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Minimally invasive correction versus open surgery for contractured second toe: comparing results

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Abstract

Introduction The use of minimally invasive techniques is of utmost importance to future developments of foot and ankle surgery requiring large-scale clinical randomized studies. This retrospective study is based on a comparison of the classical open and minimally invasive techniques. **Material and methods** The review included 65 hammertoe surgical cases (76 feet) treated with minimally invasive approach and postoperative strapping and taping techniques (group A, n = 39) and with open procedure using transarticular wire fixation (group B, n = 37) . Open surgical procedures were performed for the first metatarsal at the same time for all patients. The mean follow-up period was 15.3 ± 2.8 months. The mean age of patients was 62.8 ± 10.2 years. **Results** The follow-up protocol included a survey, physical examination, assessment of pain, function and treatment satisfaction (AOFAS, VAS FA, PGIC) and radiographic estimation of fusion. A floating toe was a common complication. **Discussion** Minimally invasive technique was demonstrated to be a less safe approach (risks associated with burr manipulations and surgeon skills) and more effective (minor and moderate pain in the postoperative period, lower risk of infection, attainment of personal anatomicity and early loading without internal fixation, extended indications with no need for use of surgical tourniquet) demonstrating adequate radiographic and clinical results and high patient satisfaction. The technique promotes patient's comfort and willingness to cooperate due to the lack of internal fixation and has a high intraoperative radiation load compared to other methods. **Conclusion** Minimally invasive technique has demonstrated good results and can be advocated for extensive orthopaedic practice with its own niche of application.

Keywords: hammertoe, metatarsalgia, minimally invasive surgery

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INTRODUCTION

The last two decades have seen the development of minimally invasive forefoot surgery. Both Russian [1, 2] and foreign authors [3–11] popularize this trend. More surgeons are using the minimally invasive technique. Minimally invasive foot surgery can be used in diabetes mellitus [12, 13], in children [14] and even in such a rare condition as hallux valgus in Pfeiffer syndrome [15]. Advantages of the open procedure which has been the "gold" standard for many decades, have not been explored. Bia et al (2018) reported a high complication rate for minimally invasive surgery in a systematic review, and the authors recommended randomized clinical trials [16].

There are good reasons to be concerned about the merits of minimally invasive surgery. The use of a minimally invasive technique should not lead to an increased rate of injured neurovascular structures and prevent thermal damage to the bone caused by the drill. Some techniques suggest absence of fixation [17] that can be associated with a higher rate of nonunions at the site of osteotomy. There is a paucity of information regarding the risks. Jowett et al (2017) reported 14 % of reoperations with minimally invasive procedures performed for hallux valgus [18]. In contrast, open calcaneal osteotomy was reported to be associated with a higher risk of nerve injury than minimally invasive osteotomy [19, 20]. Yassin (2106) reported minimally invasive toe surgery followed by bandaging being as safe as open osteotomies and pin fixation [21]. Some authors suggest that minimally invasive forefoot surgery is safer than open surgery [22]. A number of hallux valgus procedures [23] demonstrated a similar risk of recurrence (about 15 %) and delayed consolidation (10 %) with both open and minimally invasive techniques.

A thermal injury caused by a minimally invasive osteotomy bur can be associated with a higher risk of delayed consolidation and nerve injury. The rotation speed and the size were shown to be important factors leading to a thermal injury [24]. The bur cooling can improve bone healing and the union rate in arthrodesis [25]. This study presents the results of minimally invasive toe procedures for hammertoe deformity and typical complications associated with these techniques.

The objective of the study was to evaluate outcomes of surgical treatment of hammertoe deformity using a statistically significant comparison of the techniques.

MATERIAL AND METHODS

Retrospective single center study.

Inclusion criteria were:

• age over 18 years;

• combined flat feet diagnosed with hallux valgus deformity combined with hammertoe deformity of the second toe;

• unstable metatarsophalangeal joint of the second toe (Hamilton-Thompson grade II–IV);

• availability of informed written consent to the operation and participation in the study.

