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Plating and cortical bone grafting of clavicular nonunions: clinical outcome and its relation to clavicular length restoration

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Background: The goal of this study was to evaluate whether plating and cortical bone grafting of shortened clavicular nonunions would restore clavicular length and enable bone healing. The association between the clavicular length difference (CLD) between sides and long-term functional outcome was also explored.
Methods: For this retrospective 2-center study, patients who underwent plate fixation with cortical bone grafting of a clavicular nonunion were assessed after ≥2 years. The CLD and bone union were assessed using radiography and navigation ultrasound. The functional outcome was determined by the Constant score, Simple Shoulder Test score, and Subjective Shoulder Value, as well as local pain (0-10 numeric rating scale).
Results: Between 2 and 13 years after surgery, 25 patients (mean age, 53 years; 13 female patients) were examined. The median CLD was 0 mm (range, −17 to 13 mm) on ultrasound measurements and 2 mm (range, −32 to 9 mm) on radiographs. At follow-up, the median Constant score, Simple Shoulder Test score, Subjective Shoulder Value, and pain level were 82 points (range, 38-95 points), 12 points (range, 3-12 points), 95% (range, 60%-100%), and 0 (range, 0-8), respectively. There was no correlation between the CLD and all functional outcome scores. Bone union was achieved in all patients. After plate removal, 4 refractures occurred, 3 of which required revision.
Conclusions: Plate fixation with cortical bone grafting of clavicular nonunions is associated with restoration of clavicular length and a high rate of bone union. There is, however, a considerable risk of refracture following plate removal. There was no association between the CLD and clinical outcome.

Fractures of the clavicle are common and mostly localized to the midshaft, followed by the lateral end.[11] Although most fractures heal, the incidence of midshaft nonunion varies from 23.1% to 31% and from 2.4% to 5.9% after nonoperative and surgical treatment, respectively.[2,15,19] Lateral fracture nonunion occurs in around 24%-33% of cases, which are predominantly displaced Neer type 2 fractures.[20] Fracture displacement and comminution, advanced age, and female sex are known risk factors.[17] If clavicular nonunion occurs, affected individuals may have pain, loss of full range of motion, poor-quality sleep, loss of strength, and crepitation.[4,21] Associated bone loss with shortening of the clavicle may lead to disturbances in scapular and glenohumeral kinematic patterns, as well as cosmetic deformity.[16]

The current treatment of clavicular nonunions involves various plate fixation and positioning techniques.[28] In cases of segmental bone loss, autologous cortical bone grafts can be applied to restore clavicular length.[12,13] To date, only 1 small case series reported on healing following cortical bone grafting and plating of clavicular nonunions.[12] Other studies presented mixed patient populations that had undergone plating with either cortical or cancellous bone grafting.[24] Overall, the efficacy of plating associated with grafting to restore clavicular length is essentially unknown.[14] At the same time, the effect of clavicular length restoration on the improvement of shoulder function remains unclear.[32] Whereas these previous studies presented level IV evidence based on heterogeneous and small patient populations, attaining conclusive evidence on the outcomes of plate fixation with graft augmentation of clavicular

The study was performed in accordance with the ethical standards of the North West and Central Swiss ethics committee (Ethikkommission Nordwest- und Zentralschweiz [EKNZ], Basel; EKNZ no. 2018-00120) and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

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nonunions is further hampered by the lack of standardized measurements to determine clavicular length.[29]

Our goal was to evaluate whether plating and cortical bone grafting of clavicular nonunions restore clavicular length and enable bone healing. We also explored the association between clavicular length restoration—defined by the clavicular length difference (CLD) between sides—and long-term shoulder functional outcome. We hypothesized that plate fixation and cortical bone grafting would facilitate union with restoration of clavicular length.

Materials and methods

Patient population and eligibility criteria

For this retrospective study involving 2 Swiss orthopedic centers, we screened consecutive adult patients who received a diagnosis of a symptomatic nonunion of the clavicular midshaft or lateral segment (Fig. 1, *a*) and had undergone plate fixation with cortical bone grafting between 2005 and 2016. Any patient with a pathologic fracture, contralateral fracture of the clavicle, or missing preoperative radiographs was excluded. All eligible patients were then contacted by telephone and invited to attend a clinical examination at the hospital where they originally received surgical treatment. Patients (except those who were pregnant) were included in the study if they completed a postoperative follow-up examination at a minimum of 2 years and provided written informed consent.

