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Clinical and Radiological Outcomes after Various Treatments of Midshaft Clavicle Fractures in Adolescents

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Background: Controversy exists about the optimal treatment of midshaft clavicle fractures in the presence of significant displacement, comminution, or shortening of the fracture in adolescents. The purpose of this study was to compare the clinical and radiological outcomes of 4 different treatments for midshaft clavicle fractures in adolescents: conservative treatment with a figure-of-8 (FO8) brace, open reduction and internal fixation with a plate (OPL), minimally invasive plate osteosynthesis (MIPO), and intramedullary nail fixation with a threaded Steinmann pin (TSP).

Methods: A total of 94 teenagers with midshaft clavicle fractures were divided into the FO8, OPL, MIPO, and TSP groups (n = 24, 33, 16, and 21, respectively). We analyzed clinical and radiological outcomes and complications in each group and compared the results among the groups.

Results: All groups showed satisfactory clinical and radiological outcomes, but each group showed different results for the assessment items. The Constant-Murley scores were higher in the operated groups than in the FO8 group. Recovery of joint motion was faster in the operated groups. The TSP group had the highest cosmetic satisfaction with respect to the satisfaction score and measured scar length. Fracture union was achieved in all patients. At the final follow-up, the bone length was closer to normal in the OPL and TSP groups than in the FO8 and MIPO groups, and angulation was less in the OPL and TSP groups than in the MIPO and FO8 groups. The TSP and MIPO groups obtained faster bone healing than the OPL and FO8 groups. In the operated groups, 9 patients had metal-induced irritating symptoms; 1, supraclavicular nerve injury symptoms; and 4, refractures after plate removal.

Conclusions: The nonoperatively treated group had no iatrogenic complications. The operated groups complained of various disadvantages induced by surgery; however, these groups achieved faster functional recovery and slightly better radiological and functional results than the nonoperative group.

Keywords: *Adolescent, Midshaft clavicle fracture, Figure of eight bandage, Plate, Threaded Steinmann pin fixation*

Although there is an increasing need for surgery for displaced clavicle midshaft fractures in adolescents, pediatric midshaft clavicle fractures have traditionally been treated nonsurgically.[1] However, relatively little clavicle growth (20%) remains in girls aged > 9 years and boys aged > 12 years. Beyond this age, remodeling potential after fracture is limited. Therefore, debates are ongoing regarding surgical indications and optimal surgical methods that can be applied for the treatment of midshaft clavicle fractures in adolescents.[2]

Recently, many reports have demonstrated that surgical treatment of displaced midshaft clavicle fractures in adults has fewer adverse effects and yields better clini-

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cal outcomes than conservative treatment.[3,4] In adults, a plate or intramedullary nail is commonly used for surgical fixation.[5] The advantages of plate fixation are anatomic reduction, firm fixation, and compression of the fractured fragments. However, this method requires a long incision and causes further soft-tissue damage. To reduce these drawbacks, the minimally invasive plate osteosynthesis (MIPO) technique and intramedullary nail fixation have been suggested as alternatives that involve short skin incisions and less soft-tissue dissection.[6]

Few studies have compared the outcomes of various fixation methods used for midshaft clavicle fractures in adolescents. The purpose of this study was to analyze and compare the clinical and radiological outcomes of 4 different treatments of midshaft clavicle fractures in adolescents: conservative treatment with a figure-of-8 (FO8) brace (Fig. 1), open reduction and internal fixation with a plate (OPL) (Fig. 2), MIPO technique (Fig. 3), and intramedullary nail fixation with a threaded Steinmann pin (TSP) (Fig. 4).