Exclusion criteria:

• contraindications to surgical treatment (chronic diseases in the stage of sub-/decompensation); congenital and acquired systemic diseases and their consequences;

• previous surgical foot interventions;

• the patient's inability for follow-up examinations during the entire period of observation determined by the design of the study.

Withdrawal criteria:

• refusal of the patient to further participate in the study;

• failures of scheduled follow-up examinations due to objective or subjective reasons.

The study included 65 patients (76 feet) with hammertoe deformity surgically treated between 2016 and 2018. There were 61 female (93.8 %) and 4 male (6.2 %) patients. The mean age of patients ($M \pm \sigma$) was 62.8 ± 10.2 years (range, 39 to 82 years, median = 64 years). The mean follow-up ($M \pm \sigma$) was 15.3 ± 2.8 months (range, 12 to 21 months, median = 15 months).

The patients in this study were diagnosed with hammertoe deformity of the second toe; patients with hammertoe deformity of the third, fourth or several toes were not included in the study. The stability of the metatarsophalangeal joint was assessed using the Hamilton-Thompson vertical stress test (0-4 grades of instability). Patients with metatarsophalangeal instability grades 2, 3 and 4 of the second toe were included in the study.

Group A included patients who underwent surgical procedures (osteotomies of the phalanges of the toes, tenotomies, distal osteotomies of the metatarsal bone) through a minimally invasive approach using special equipment and subsequent fixation with a bandage. Group B included patients who underwent open resection arthroplasty of the proximal interphalangeal joint in combination with Weil osteotomy and transarticular pin fixation for 6 weeks. Open operations performed simultaneously with the second toe procedure on the first metatarsal bone and the first toe in both groups included: Scarf osteotomy of the first metatarsal bone, Akin osteotomy of the proximal phalanx of the first toe, since the study included patients with hallux valgus (isolated hammertoe deformity was an exclusion criterion). Additional procedures (distal metaphyseal minimally invasive metatarsal osteotomy for group A and Weil osteotomy for group B) were performed on the second metatarsal in all cases and shortening of the metatarsal bones was performed with signs of overloaded metatarsal heads of the third or fourth toes (metatarsalgia, hyperkeratosis). The study did not include patients who had undergone midfoot or hindfoot procedures, minimally invasive soft tissues procedures (tenotomy) or patients who had not undergone procedures on the first metatarsal and first toe in the specified volume. All patients were operated on by a permanent operating team, by one surgeon. The sample population was characterized by a normal distribution by age and follow-up period (Kolmogorov-Smirnov test, asymptotic significance > 0.05) and non-normal according to questionnaire data (Kolmogorov-Smirnov test, asymptotic significance < 0.05). Major preoperative characteristics of patients are presented in Table 1.

Table 1

Distribution of patients by comparison groups

Description		Minimally invasive procedures	Arthroplasty of the proximal interphalangeal joint
		Group A (n = 32)	Group B (n = 33)
Total number of the feet involved, n = 76		39 (100 %)	37 (100 %)
Mean age, years	($M \pm \sigma$)	62.4 ± 10.8	63.1 ± 9.6
	range	min 40 – max 80	min 39 – max 82
Mean follow-up period, months	($M \pm \sigma$)	17.0 ± 4.0	16.7 ± 4.4
Metatarsophalangeal joint stability of 2 toe (Hamilton-Thompson test)	grade 0	0	0
	grade1	0	0
	grade 2	6 (15.4 %)	5 (13.5 %)
	grade 3	8 (20.5 %)	8 (21.6 %)
	grade 4	25 (64.1 %)	24 (64.9 %)
American Orthopaedic Foot and Ankle Score Forefoot (AOFAS FF)	preoperative mean score ($M \pm \sigma$)	36.5 ± 14.1	35.4 ± 10.3
Visual analog scale for assessing foot and ankle pain		60 ± 8.7	59.3 ± 9.1

Minimally invasive procedure (Group A)

Minimally invasive procedures were performed without a tourniquet. Osteotomies of the phalanges of the toes (interphalangeal joint access) and minimally invasive distal metatarsal osteotomies (access to the metatarsal neck) were performed using a Shannon 2*12 mm drill (Integra Life sciences Ltd.) at low speed (up to 1500 turns /min). Continuous work with the drill was produced for no more than 20 seconds. The drill was cooled by irrigation with saline from a syringe at the working time. The completion of the osteotomy was checked manually and radiographically. Tenotomies of the flexor brevis and extensor muscles were performed using a minimally invasive scalpel at the metatarsophalangeal level. Completion of tenotomies was checked manually. Fixation of osteotomies was performed by tight taping with self-fixing bandages (Peha-haft, Hartmann) for 6 weeks.