Surgical treatment and postoperative rehabilitation

All surgical procedures were performed at each clinic by an experienced surgeon in a standardized (surgeon-specific) manner. With the patient in the beach-chair position, the clavicular nonunion was exposed via an infraclavicular approach until bleeding occurred at both ends of the nonunion. The resulting bone defect was assessed. Tricortical autologous bone was then harvested from the ipsilateral iliac crest and shaped to match the bone defect. A graft no larger than 3 cm was interposed into the bone

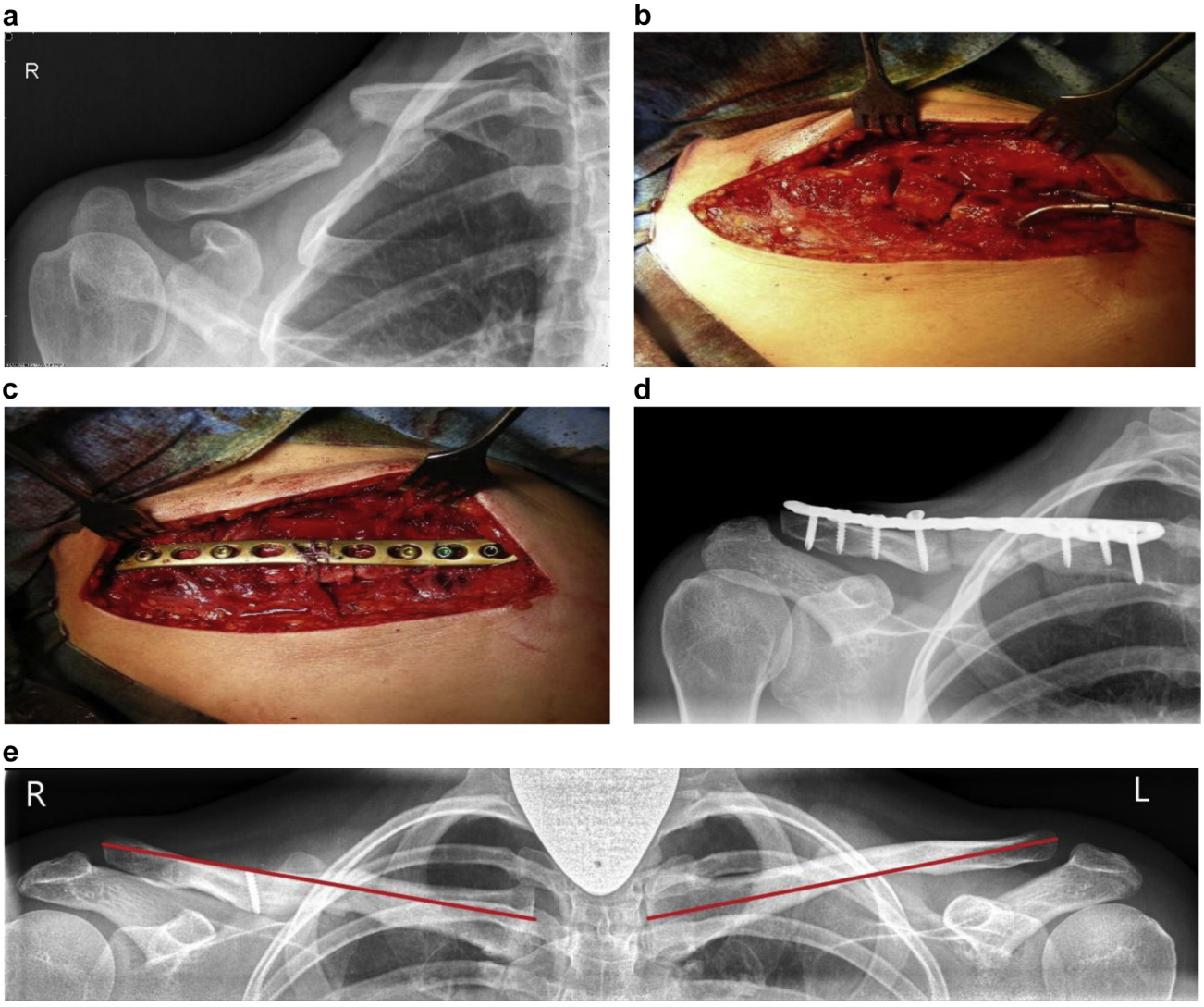

Figure 1 **(a)** Anteroposterior radiograph of a 23-year-old female patient with a right-sided midshaft clavicular fracture nonunion 15 months after undergoing conservative treatment. Surgical treatment was performed with a 2-cm iliac bone graft **(b)** and combined with single plating **(c, d)**. Plate removal was performed at 3.8 years. **(e)** A panoramic radiograph taken 10.8 years after surgery shows complete bone union. The landmarks—as defined by Smekal et al[25]—at the clavicular joints were used to measure the clavicular length difference between sides; the — indicate the linear distance between the acromioclavicular and sternoclavicular joints. *R*, right; *L*, left.

defect in a press-fit manner (Fig. 1, *b*). A precontoured locking compression (3.5-mm LCP Superior Clavicle Plate or 3.5-mm VA-LCP Anterior Clavicle Plate; DePuy Synthes, Zuchwil, Switzerland) or 3.5-mm reconstruction plate (DePuy Synthes) was used for superior or anteroinferior fixation (Fig. 1, *c* and *d*). For all patients, nonlocking screws were applied to initially fix the plate to thin clavicular bone fragments, as well as to fix the graft to the plate. Locking screws were then used to complete the osteosynthesis.

All patients followed a standardized rehabilitation program in which the affected shoulder was immobilized in a sling for the first 2 weeks after surgery. During the 6-week postoperative period, all patients undertook physical therapy with active elevation and abduction limited to 90° and restricted weight bearing.

Radiographic follow-up examination

