand value. The subjective hand value was defined as a patient's subjective hand assessment result expressed as the percentage of an entirely normal hand that would score 100%. We asked the patient the following question based on the report of Gilbart and Gerber[17]: "What is the overall percent value of your hand if a completely normal hand represents 100%?" We acknowledge that the reliability and validity of this patient-reported outcome has not yet been established for the hand.

Pre- and postoperative OA grading was performed using conventional radiographs (anteroposterior and lateral views of the wrist). Therefore, radiographs taken before the corrective osteotomy and those taken at the last follow-up were considered. Osteoarthritis, based on the radiographs, was scored by 2 independent readers (J.L. and S.S.), who were not involved in the surgeries, according to the grading system described by Knirk and Jupiter,[8] which is as follows: grade 0 = none, grade 1 = slight joint space narrowing, grade 2 = marked joint space narrowing, and grade 3 = bone on bone. The progression of OA was

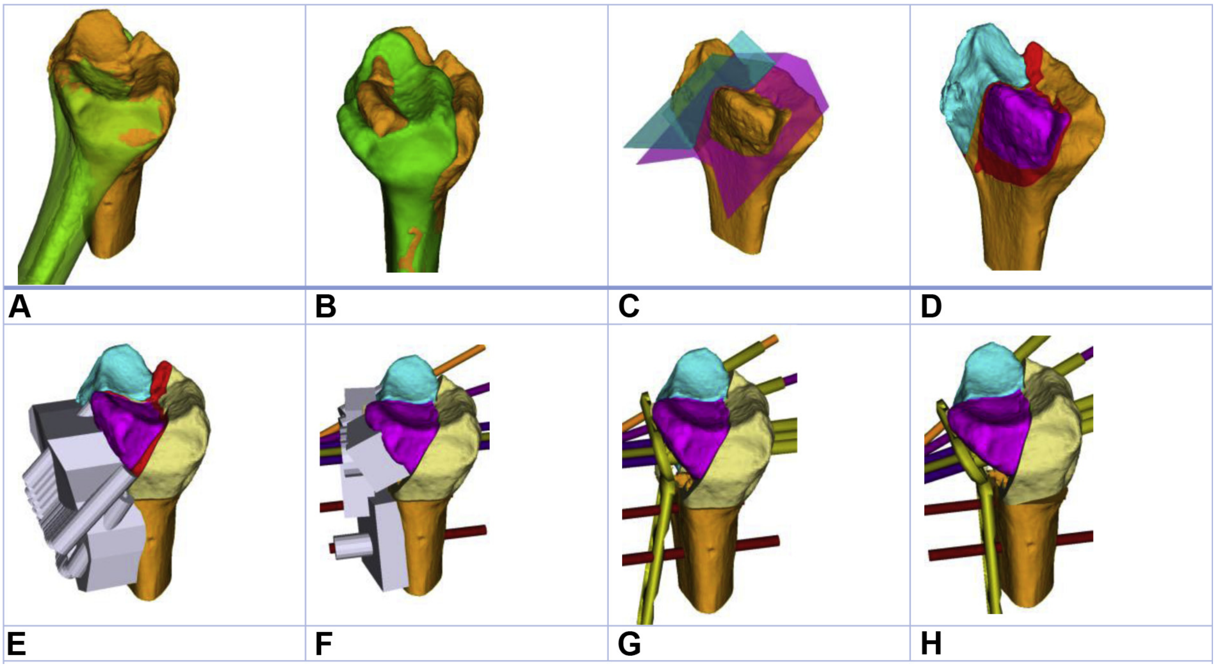

FIGURE 2: Example for surgical planning for intra- and extra-articular radius OT. **A, B** Orange indicates the pathological side, and green indicates the mirrored healthy side, showing **A** extra- and **B** intra-articular differences. **C** Pink and blue indicate the calculated osteotomy planes fragment. **D** Pink and blue indicate the calculated osteotomy fragment; red indicates bone resection fragment. **E** Application of the osteotomy guide. **F** The fragment was shifted along the osteotomy plane. **G** The desired intra-articular correction. **H** The desired extra-articular correction. OT, osteotomy.