Classic open technique (group B)

The operation was performed under a tourniquet through the dorsal access at the site of the proximal interphalangeal joint. Access was made to the head of the proximal phalanx, head of the proximal phalanx and the articular surface of the middle phalanx resected, the axis of the toe corrected, and transarticular fixation with a pin performed. The pin was removed 6 weeks after the operation. Weil osteotomy was performed as an additional procedure. Osteotomy was performed through the dorsal approach at the metatarsophalangeal joint of the second toe followed by fixation with a self-breaking screw.

Early postoperative period

Early ambulation with full weight-bearing was recommended for patients of both groups on the next day after surgery using postoperative Baruka shoes. Postoperative footwear was recommended for at least 6 weeks after surgery. Non-steroidal anti-inflammatory drugs were prescribed in combination with proton pump inhibitors for pain relief.

Follow-up

Physical examination was performed preoperatively, on the first day after surgery, at 12–14 days after surgery (removal of sutures), 6 weeks, 3 months and 12 months after surgery. An additional follow-up visit at 6 months was recommended in case of negative dynamics of the condition or absence of consolidation on radiographs at 3 months. Radiological examination of the feet [26] with weight-bearing AP and lateral views was performed preoperatively, on the first day after surgery, at 6–8 weeks and 3 months after surgery.

Grading Scales [27]

Clinical assessment was produced with the American Orthopedic Foot and Ankle Society Score (AOFAS Score) [27–31] preoperatively and at 12 months after surgery. The visual analogue scale for assessing The functionality of the foot and ankle was assessed with VAS FA (Visual Analogue Scale Foot and Ankle) [32, 33] preoperatively, at 2 weeks, 6 weeks, 3 months and 12 months after surgery. The VAS-FA subjective form consisted of 20 questions with the answers to each ranging from 0 to 10 points. The total score for this questionnaire (200 points) was translated into a 100-point coefficient. The Patient Global Impression of Change scale (PGIC) [34] was completed at 12 months after surgery. The results were interpreted as: 1, worsening condition; 2–3, minimal improvement; 4–5, average improvement; 6–7, a significant improvement.

Statistical analysis

The data were recorded and processed in the Microsoft Excel program. Hypothesis testing was carried out in the SPSS Statistica 23 program. The single-sample Kolmogorov-Smirnov test was used to determine the subordination of the sample to the Gauss law according to the specified characteristics. The U-Mann-Whitney test was used to determine the significance of differences in the results between groups (independent groups). The Wilcoxon T-test was used to determine the significance of differences in the results of each of the groups before and after treatment (dependent samples).

RESULTS

Clinical assessment of pain with the American Orthopedic Foot and Ankle Society Score (AOFAS Score)

The mean preoperative AOFAS score was 36.8 ± 21.8 (range, 4 to 78). The mean score was identical in patients treated with minimally invasive approach and the classical open procedure ($p > 0.05$). Postoperative results improved significantly with the questionnaire in both groups. Outcomes are presented in Table 2 and Figure 1.

Visual analog scale for assessing the functionality of the foot and ankle

The VAS score was significantly lower in the minimally invasive surgery group, with a statistically significant difference observed at 2 and 6 weeks postoperatively ($p < 0.05$). The pain assessed with VAS FA is presented in Table 3 and Figure 2.