At the final follow-up, a panoramic radiograph of both clavicles and a tangential view of the affected clavicle were obtained. Union was defined as the complete consolidation of 3 of 4 cortices. Clavicular length was measured bilaterally in a standardized fashion by an experienced radiologist as described by Smekal et al[25] and defined as the linear distance between the acromioclavicular (AC) and sternoclavicular (SC) joints. This distance is a common surrogate for the actual length of the S-shaped clavicular bone. On the panoramic view, the distances between the AC and SC joints were assessed (Fig. 1, *e*). The lateral starting point of the measurement was the intersection between a line within the lateral axis of the clavicle and the AC joint. The endpoint of the measurement corresponded to the intersection between a line centered in the medial axis of the clavicle and the SC joint. Measurements of clavicular length performed in this way showed high reproducibility in previous studies.[25]

Ultrasound follow-up examination

Standardized radiographic measurements of clavicular length may still be biased by rotation and the distance of the patient relative to the x-ray beam. Therefore, a second measurement of the length of both clavicles was performed using navigation ultrasound as described by Thorsmark Høj et al.[30] Clavicular length was again defined as the linear distance between the AC and SC joints. In brief, the technique uses a magnetic field within the examination area, which is expanded by a magnet placed next to the patient. By use of the ultrasound probe, magnetic markers are placed on anatomic structures and recorded as an x-y-z point within a 3-dimensional coordinate system of the magnetic field. A cadaveric study showed that the distance between 2 anatomic points can be measured in this manner with high reproducibility and accuracy (ie, intraclass correlation coefficients [ICCs] range from 0.942 to 0.977).[30] For the measurements, the patient lay in a supine position and the ultrasound probe was held in the clavicular plane. The most medial point of the clavicle was identified and marked, and its x-y-z position within the magnetic field was recorded. The most lateral point of the clavicle at the AC joint was then recorded in the same manner. The distance between these 2 points was calculated by software. To minimize operator dependence, ultrasound measurements were performed by a single clinician consultant assessor who was trained prior to the study by both a radiologist specialized in shoulder assessment and a representative of the company that provided the measurement device for the study.