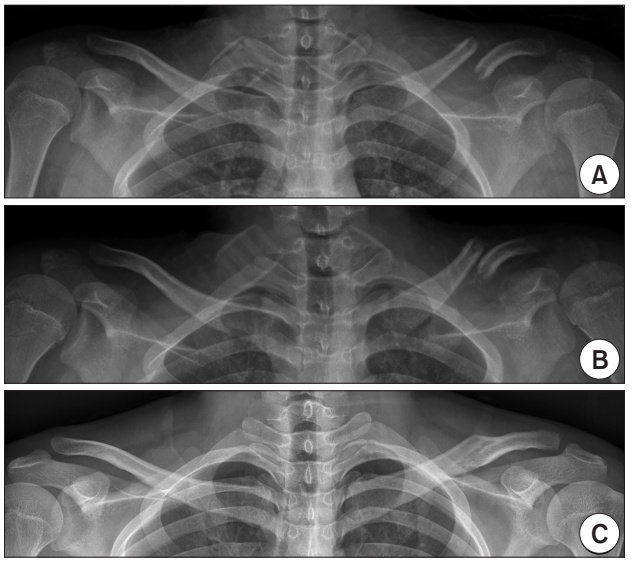

Fig. 1. (A) Preoperative anteroposterior simple radiograph of a displaced midshaft fracture of the left clavicle in a 13-year-old boy. (B) The figure-of-8 brace was applied. (C) Bony union was achieved at the final follow-up.

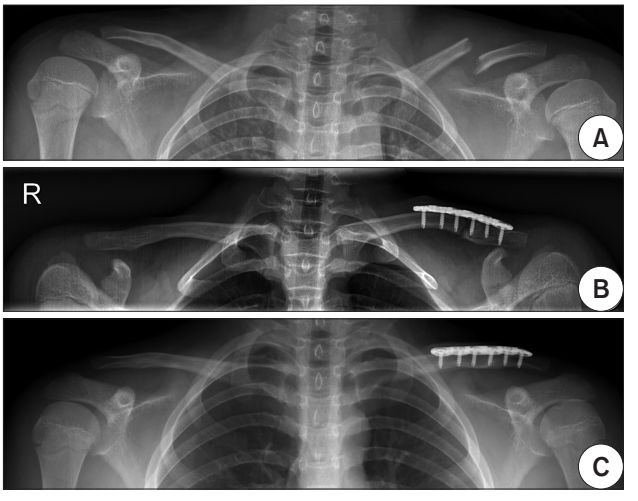

Fig. 3. (A) Preoperative anteroposterior simple radiograph of a 12-year-old boy showing displacement of a midshaft fracture of the left clavicle. (B) Minimally invasive plate osteosynthesis was performed. (C) The radiograph at postoperative 13 months showed complete union.

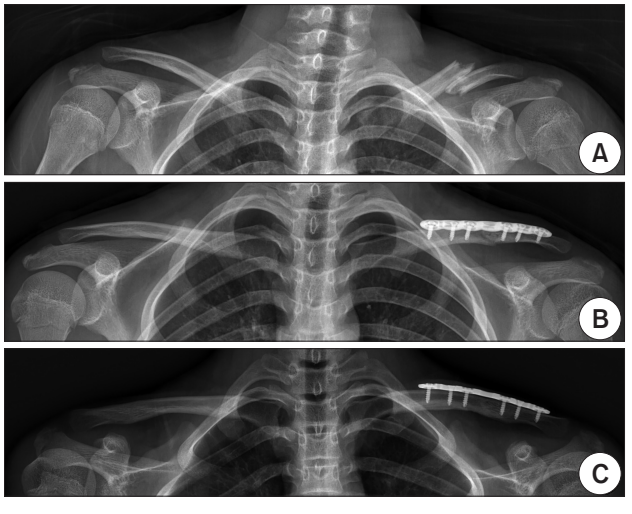

Fig. 2. (A) Preoperative anteroposterior simple radiograph of a 14-year-old boy showing displacement and shortening of a midshaft fracture of the left clavicle. (B) Open reduction and internal fixation with a plate was performed. (C) The radiograph at postoperative 12 months showed complete union of the fracture site.