Table 2

The results of surgical treatment measured with the AOFAS

Descriptive statistics	Preop AOFAS	AOFAS at 12 months	N valid (according to the list)
N	76	76	76
Minimum	4	32	
Maximum	78	100	
Mean	36.80	79.96	
Standard deviation	21.769	13.142	

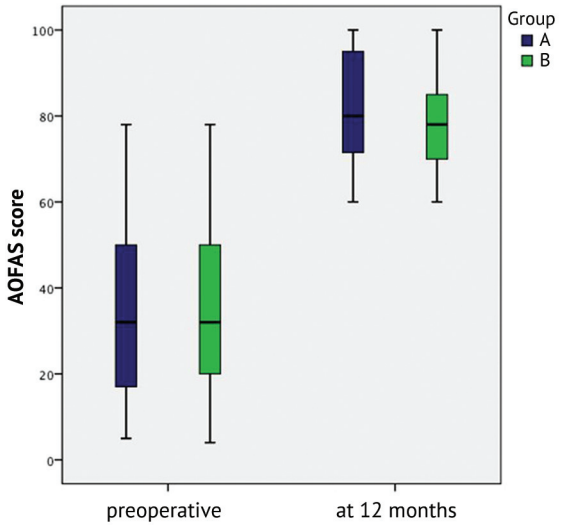

Fig. 1 The results of surgical treatment measured with the AOFAS

Table 3

Results of surgical treatment measured with VAS FA

	Visual analog scale for assessing foot and ankle pain(M ± σ)	
	Minimally invasive procedure	Open surgery
Preop	60.0 ± 8.7	59.2 ± 4.6
2 weeks after surgery	32.8 ± 6.3	38.7 ± 1.9
6 weeks after surgery	19.8 ± 6.8	25.7 ± 2.6
3 months after surgery	16.0 ± 5.5	17.2 ± 6.5
12 months after surgery	15.2 ± 7.5	15.9 ± 7.7

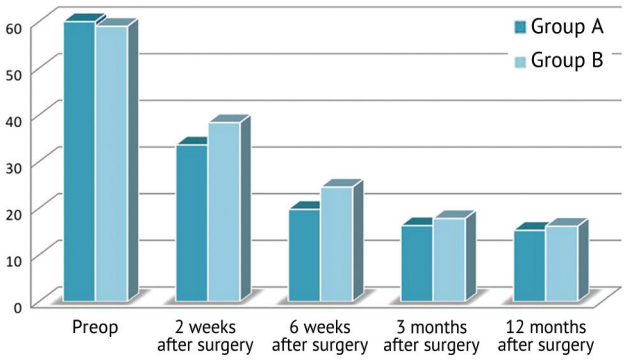

Fig. 2 The results of surgical treatment measured with the visual analog scale, average values

Patients' global impression of change (PGIC)

The PGIC assessment showed that 25.0 % (19 patients, n = 76) patients reported a significant improvement (6–7 points on the scale). 38.2 % (29 patients, n = 76) reported some improvement (4–5 points on the scale), while the rest (36.8 %, 28 patients, n = 76) reported minimal improvement (2–3 points on the scale) at 12 months. None of the patients reported worsening of the condition (first item). The mean PGIC value (M ± σ) in the minimally invasive group (Group A) was significantly better (4.5 ± 1.5) than in the open technique group (Group B) (4.1 ± 1.6) ($p < 0.05$) (Fig. 3).

Table 4

Results of surgical treatment measured with PGIC

Descriptive statistics	Group A	Group B	N valid (according to the list)
N	39	37	37
Minimum	2	2	
Maximum	7	7	
Mean	4.51	4.08	
Standard deviation	1.537	1.605	

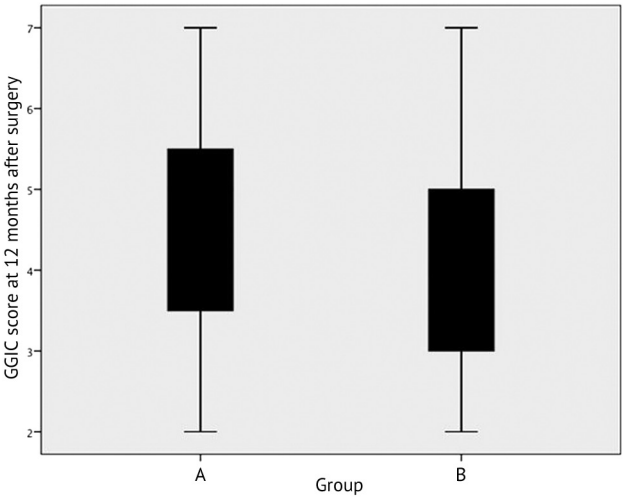

Fig. 3 Results of surgical treatment measured with PGIC

Radiographic examination

There were statistically significant differences in the fusion of osteotomy between the groups ($p < 0.05$). The average term for union was 5.1 ± 2.6 months in group A and 4.3 ± 2.8 months in group B.