FIGURE 3: Surgical photographs of the patient in Figure 2. **A** Volar approach, with the osteotomy guide. **B** Osteotomy planes. **C** Reposition guide.

defined as a change of 1 or more grades according to the Knirk and Jupiter grading system. Additionally, articular stepoff was assessed using a preoperative CT scan and the first postoperative CT scan as previously described.[18]

The early clinical outcomes and accuracy of 3D-guided osteotomy in our patients have been reported earlier.[18]

Statistical analysis

Demographic data, clinical parameters (ROM and grip strength), and the patient-reported outcomes were analyzed using descriptive statistics. Difference in OA grade before and after the surgery was tested using the Wilcoxon signed-rank test for each rater separately. The statistical significance level was set at 0.05. Inter-rater reliability was measured using the Cohen kappa coefficient and interpreted according to the method described by Landis and Koch.[19]

RESULTS

In total, 15 of 20 patients could be included. This included 8 female and 7 male patients with a mean

TABLE 1. Demographic Data of the 15 Patients Included

Patient	Age (y)	Sex	Side	Dominant	Injury	Time From Injury to Osteotomy (y)	Follow-Up (y)	Occupation
1	63.2	M	R	R	AO 2R3C1.3	1.2	10.4	Flight attendant
2	38.8	M	R	R	AO 2R3C1.3	1.0	8.8	Electrician
3	33.2	M	L	R	AO 2R3C1.3	0.7	7.2	Mechanic
4	49.0	F	R	R	AO 2R3C3.2	1.4	7.0	Nurse
5	50.1	M	L	R	AO 2R3C3.2	1.0	6.2	Locksmith
6	60.3	F	R	R	AO 2R3B3.1	0.7	6.1	Yoga teacher
7	63.7	F	R	R	AO 2R3C1.3	0.9	5.9	Teacher
8	60.0	M	R	R	AO2R3C3.2	0.6	5.1	Human resource
9	59.0	F	L	L	AO 2R3B1.3	1.0	4.9	Physiotherapist
10	51.3	F	R	R	AO 2R3C3.2	1.0	4.7	Nursing home
11	26.8	F	R	R	AO 2R3C3.2	1.3	4.5	Social education
12	39.8	M	L	R	AO 2R3C3.2	0.3	4.1	Project manager
13	66.0	F	L	R	AO 2R3C3.2	0.4	4.3	Office
14	40.9	M	L	R	AO 2R3C1.3	0.8	4.3	Plaster
15	35.4	F	R	R	AO 2R3C3.3	0.7	6.0	Mail carrier
Mean	49.2 (±12.7)					0.9 (±0.3)	6.0 (±1.8)	

AO, Arbeitsgemeinschaft für Osteosynthesefragen.

age of 49.2 years (range, 26.8−66.0 years). The mean follow-up length was 6.0 years (range, 4.1−10.4 years). The mean time from injury to corrective osteotomy was 0.9 year (range, 0.2−1.3 years) (Table 1).

Radiological results

The inter-rater reliability of OA grading between the raters was 0.61 ($P < .05$) before the surgery and 0.63 ($P < .05$) after the surgery, showing substantial agreement according to Landis and Koch.[19] A significant change between the preoperative and postoperative OA grades was measured by both the raters. According to rater 1, there was no progression in 8 cases and there was progression of 1 grade in 6 cases and progression of 2 grades in 1 case. According to rater 2, there was no progression in 11 cases and there was progression of 1 grade in 2 cases and progression of 2 grades in 2 cases (Table 2). No correlation (Spearman) was detected between age, preoperative stepoff on CT scan or length of follow-up, and change of OA grade.

All osteotomies showed radiological signs of consolidation in the postoperative CT scan after 8−10 weeks. The mean articular stepoff, measured using CT, was 2.3 mm (±0.6 mm) before the surgery and 0.7 mm (±0.2 mm) after the surgery. The mean reduction after the surgery was 66.3% (±12.5%) compared with that before the surgery, determined using CT (Table 3).