Clinical outcome measurements

The final follow-up examination included measurements of active and passive shoulder range of motion and abduction strength using a spring balance. The presence of scapular dyskinesis was recorded using the simplified dichotomous method described by the working group of Kibler et al[10] (ie, yes or no, in which yes indicates an abnormal dyskinesis pattern whereas no indicates normal scapular motion).[31] The clinical functional outcome was also assessed using the Constant score (CS).[3] Subjective patient-rated outcomes were determined with the questionnaires for the Simple Shoulder Test (SST) and Subjective Shoulder Value (SSV),[5] in addition to a 0-10 numeric rating scale for locally perceived pain level, on which 0 indicated no pain and 10 indicated maximal pain. Quality of life was documented using the 5-dimension EuroQol instrument (EQ-5D-5L),[8,9] which included a visual analog scale to document patient general health. Patients were asked to rate their perceived improvement in shoulder condition and quality of life either as “much better” or “somewhat better.” On the basis of the 0-10 numeric rating scale, patients reported whether their expectations of the operation were met (with 10 indicating fully met) and whether they were satisfied with the overall outcome (with 10 indicating fully satisfied). Patients were also asked whether they would agree to undergo the same operation again. Finally, all postoperative events of implant removal and complications (ie, superficial and deep infection, plate breakage, and refracture) were recorded.

Statistical analysis

All data were entered into a web-based electronic database using REDCap software (version 8.11.5; Vanderbilt University, Nashville, TN, USA)[6] and exported for analysis into Intercooled STATA (version 14.2; StataCorp, College Station, TX, USA). We compared baseline patient demographic characteristics and clavicular status between enrolled patients and those who could not be enrolled using descriptive statistics and respective standardized differences. Standardized differences were calculated to 2 decimal places as the absolute difference between group means divided by the common standard deviation,[1] where values closest to 0.10 indicate stronger group similarity. All baseline and follow-up outcome parameters were described by standard descriptive statistics including absolute and relative frequencies for categorical variables and the mean, standard deviation, median, and range for continuous variables. Median and range values were also used for categorical ordered variables.

For the radiographic and ultrasound measurements, the absolute CLD was calculated as the difference in the clavicular length between sides (ie, CLD on contralateral side minus CLD on operated side). The proportional CLD was defined in relation to the length of the healthy contralateral clavicle.[12,25] Absolute and proportional CLDs were tabulated. The intraobserver reliability of both radiographic and ultrasound clavicular length measurements was assessed by calculating the ICC. The association between ultrasound-derived measurements of absolute and proportional CLDs and the outcome parameters of range of motion and functional score (ie, CS, SST score, and SSV) was explored by scatter-plot and correlation analysis.

Results

Patient selection and inclusion

Of 46 initially identified patients, 3 died, 6 were lost to follow-up, and 12 did not consent to further clinical assessment. The remaining 25 patients (54%) (median age, 53 years [range, 19-82 years]; 13 women) were available for a final follow-up examination at a median postoperative time point of 6.2 years (range, 2.1-13.4 years). We found minor differences between these patients

regarding baseline demographic characteristics and clavicular status, which were not considered a relevant source of study bias (Supplementary Table S1).

Of the 25 study participants, 19 had a nonunion following a clavicular midshaft fracture and 6, following a lateral Neer type 1 (n = 2), type 2 (n = 3), or type 5 (n = 1) fracture (Table I). Furthermore, our nonunion cohort had various morphologic profiles defined by the status of multi-fragmentation and shortening >2 cm, as well as the degree of dislocation and type of pseudarthrosis (Table II).

We recorded a primary nonunion after nonoperative treatment in 10 patients. Internal fixation was completed with the plate positioned in a superior, anterior, and anteroinferior manner in 14, 8, and 3 patients, respectively. One patient received bone morphogenetic protein to promote healing. The length of surgery averaged 147 minutes (range, 81-213 minutes). We did not observe any intraoperative adverse events. Twenty patients received postoperative nonsteroidal anti-inflammatory drugs for pain relief. For 19 patients, the plate was removed at between 6 and 46 months (median, 20 months)—with plate removal in 7 patients within 18 months—after osteosynthesis owing to pain (n = 17) or poor cosmesis (n = 2).