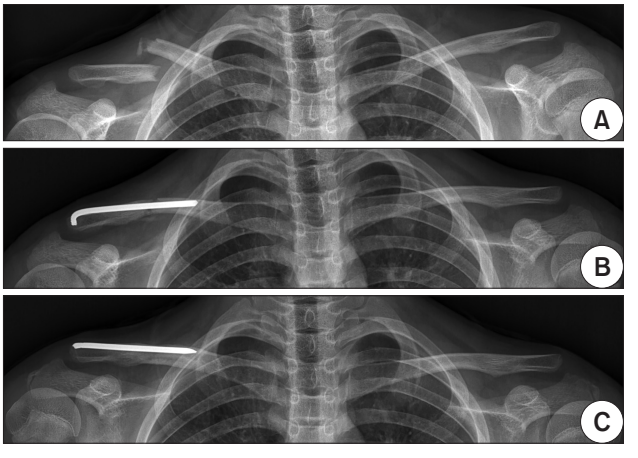

Fig. 4. (A) Preoperative anteroposterior simple radiograph of a 12-year-old boy showing displacement of a midshaft fracture of the right clavicle. (B) Intramedullary nail fixation with a threaded Steinmann pin was performed and the displaced butterfly fragments were reduced and fixed with Vicryl suture. (C) The radiograph at postoperative 13 months showed complete union.

METHODS

Patients

The protocol of this study was reviewed and approved by the Institutional Review Board of Eulji University Hospital (IRB No. EMC 2017-06-005). Written informed consents were obtained. This retrospective study included 94 teenagers who were treated for midshaft clavicle fractures from 2010 to 2015 and followed up for > 1 year. Excluded patients were those who did not return for follow-up, were hospitalized for a long time because of multiple fractures, and had a bilateral clavicle shaft fracture or a history of clavicle shaft fractures that could not be radiologically evaluated. The included patients were divided according to the treatment method as follows: FO8 group (24 patients), OPL group (33 patients), MIPO group (16 patients), and TSP group (21 patients) (Table 1). The mean age of the patients was 15 years (range, 12 to 18 years). Common injury mechanisms were soccer injuries (n = 25), bicycle injuries (n = 18), and falls (n = 18). There were more left clavicle fractures than right clavicle fractures (n = 56). The most common fracture type was the noncomminuted oblique fracture (n = 52) and spiral wedge fracture (n = 22) according to AO classification. Surgical indications were shortening > 1 cm, displacement > 100%, and severe angulation in initial X-ray, palpable fragments just beneath the skin, and multiple fractures. We recommended surgery to patients with an explanation on the various treatment modalities. A final decision was made by patients and their parents. A total of 70 patients were treated with surgical methods: there were 64 boys and 6 girls (only a number of girls underwent surgery because most girls did not want to have a surgical scar). Patients were followed up every 2 weeks until bony union, and both anteroposterior (AP) and axial images of the clavicle were taken. The average follow-up period is shown in Table 1.

Surgical Procedure

In the OPL group, an incision with the same length of the plate was made. The plate was fixed on the superior clavicular surface. In the MIPO group, plating was relatively easier to perform in children than in adults, because fracture comminution was not common. Two incisions were made medially and laterally for the MIPO technique. Plates used for fixation were the LCP superior clavicle plate (Depuy Synthes, Oberdorf, Switzerland) and precontoured locking plate (Acumed, Hillsboro, OR, USA).

In the TSP group, a 3.2-mm or 3.6-mm TSP was used for fixation depending on the clavicle size. For surgery, a 1- to 2-cm skin incision was made over the fracture site. The medullary canals of the medial and lateral fragments were reamed and widened by using Kirschner wires (K-wires) and Steinmann pins. After reaming, a 3.2-mm or 3.6-mm TSP was inserted to internally fix the fracture. The TSP was cut to an appropriate length and was placed under the skin.

Clinical and Radiological Outcomes

Hospitalization status, clinical and radiological results, and complications in each group were analyzed, and the results were compared among the groups. Medical records were reviewed to evaluate the hospitalization status including the length of stay, operation time, and time to implant removal. For the clinical outcomes, we evaluated the Disabilities of the Arm, Shoulder, and Hand (DASH) scores, Constant-Murley scores, time to regain a normal range of motion (ROM) after surgery, and cosmetic satisfaction (using the survey and scar length). A 5-point scale (1, dissatisfied to 5, satisfied) was used for the cosmetic satisfaction survey.