Clinical results

After the surgery, the mean grip strength increased by 14.8 kg (±12.6 kg). Compared with preoperative measurements, the ROM improved on average by 5.7° (±18.1°) for wrist extension, 8.7° (±17.5°) for wrist flexion, 10° (±14.0°) for pronation, and 8.2° (±14.1°) for supination (Table 4). Regarding subjective scores, a Patient-Rated Wrist Evaluation score of 11.0 (±12.5), Disabilities of Arm, Shoulder and Hand score of 9.5 (±10.4), and mean residual pain score of 0.8 (±1.0) on the visual analog scale was reported at the last follow-up (Tables 4, 5). The subjective hand value showed a mean improvement of 48% (±18.1%). All signs for wrist instability and crepitus were absent. All the patients resumed their sport and work activities. Three had heavy, 5 had medium, and 7 had light physical demands at work. There were no complications in 14 of the 15 patients. In 1 patient, an osseous spur had to be removed arthroscopically after the corrective osteotomy.

TABLE 2. Radiological Assessment of OA

Preoperative OA Grading of 15 Patients		
Grade	Cases According to Rater 1	Cases According to Rater 2
0	10	7
1	5	8
2	0	0
3	0	0
4	0	0
Postoperative OA Grading of 15 Patients		
Grade	Cases According to Rater 1	Cases According to Rater 2
0	3	4
1	11	9
2	1	2
3	0	0
4	0	0
Postoperative OA Grading of 15 Patients		
Progression	Cases According to Rater 1	Cases According to Rater 2
0	8	11
1	6	2
2	1	2
3	0	0
4	0	0

DISCUSSION

In our study, we demonstrated improvements in the grip strength, ROM, and pain in 15 cases following 3D-guided corrective osteotomies for distal radius intra-articular malunions. Similar clinical outcomes were reported in a retrospective study of reconstruction using an open approach by Ring et al[7] and in other retrospective studies, in which the final ROM and grip strength improved after arthroscopic-assisted corrective osteotomy.[6]

Union was achieved within the first 8−10 weeks after the osteotomy, and there was no loss of correction in an intermediate term of 6.0 years (range, 4.1−10.4 years).

In majority of the 15 cases, no progression of OA was reported (rater 1, 8 cases; rater 2, 11 cases). Of the 15 cases in which OA occurred, most showed OA progression change of 1 grade (rater 1, 6 cases; rater 2, 2 cases) and a minority of the cases showed progression change of 2 grades (rater 1, 1 case; rater 2, 2 cases). In the postoperative OA grading, most of the cases had grade 1 (rater 1, 11 cases; rater 2, 9 cases), and a minority of the cases had grade 0 (rater 1, 3 cases; rater 2, 4 cases) and grade 2 (rater 1, 1 case; rater 2, 2 cases). A change of 1 grade of OA had no clinical relevance in terms of patient-reported outcome. Even the minority of the patients who developed grade 2 changes of OA had good patient-reported outcomes and improvements in the ROM and grip strength. Therefore, we interpreted this as indicating that there was no clinically relevant OA occurring during the follow-up of these cases.

de Muinck Keizer et al[5] summarized and evaluated the results of 3D-planned corrective osteotomies for malunited distal radius fractures. Fifteen studies, with a total of 68 patients, were included in their systematic review and meta-analysis. They concluded that corrective osteotomies improved both functional and radiographic results significantly ($P < .05$).