Radiographic and ultrasound measurements

At the follow-up examination, union was confirmed on radiographs for all except 1 patient with a refracture, which was treated conservatively and resulted in a tense asymptomatic nonunion. The median absolute and proportional CLDs were 2.0 mm and 1.3%, respectively, based on radiographic determination, and the ultrasound measurements were 0 mm and 0%, respectively (Table III). The ICCs for radiographic and ultrasound measurements of clavicular length on the operated and opposite shoulders were 0.826 and 0.843, respectively. There were 2 patients with clavicular shortening of 17 mm as measured by ultrasound.

Table I
Patient demographic and injury characteristics (N = 25)

	Median (range) or n (%)
Demographic characteristic	
Age at surgery, yr	53 (19-82)
Female sex	13 (52)
Smoking at time of surgery	6 (24)
Comorbidity	6 (24)
Anamnesis	
Dominant side injured	13 (52)
Previous infection	1 (4)
No. of previous operations	
0	10 (40)
1 using plate	8 (32)
>1*	7 (28)
Clavicular status	
AO-OTA fracture classification	
Shaft (type 15-B)	19 (76)
Lateral (type 15-C)	6 (24)
Multifragmentary fracture	10 (40)
Clavicular shortening >2 cm	
No	13 (52)
Yes	9 (36)
Not known	3 (12)
Dislocation	
None	11 (44)
Yes, up to half of shaft diameter	7 (28)
Yes, shaft diameter or more	7 (28)
Pseudarthrosis	
Hypertrophic	2 (8)
Atrophic	23 (92)

OTA, Orthopaedic Trauma Association.
* Regarding primary surgical procedures, 4 patients received a new plate and underwent an additional surgical procedure: screw replacement on the lateral side followed by implant removal in 1, implant removal in 1, and a new osteosynthesis in 2. Two patients received an intramedullary nail and underwent an additional surgical procedure: shortening of the osteosynthesis material followed by implant removal in 1 and implant removal in the other. Finally, 1 patient received K-wire refixation of the fracture followed by implant removal because of infection.

Clinical outcome measurements

Three patients presented with scapular dyskinesis. Clinical outcome measurements at the final follow-up are outlined in Table IV. We found no significant association between the absolute CLD and the respective outcome parameters of the CS ($r = -0.33$, $P = .112$), SST score ($r = -0.33$, $P = .115$), and SSV ($r = -0.40$, $P = .054$) (Fig. 2).

Complications

Overall, 8 complications were reported in 7 patients (28%). Four patients sustained a refracture at the same location as the former nonunion after removal of the osteosynthesis material, of whom 3 were successfully treated with plate fixation. The fourth patient presented with positive biopsy findings indicating a *Cutibacterium acnes* infection after nonunion surgery. Three weeks after implant removal, the clavicle fractured again and the patient refused any further surgical intervention. Nonsurgical treatment failed, with a resultant CLD of 17 mm; however, the patient achieved an adequate functional outcome (CS, 76 points; SST score, 12 points; SSV, 85%). Another patient had a superficial infection in the early postoperative phase due to a suture granuloma that was treated successfully with antibiotics. The last 2 patients reported residual pain in the operated shoulder at the final follow-up owing to symptomatic osteoarthritis of the AC joint in 1 and muscular imbalance of the ipsilateral trapezius in the other.