Complications

A floating toe was a common complication in the surgical treatment of hammertoe deformity. The complication developed in 27 feet (69.2 %, n = 39) of group A and in 32 feet (86.5 %, n = 37) of group B. The differences between groups were statistically significant ($p < 0.05$) and correlated with the degree of metatarsophalangeal joint instability. There was one case of nonunion in group B with a breakage of the fixation pin that required the removal of the pin. There were no infectious complications in the groups.

Clinical instance 1 (group A)

A 61-year-old patient A. presented with pain and deformity in both feet (more severely on the right), hyperkeratosis under the head of the second metatarsal bone and at the site of the proximal interphalangeal joint of the second toe of the right foot. She suffered from the condition for more than 5 years. She was diagnosed with adult acquired flatfoot, valgus deformity of the first toe of both feet, hammertoe deformity of the second toe of the right foot, overload metatarsalgia (Fig. 4).

Fig. 4 Preoperative appearance of the right foot

Physical examination of the feet demonstrated decreased height of the longitudinal and transverse arches of both feet, valgus deformity of the first toe of both feet and varus deformity of the first metatarsal bone of both feet, hammertoe deformity of the second toe of the right foot, unstable metatarsophalangeal joint of the 2nd toe of the right foot (grade 2), hyperkeratosis under the head of the second metatarsal bone along the dorsal surface of the proximal interphalangeal joint of the second toe of the right foot. On palpation, the patient had pain along the medial surface of the head of the first metatarsal, under the head of the second metatarsal bone, along the dorsal surface of the proximal interphalangeal joint of the second toe of the right foot. Weight-bearing AP and lateral radiographic views demonstrated decreased height of the longitudinal and transverse arches, hammertoe deformity of the second toe of the right foot (Fig. 5). Preoperative AOFAS scored 50 and the VASFA scored 65 points.

Fig. 5 AP and lateral radiographic views of the right foot before surgery (a) and on the first day after surgery (b)

Surgical treatment included minimally invasive osteotomy of the proximal phalanx of the second toe, distal minimally invasive metatarsal osteotomies of the second and third metatarsal bones, minimally invasive tenotomy of the flexor tendon of the second toe, Scarf osteotomy of the first metatarsal bone fixed with two screws, Akin osteotomy of the proximal phalanx of the first toe and screw fixation (Fig. 5). The VAS FA scored 40 at 2 weeks of surgery. Radiographs of the left foot showed consolidation of the osteotomy sites at 18 months (Fig. 6).

Fig. 6 Radiographs of the right foot at 18 months of surgical treatment

The patient reported decreased sensitivity of the second toe of the right foot causing no discomfort at 18 months (Fig. 7). The AOFAS scored 83 points and the VASFA scored 18 that was rated as a good result.

Fig. 7 Appearance of the right foot at 18 months of surgical treatment

Clinical instance 2 (group B)

A 69-year-old patient B. presented with pain and deformity in both feet (more severely on the left), symptomatic hyperkeratosis under the heads of the second and third metatarsal bones and at the site of the proximal interphalangeal joint of the second toe of the left foot. She suffered from the condition more than 10 years. She was diagnosed with adult acquired flatfoot, valgus deformity of the first toe of both feet, hammertoe deformity of the second toe of the left foot, overload metatarsalgia (Fig. 8). Physical examination of the feet showed a decreased height of the longitudinal and transverse arches of both feet, valgus deformity of the first toe of both feet and varus deformity of the first metatarsal bones of both feet, hammertoe deformity of the second toe of the left foot, degenerative dislocation of the main phalanx in the metatarsophalangeal joint of the 2nd toe of the left foot (grade 3), lack of support ability of the second toe of the left foot, hyperkeratosis under the heads of the second and third metatarsal bones, along the dorsal surface of the proximal interphalangeal joint of the second toe of the left foot. On palpation, the patient had pain along the medial surface of the head of the first metatarsal bone, under the head of the second and third metatarsal bones, along the dorsal surface of the proximal interphalangeal joint of the second toe of the left foot.