Radiological outcome was assessed by evaluating shortening and angulation at the final follow-up and time to bony union. Clavicle length and angulation were measured on AP clavicle radiographs using the Picture Archiving and Communication System (PACS) software (M-View, Marotech, Seoul, Korea) by 2 experienced orthopedic surgeons (SHK and SBM) who had not been involved in any of the operations reviewed in this study

Table 1. Demographics of Adolescents with Midshaft Clavicle Fractures

Variable	FO8 group	OPL group	MIPO group	TSP group	*p*-value
Number	24	33	16	21	-
Mean age at injury (yr)	14.5	15.1	14.6	14.2	0.71
Male sex (%)	20 (91.6)	32 (96.9)	14 (87.5)	18 (85.7)	0.22
Follow-up (mo), mean (range)	13.5 (12–16)	16.4 (13–20)	14.1 (12–17)	13.9 (12–16)	0.62

FO8: figure-of-8, OPL: open reduction and internal fixation with a plate, MIPO: minimally invasive plate osteosynthesis, TSP: threaded Steinmann pin.

Table 2. Clinical Outcomes after Various Treatments of Midshaft Clavicle Fractures in Adolescents

Evaluation	FO8 group	OPL group	MIPO group	TSP group	*p*-value
Length of stay (day)	None	3.5 ± 1.8	2.5 ± 1.0	2.8 ± 1.3	0.032
Operation time (min)	None	52.2 ± 12.9	54.7 ± 13.8	38.8 ± 6.3	0.026
Time to implant removal (mo)	None	12.2 ± 9.0	9.4 ± 5.5	5.6 ± 2.0	0.047
DASH score	4.6 ± 3.6	2.1 ± 2.6	2.7 ± 3.9	2.2 ± 2.4	0.034
Constant-Murley score	90.0 ± 6.7	94.1 ± 5.3	95.4 ± 3.6	95.7 ± 2.3	0.047
Time to regain normal ROM (wk)	12.7 ± 1.9	10.2 ± 0.9	9.3 ± 0.7	9.0 ± 0.6	0.016
Satisfaction score	4.0 ± 0.8	4.2 ± 0.9	4.3 ± 1.1	4.6 ± 0.6	0.041
Scar length (cm)	None	8.2 ± 2.1	5.9 ± 1.6	3.6 ± 1.6	0.038

Values are presented as mean ± standard deviation.
FO8: figure-of-8, OPL: open reduction and internal fixation with a plate, MIPO: minimally invasive plate osteosynthesis, TSP: threaded Steinmann pin, DASH: Disabilities of the Arm, Shoulder, and Hand, ROM: range of motion.

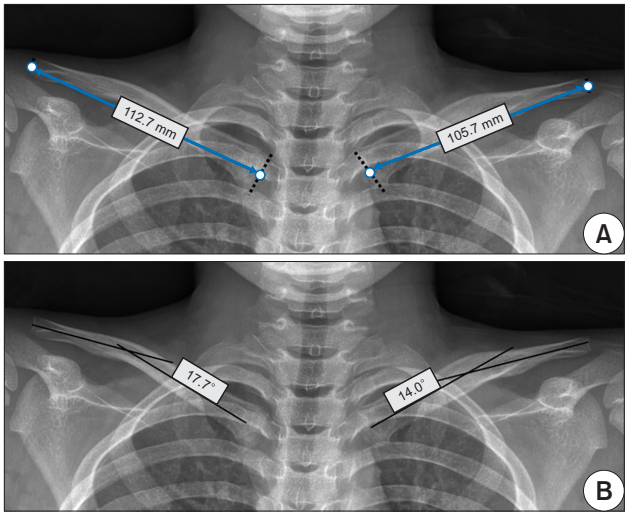

Fig. 5. Radiological evaluation. (A) Measurement of the clavicle length on the anteroposterior (AP) X-ray of the clavicle: clavicle length was defined as the length of the line connecting the midpoint of the lateral border of the clavicle and the midpoint of the medial border. Shortening was calculated by subtracting the length of the fractured clavicle from the length of the uninjured clavicle. (B) Measurement of angulation on the AP image of the clavicle: angulation was defined as the angle between the long axes of the medial and lateral diaphysis. Angulation was calculated by subtracting the angle of the fractured clavicle from the angle of the uninjured clavicle.