Discussion

The primary goal of our study was to evaluate whether plating and structural bone grafting of a clavicular nonunion would lead to the restoration of clavicular length and good healing. We observed bone union in all patients but 1. A previous case series of clavicular nonunions also reported high rates of healing with the interposition of a cortical structural allograft.[12,24] It is known that autologous grafts can be used to bridge bone defects of up to 2.5-3 cm with good healing rates, even in less favorable environments such as the tibia diaphysis.[23] We did not measure preoperative clavicular shortening, but our surgeons reported that this aspect was <3 cm even if the additional intraoperative resection of devitalized bone fragments was taken into consideration. Nevertheless, 4 of the patients in our series (ie, 16%) sustained a refracture following implant removal at the previous nonunion site. In all of these patients, union was confirmed on plain radiographs. Bone healing was also confirmed clinically by firm palpation of the union site at the time of implant removal. Refractures of healed clavicles following plate removal are well-known complications and may be related to conditions other than the status of bone healing, such as female sex and low body mass index.[31] Nevertheless, all of these patients had undergone multiple operations prior to the index surgical procedure. All refractures also occurred in the midshaft area known as the "vascular watershed line" of the clavicular bone.[7] Thus, the observed refractures may have occurred in clavicular segments with impaired blood supply and, thus, reduced bone-remodeling capacity. Therefore, the graft may have healed to the adjacent clavicular fragments but may not have been fully converted into vital tissue. This hypothesis, however, requires verification in

Table II
Clavicular fracture and pseudarthrosis profiles

AO-OTA classification	Multifragmentary	Shortening > 2 cm	Dislocation	Pseudarthrosis	Patients, n
Shaft (type 15-B)	No	No	None	Atrophic	3
			Yes, up to half of shaft diameter	Atrophic	1
			Yes, shaft diameter or more	Atrophic	1
		Yes	Yes, up to half of shaft diameter	Hypertrophic	1
			Yes, shaft diameter or more	Atrophic	2
		Not known	None	Atrophic	1
			Yes, shaft diameter or more	Atrophic	1
	Yes	No	None	Atrophic	2
			Yes, up to half of shaft diameter	Atrophic	1
		Yes	None	Atrophic	1
			Yes, up to half of shaft diameter	Atrophic	1
			Yes, shaft diameter or more	Atrophic	3
		Not known	None	Atrophic	1
Lateral (type 15-C)	No	No	None	Atrophic	3
			Yes, up to half of shaft diameter	Hypertrophic	1
		Yes	Yes, up to half of shaft diameter	Atrophic	1
	Yes	No	Yes, up to half of shaft diameter	Atrophic	1

OTA, Orthopaedic Trauma Association.

Table III
CL measurements and between-side differences

	n	Radiograph		Ultrasound	
		Mean (SD)	Median (range)	Mean (SD)	Median (range)
CL on operated side, mm	25	148 (14)	150 (115 to 176)	149 (15)	147 (124 to 184)
CL on opposite side, mm	24*	150 (14)	148 (128 to 185)	150 (15)	149 (124 to 180)
Absolute CLD, mm	24	2.6 (8.8)	2.0 (−9.0 to 32.0)	1.7 (7.2)	0.0 (−13.0 to 17.0)
Proportional CLD, %	24	1.6 (5.9)	1.3 (−6.5 to 21.8)	1.0 (4.8)	0.0 (−7.6 to 12.1)

CL, clavicular length; *CLD*, clavicular length difference.
* Comparison with the affected (operated) shoulder was not possible because 1 patient underwent acromioclavicular joint resection on the contralateral shoulder.

further studies. For these cases, implant removal should be avoided if tolerated by the patient. The rate of plate removal in this study was substantially higher than that reported in other clinical studies[33] but may be explained by socioeconomic differences between health care systems.

The implantation of cortical bone graft could successfully restore clavicular length compared with that of the healthy contralateral shoulder. On the basis of the ultrasound assessment, the median difference between the healthy and affected sides was 0 mm, with no value being >2 cm. Given the known accuracy of approximately 1%-2% for navigation ultrasound,[29] the observed difference may be close to the systematic error for this particular technique. The accuracy of length restoration was surprising, given that intraoperative measurement of the bone defect is challenging. Following débridement of devitalized structures, the bone defect does not correlate with preoperative shortening. There is no clear anatomic landmark that would indicate a correct clavicular length at the time of reduction. Comparative fluoroscopic measurements may be flawed because of rotational errors. Intraoperative computed tomography (CT) measurements or patient-specific instrumentation[22] is not yet integrated as part of our clinical routine. The 2 surgeons in this series based their estimate of the bone defect size on intraoperative measurements made with a ruler that were not systematically documented. Previous studies also reported on the accurate restoration of clavicular length based on intraoperative judgment.[12,27] In light of these results, the need for extended intraoperative imaging techniques (eg, navigation or CT) to assess clavicular length may be limited in the treatment of clavicular nonunions.