An alternative to 3D-guided osteotomies is conventional osteotomy of the distal malunited distal radius. Andreasson et al[20] investigated the long-term outcome of corrective osteotomy for the treatment of the malunion of distal radius fractures. They evaluated 37 patients 3−10 years after they underwent conventional osteotomy. The radiographs showed significantly ($P < .001$) more advanced OA. The study group experienced levels of pain higher than reference values. At long-term follow-up, the functional outcome of corrective osteotomy was generally good, although the authors reported that the patients might have experienced some degree of pain.[20]

Despite these reports, it is unclear whether the restoration of the articular surface of the distal radius, as a singular goal, is required for all patients, at least for patients with acute distal radius fractures. Arora et al,[21] in a prospective randomized study, compared 73 patients with a displaced and unstable distal radial fracture. They were randomized to either open reduction and internal fixation with a volar locking plate (n = 36) or closed reduction and cast immobilization (n = 37). At the 12-month follow-up examination, the ROM, level of pain, and patient-rated wrist evaluation and Disabilities of Arm, Shoulder and Hand scores were similar between the operative and nonsurgical treatment groups. They concluded that the achievement of anatomic reduction did not necessarily result in any improvement in terms of ROM or the ability to perform activities of daily living.

The radiographic appearance of a malunion may not necessarily be associated with deterioration later.

TABLE 3. Pre- or Postoperative Articular Stepoff Measured Using CT Scan

Patient	Preop Stepoff (mm)	Postop Stepoff (mm)	Stepoff Change (mm)	Stepoff Change (%)
1	2.73	0.71	2.02	74.0
2	2.53	0.9	1.63	64.4
3	3.69	0.81	2.88	78.0
4	1.91	0.65	1.26	66.0
5	2.07	0.87	1.2	58.0
6	1.84	0.65	1.19	64.7
7	2.04	1.15	0.89	43.6
8	2.4	0.85	1.55	64.6
9	1.52	0.93	0.59	38.8
10	2.48	0.92	1.56	62.9
11	1.38	0.34	1.04	75.4
12	2.47	0.68	1.79	72.5
13	2.37	0.76	1.61	67.9
14	3.29	0.54	2.75	83.6
15	2.11	0.41	1.7	80.6
Mean	2.3 (±0.6)	0.7 (±0.2)	1.6 (±0.6)	66.3 (±12.5)

Postop, postoperative; Preop, preoperative.

Nevertheless, an intra-articular malunion may be considered a modifiable risk factor for the progression of OA. Patients with a residual articular stepoff can have a satisfactory outcome in the long term, meaning that the progression of arthritis, determined using radiography, does not always require an intervention.[8,22]

The early clinical outcomes and accuracy of the 3D-guided osteotomy of our patients have been reported earlier.[18] Residual articular incongruency after corrective osteotomy of the distal radius was also investigated in 37 patients earlier. The preoperative intra-articular stepoff was 2.5 mm (±0.6 mm; range, 1.4−4.2 mm) and was significantly ($P < .05$) reduced to 0.8 mm (±0.2 mm) after the surgery. Therefore, the use of 3D preoperative planning and PSIs seems to be an accurate technique for reducing articular incongruity.[18] Several authors have reported that plain radiographs underestimate the degree of articular stepoffs and that CT data are more valid.[23,24]

The potential of the 3D planning of corrective osteotomy has been described by various authors.[2,4,5,12,14,3,25] Carrillo et al[26] demonstrated that a machine learning algorithm can calculate extra-articular corrective osteotomy more accurately than a surgeon. Qualitative validation was carried out in 36 cases of radius osteotomy, wherein solutions calculated by an optimization algorithm were compared with the reference standard solutions established by experienced surgeons. The results were blinded and presented to 6 readers, who decided that optimization algorithm solutions were better 55% of the time.[26] In our opinion, further developments in the automated planning of computer-assisted corrective osteotomy will contribute to the treatment of complex intra-articular malunions of the distal radius.