(Fig. 5). After a 2-week interval, they made repeated measurements. The acceptable intraobserver and interobserver reliability ranges for all radiographic measurements were 0.90–0.99 and 0.87–0.99, respectively.

Statistical Analysis

Treatment results were statistically compared among the groups. Statistical analysis was performed by using the Kruskal-Wallis test for the comparison of multiple groups. A $p < 0.05$ was considered statistically significant. IBM SPSS ver. 21.0 (IBM Corp., Armonk, NY, USA) was used for statistical analysis.

RESULTS

The mean hospital stay was 1 day longer in the OPL group than in the TSP or MIPO group ($p < 0.05$) (Table 2). The operation time was significantly shorter in the TSP group than in the OPL and MIPO groups (Table 2). There was no statistically significant difference in the mean DASH scores among the operated groups (Table 2). The Constant-Murley scores at the final follow-up showed good results in all groups; however, they were higher in the operated groups than in the FO8 group (Table 2). The time to regain normal ROM was statistically significantly longer in the FO8 group than in the operated groups (Table 2). Cosmetic satisfaction scores (5-point scale) were statistically significantly higher in the TSP group than in the OPL, MIPO, and FO8 groups (Table 2). The scar length was the shortest in the TSP group among the operated groups (Table 2).

Radiological bone union was achieved in all patients in a mean of 8.4 weeks (range, 6 to 16 weeks). The mean bone length corrected by surgery at the time of the final follow-up is shown in Table 3. At the final follow-up, the bone lengths in the OPL and TSP groups were closer to normal than those in the FO8 and MIPO groups ($p < 0.05$)

Table 3. Radiologic Outcomes after Various Treatments of Midshaft Clavicle Fractures in Adolescents

Evaluation	FO8 group	OPL group	MIPO group	TSP group	*p*-value
Shortening (mm)					
Injury	3.8 ± 9.3	10.5 ± 7.9	10.7 ± 11.5	9.7 ± 5.6	0.044
Postoperative	NA*	3.4 ± 4.1	7.4 ± 9.3	5.9 ± 4.8	0.013
Final	10.5 ± 7.5	3.6 ± 5.8	7.4 ± 5.0	4.6 ± 3.6	0.038
Angulation (°)					
Postoperative	11.4 ± 6.7†	9.5 ± 9.1	17.1 ± 6.5	13.5 ± 5.3	0.016
Final	18.3 ± 6.4	9.2 ± 6.7	13.2 ± 7.1	10.3 ± 4.0	0.023
Union duration (wk)	7.5 ± 2.5	10.5 ± 0.9	7.3± 1.2	7.4 ± 0.7	0.039

Values are presented as mean ± standard deviation.
FO8: figure-of-8, OPL: open reduction and internal fixation with a plate, MIPO: minimally invasive plate osteosynthesis, TSP: threaded Steinmann pin.
*There was no postoperative value in the case of the FO8 group because patients in the group did not undergo an operation. †Initial angulation in the case of the FO8 group because patients in the group did not undergo an operation.

(Table 3). The mean angulation at the final follow-up was the smallest in the OPL group and was statistically significantly smaller in the OPL and TSP groups than in the MIPO and FO8 groups ($p < 0.05$) (Table 3). The FO8, TSP, and MIPO groups showed statistically significantly faster bone healing than the OPL group ($p < 0.05$) (Table 3).

In the operated groups, 9 patients had metal-induced irritating symptoms. Superficial skin infections occurred in 2 patients in the OPL group and in 1 patient in the TSP group. They were treated with antibiotics therapy without a surgical procedure. In the OPL group, 1 patient complained of supraclavicular nerve injury symptoms at the final follow-up. Refractures after plate removal occurred in 4 patients (2 in the MIPO group and OPL group each). Three fractures were caused by another trauma at >3 months after metal removal. However, 1 refracture occurred within 6 weeks after plate removal in the MIPO group (Table 4). They were treated with a FO8 brace because displacement was less than 100%.