We did not observe any significant correlation between the calculated CLD and any functional outcome score. There is ongoing debate as to whether clavicular shortening is associated with poor functional outcome.[14,29,32] Clinical data are predominantly available from patients undergoing nonoperative treatment of clavicular fractures: In a retrospective study, Lazarides and Zafiropoulos[13] demonstrated that clavicular shortening of 14 mm and 18 mm in women and men, respectively, led to unsatisfactory clinical outcomes and limitations in carrying out daily activities. Furthermore, a systematic review of 4 randomized controlled trials and 12 nonrandomized, retrospective comparative studies did not find any significant association between clavicular shortening and shoulder outcome scores for nonoperatively managed fractures.[14] It remains uncertain whether these results from acute fracture patients are applicable to patients with nonunions. Clavicular shortening may also only affect clinical outcomes if it effectively alters shoulder kinematics. Stegeman et al[26] showed the presence of kinematic alterations in patients with nonoperatively treated clavicular fractures compared with uninjured contralateral shoulders; clavicular shortening averaged 25 mm, which was more pronounced than in our patient series. On the other hand, we effectively observed scapular dyskinesis in 3 patients, as well as shortening > 17 mm in 2 patients. Therefore, the paucity of patients with substantial clavicular shortening in our series may have obscured an actual correlation between clavicular shortening and functional outcome. In light of these results, the use of a structural bone graft to restore clavicular length in the treatment of nonunions still appears indispensable.

There are several limitations to this study, which are mostly associated with the retrospective design and long-term follow-up examination. There were inherently many patients who could not be examined at follow-up; the observed similarity in baseline characteristics between enrolled patients and other patients nevertheless suggests that the selection bias may remain limited. Furthermore, clavicular length measurements were not performed

Table IV
Objective clinical and subjective patient-reported outcomes (N = 25)

	n (%)	Median (range)
Objective clinical outcomes		
Flexion, °		
Active	25	160 (110-180)
Passive	25	165 (115-180)
Abduction, °		
Active	25	160 (100-180)
Passive	25	165 (100-180)
External rotation in 0° abduction, °		
Active	25	60 (35-75)
Passive	25	60 (40-80)
Abduction strength, kg	25	8 (0-13)
Constant score (0-100 points), points	25	82 (38-95)
Patient-reported subjective outcomes		
SST score (0-12 points), points	25	12 (3-12)
SSV (0%-100%)	25	95 (60-100)
Local pain level (0-10 NRS)*	25	0 (0-8)
0	13 (52)	
1	7 (28)	
2-5	3 (12)	
>5	2 (8)	
EQ-5D-5L utility index (0-1)	25	1.00 (0.25-1.00)
General-health VAS score (0-100)	25	91 (50-100)
Perceived improvement of shoulder condition		
Much better	22 (88)	
Somewhat better	3 (12)	
Expectations regarding operation met (0-10 NRS)†	25	10 (6-10)
Perceived improvement in quality of life		
Much better	22 (88)	
Somewhat better	3 (12)	
Overall patient satisfaction with results (0-10 NRS)‡	25	10 (5-10)
Patient would opt to undergo same operation again		
Do not know	2 (8)	
Yes	23 (92)	

SST, Simple Shoulder Test; *SSV*, Subjective Shoulder Value; *NRS*, numeric rating scale; *EQ-5D-5L*, 5-dimension EuroQol instrument; *VAS*, visual analog scale.
* NRS on which 0 indicates no pain and 10 indicates maximum pain.
† NRS on which 0 indicates not at all and 10 indicates fully met.
‡ NRS on which 0 indicates not at all satisfied and 10 indicates fully satisfied.