The limitations of this study are its small sample size and the heterogeneity of the length of follow-up. Three-dimensional planning and PSIs for corrective osteotomy are associated with additional expenses of production ($600 USD) and 3D planning ($2,500 USD).[14] Furthermore, specialized software, time and effort for preoperative planning, and creation of PSIs are needed. Another limitation is the absence of a control group, either with an alternative treatment or without treatment. The natural history of an intra-articular malunion has not been fully studied. In the current climate of concern regarding rising health care costs in North America and Europe, the additional cost and clinical outcome have to be balanced precisely for each patient individually.[27]

TABLE 4. Results of Clinical Examination at the Last Follow-Up of the 15 Patients Included

Patient	Follow-Up (y)	Flexion (Degree of Improvement)	Extension (Degree of Improvement)	Radial Adduction (Degree of Improvement)	Ulnar Adduction (Degree of Improvement)	Pronation Degree (Degree of Improvement)	Supination (Degree of Improvement)	Strength Jamar (Degree of Improvement)	Pain (VAS)
1	10.4	30 (15)	30 (−20)	20 (0)	40 (0)	70 (0)	70 (0)	54 (18)	1
2	8.8	80 (10)	70 (20)	40 (0)	20 (0)	80 (−10)	80 (30)	60 (0)	0
3	7.2	70 (20)	60 (−10)	20 (0)	50 (40)	70 (5)	80 (0)	38 (10)	1
4	7.0	60 (40)	50 (10)	20 (NA)	40 (NA)	90 (NA)	80 (NA)	16 (1)	1
5	6.2	50 (20)	60 (45)	10 (−15)	30 (−10)	70 (15)	80 (10)	42 (27)	2
6	6.1	70 (20)	60 (10)	40 (15)	10 (−25)	80 (10)	80 (−10)	26 (12)	0
7	5.9	50 (20)	60 (0)	20 (5)	50 (15)	70 (−5)	80 (5)	26 (6)	0
8	5.1	30 (0)	45 (−5)	10 (0)	20 (0)	60 (15)	50 (−5)	52 (40)	0
9	4.9	70 (20)	70 (0)	20 (0)	40 (10)	80 (−10)	80 (0)	12 (12)	2
10	4.7	50 (−5)	40 (20)	10 (−5)	20 (0)	80 (20)	70 (−5)	22 (21)	0
11	4.5	40 (−10)	60 (0)	10 (0)	20 (−10)	80 (20)	70 (20)	36 (−4)	2
12	4.1	50(10)	50 (25)	20 (NA)	40 (NA))	80 (25)	90 (35)	56 (32)	0
13	4.3	40 (20)	50 (−10)	10 (−5)	40 (20)	80 (40)	90 (25)	20 (14)	0
14	4.3	45 (15)	30 (20)	12 (2)	30 (15)	80 (10)	70 (10)	44 (27)	0
15	6.0	50 (-25)	60 (−20)	20 (0)	50 (20)	80 (5)	80 (0)	22 (6)	3
Mean	6.0 (4.1−10.4)	8.7 (±17.5)	5.7 (±18.1)	1.2 (±8.4)	8.2 (±18.5)	10.0 (±14.0)	8.2 (±14.1)	14.8 (±12.6)	0.8 (±1.0)

NA, not applicable; VAS, visual analog scale.

TABLE 5. Patient-Reported Outcomes: Subjective Hand Value, PRWE, and DASH

Patient	Follow-Up (y)	Preop SHV	Postop SHV	Postop PRWE	Postop DASH
1	10.4	50	99	2	1
2	8.8	50	100	0	0
3	7.2	0	60	26.5	30
4	7.0	10	80	15.5	23
5	6.2	30	90	26.5	7
6	6.1	80	100	0	7
7	5.9	30	100	0	1
8	5.1	25	75	19	15
9	4.9	50	90	38	21
10	4.7	30	100	7	9
11	4.5	60	85	12	9
12	4.1	60	90	0.5	1
13	4.3	30	100	4	5
14	4.3	60	90	6	2
15	6.0	40	70	20.5	36
Mean	6.0 (4.1−10.4)	40.3 (±21.1)	88.6 (±12.5)	11.8 (±12.0)	11.1 (±11.4)

DASH, Disabilities of Arm, Shoulder and Hand; Postop, postoperative; Preop, preoperative; PRWE, patient-rated wrist evaluation; SHV, subjective hand value.

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