Table 4. Complications after Various Treatments of Midshaft Clavicle Fractures in Adolescents

Complication	FO8 group	OPL group	MIPO group	TSP group
Nonunion	0	0	0	0
Metal-induced irritating symptom	0	4	3	2
Infection (superficial)	0	2	0	1
Neurology	0	1	0	0
Refracture	0	2	2	0
Total	0	12	5	3

FO8: figure-of-8, OPL: open reduction and internal fixation with a plate, MIPO: minimally invasive plate osteosynthesis, TSP: threaded Steinmann pin.

DISCUSSION

Treatment of displaced clavicle shaft fractures in adolescents is still controversial. Up until now, conservative treatment has been considered as the main treatment modality for clavicle shaft fractures in adults and children.[1] However, there have been many changes in the treatment of clavicle shaft fractures in adults over the last decade.[7] Recently, many reports have indicated that the time to union was faster and nonunion and malunion were less frequent after surgical treatment of displaced clavicle shaft fractures in adults. Robinson et al.[8] reported a 4.5% nonunion rate, decreased muscle power, and low satisfaction in adults with clavicle shaft fractures treated with conservative methods.

The results for adults cannot be directly applied to children. However, in an adolescent whose growth potential is limited, malunion or delayed union might result in unsatisfactory results, especially in girls and boys older than 9 years and 12 years, respectively.[9] Schulz et al.[2] reported the shortening of the clavicle length after conservative treatment in pediatric patients, which was highly correlated with the reduction in external rotation and abduction power. Bae et al.[10] reported 16 cases of malunion in adolescents with unstable clavicle shaft fractures treated with conservative methods; in their study, 20% of patients

complained of pain during follow-up. Randsborg et al.[7] reported that 10 boys (age, 18 years) who underwent nonsurgical treatment of displaced clavicle shaft fractures showed poor results with respect to functional scores, cosmetic outcomes, and overall satisfaction. Therefore, recently, adolescents with displaced clavicle shaft fractures tend to undergo surgical treatment. In the current study, the clinical and radiological results of the operated groups were better than those of the nonoperative group (FO8 group). The operated groups were able to initiate rehabilitation earlier and return to daily life sooner and had less shortening and angulation than the FO8 group at the last follow-up. Therefore, surgical treatment of the displaced fracture might result in less shoulder pain, fewer functional defects, and better results.

The indications for clavicle shaft fractures in adolescents remain controversial. McIntosh[11] recommended surgery for a completely displaced midshaft fracture with shortening of > 1 cm, superior displacement with skin tenting, impending open fracture, associated neurovascular injury, open clavicle fracture, and floating shoulder. Backus et al.[12] reported that displacement and shortening were more severe on upright films than on supine films and that upright radiographs should be checked. The indications for surgery are recently becoming broader. In this study, we recommended surgery to patients according to the indications suggested by McIntosh[11] and the patients obtained good results. As prominence due to malunion, a surgical scar, slight limitation of joint motion, and weakness are quite subjective symptoms, they could variably affect an individual's satisfaction. The likelihood of malunion or delayed union is lower in children than in adults, and there is some potential for remodeling in children. Thus, the recommendation for adults could be the relative indications for adolescents. The decision for surgery should be made by the patients and their parents after they have been well informed on the treatment modalities and results.

Implants commonly used for the fixation of fractured clavicle shafts are K-wires, screws, plates, and intramedullary nails of various types (e.g., TSPs, elastic stable intramedullary nails, and Sonoma nails). Plates and screws are most commonly used because they require a short fixation period and provide accurate reduction and firm fixation and good clinical and radiological results.[7] In our study, the OPL group showed the best radiological results. However, OPL is known to result in a relatively long scar on the neck, hardware irritation, and numbness to the supraclavicular nerve.[13] Indeed, the satisfaction scores concerning the surgical scar were low and the scar length was the longest in the OPL group. Four patients in the OPL group experienced discomfort and numbness at the surgical site. We noted refractures after plate removal in both the OPL and MIPO groups. One occurred within 6 weeks after removal. We recommend explaining the possibility of refractures after plate removal to adolescents. Additionally, a thinner metal plate and screw for this age group should be developed for clavicle fixation.