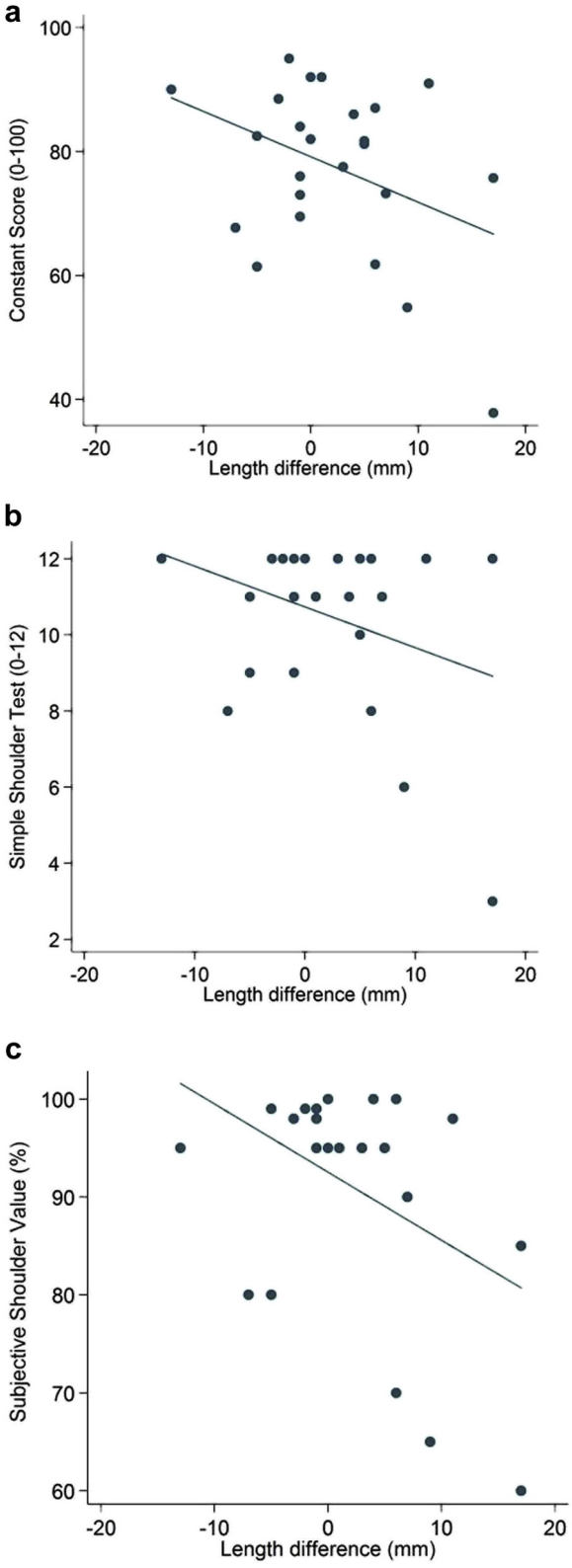

Figure 2 Association between absolute clavicular length difference and Constant score (**a**), Simple Shoulder Test score (**b**), and Subjective Shoulder Value (**c**).

using CT scans because of ethical considerations, and hence, we relied on plain radiographs and ultrasound. Although 2-dimensional radiographic measurements of clavicular length are clearly impaired by rotation of the patient in relation to the x-ray beam,[18,29] ultrasound measurements are known to be highly accurate in cadaveric studies.[30] Accordingly, differences between radiographic and ultrasound measurements were observed. Moreover, clavicular length was defined as the linear distance between the AC and SC joints, which does not correspond to the actual length but rather is the surrogate length of the S-shaped clavicular bone. However, in this study, we did not focus on the actual length between these 2 anatomic landmarks; rather, we focused on the difference between sides, which was correlated with clinical outcome measurements in multiple previous studies.[14] We did not perform a sample size estimation prior to the study because the indication and technique are rather rare and the total number of patients available for follow-up was limited. Although this study was essentially explorative and descriptive, it is one of the largest series of those published to date. Nonetheless, we cannot exclude a type 2 error in our analysis.

Conclusion

Plate fixation and cortical bone grafting are associated with restoration of clavicular length—compared with the contralateral side—and a high rate of union in patients with clavicular fracture nonunion. Within the achieved range of CLD measurements, there was no association with clinical outcome.

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Supplementary Data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jseint.2020.04.002.

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