The MIPO technique is quite ideal to reduce the size of skin incision and dissatisfaction due to a long scar in the OPL group. Furthermore, the MIPO technique is technically easy to perform in adolescents because there is little bone comminution in these patients.[14] Fractures united faster in the MIPO group than in the OPL group because of less soft-tissue dissection. However, accurate anatomic reduction could not be achieved in the MIPO group in our study, and radiological results were slightly poorer in the MIPO group than in the OPL group. In addition, Beirer et al.[15] reported that the small-incision MIPO technique could not reduce the supraclavicular nerve injury compared to the conventional open reduction. In addition to these disadvantages of the MIPO technique, refractures might occur after implant removal as shown in our study.

Few studies have compared the results of plate and intramedullary nail fixations in adolescents. However, there have been many studies in adults. Houwert et al.[16] reported there was no statistical difference in functional outcomes and complications between plate and intramedullary nail fixations. In the past, several reports indicated that smooth pins used for fixation of clavicle shaft fractures had migrated in the direction of the aorta and vertebrae.[17] Because of this risk, surgeons were reluctant to use smooth pins such as K-wires for clavicle fixation. In addition, Frigg et al.[18] reported that intramedullary nailing of clavicle shaft fractures has disadvantages with respect to technicality, risk of longer exposure to fluoroscopy, longer surgical time, cortical perforation, nail breakage, and hardware irritation. In contrast, Rapp et al.[14] recently reported that intramedullary nail fixation of clavicle shaft fractures in adolescents using K-wires and elastic stable intramedullary nails showed good results with less pain, improved patient satisfaction, and shorter immobilization. Migration of smooth pins such as K-wires might not occur with TSPs. Grassi et al.[19] reported the results of intramedullary nail fixation with TSP using a surgical technique similar to ours in this study. However, Grassi et al.[19] reported a high rate of complications with TSP fixation, such as infection, refracture, nonunion, and delayed union. Contrary to this study, they used a thinner threaded pin (2.5 mm) and placed the pin outside the skin.[19] Whether a pin of

any size is appropriate remains controversial. A stronger fixation can be achieved with longer and bigger pins; however, it is difficult to insert a longer pin into the curved clavicle because the bigger the pin is, the stiffer it is. We reamed and widened the intramedullary space and used a bigger TSP (3.2 mm or 3.6 mm) in this study. In addition, all TSPs were placed under the skin to reduce the risk of infection. In the present study, intramedullary nail fixation with TSP had many advantages such as shorter hospitalization and operation time, faster union than the OPL and MIPO technique, and higher subjective cosmetic satisfaction. However, it was difficult to use when the comminution at the fracture site was severe and the marrow was sclerotic due to a previous fracture. In these cases, the OPL technique would be easier to perform than fixation using a TSP.

Our study has some limitations, First, it is a retrospective study. Second, we did not determine operative indications for midshaft clavicle fractures in adolescents. Third, the duration of outcome evaluation was relatively short because 20% of the total clavicle length can grow after age 9 years in girls and age 12 years in boys. Therefore, further research needs to be conducted.

In conclusion, all of the various treatments for midshaft clavicle fractures compared in our study showed satisfactory clinical and radiological outcomes in the adolescents. Although the nonoperatively treated group showed slightly worse clinical and radiological outcomes than the operative groups, the nonoperative method was comparable to the operative methods because it has no risk of iatrogenic complications induced by surgery. The operative groups complained of various disadvantages induced by surgery such as a surgical scar, metal irritation, infection, and refracture after plate removal. These groups, however, achieved faster functional recovery and slightly better radiological and functional results than the nonoperative group.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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