Preoperative weight-bearing AP and lateral radiographic views demonstrated decreased height of the longitudinal and transverse arches, hammertoe deformity of the second toe of the left foot (Fig. 9). Preoperative AOFAS scored 30 and the VASFA scored 78.5 points.

Surgical treatment included resection arthroplasty of the proximal interphalangeal joint of the second toe and transarticular pin fixation, Weil osteotomy of the second and third metatarsal bones and screw fixation, Scarf osteotomy of the first metatarsal bone and two screw fixation, Akin osteotomy of the proximal phalanx of the first toe and screw fixation (Fig. 10).

The VAS FA scored 64 points at 2 weeks. The patient reported moderate pain under the heads of the metatarsal bones and the absence of active flexion and extension of the 2nd toe at follow-up examinations. X-rays of the left foot showed consolidation of the osteotomy sites and subluxation in the second metatarsophalangeal joint at 12-month follow-up (Fig. 11).

Physical examination showed maintained restriction of active flexion and extension of the proximal interphalangeal joint of the second toe at 12-month follow-up (Fig. 12). She developed a common complication – the floating toe with the second toe not touching the surface of the support, she had no pain. The AOFAS scored 70 points and the VASFA scored 50 that was rated as a good result.

Fig. 8 Preoperative appearance of the left foot

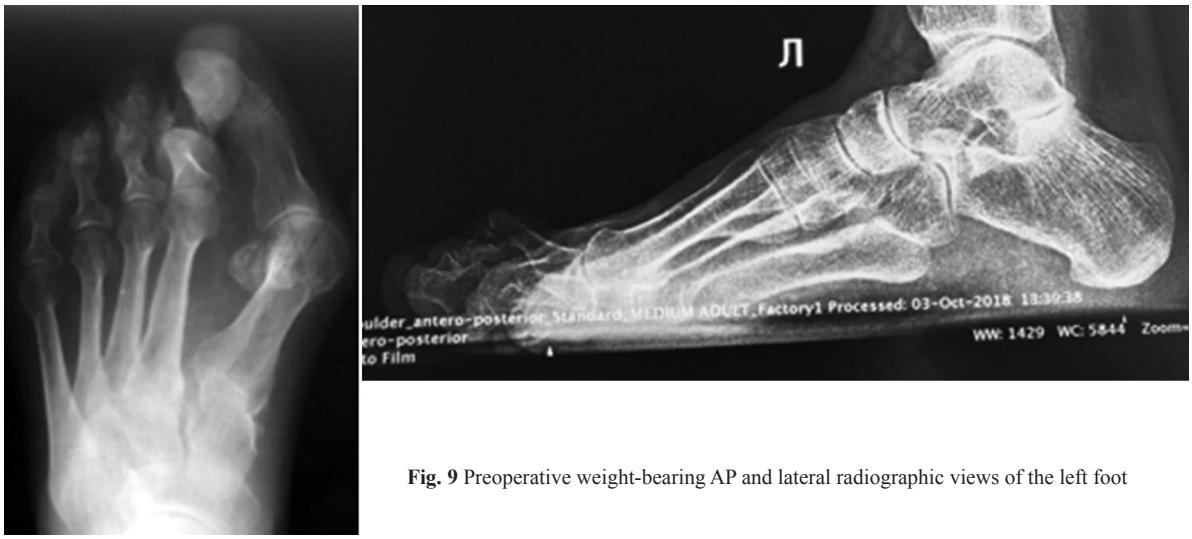

Fig. 9 Preoperative weight-bearing AP and lateral radiographic views of the left foot

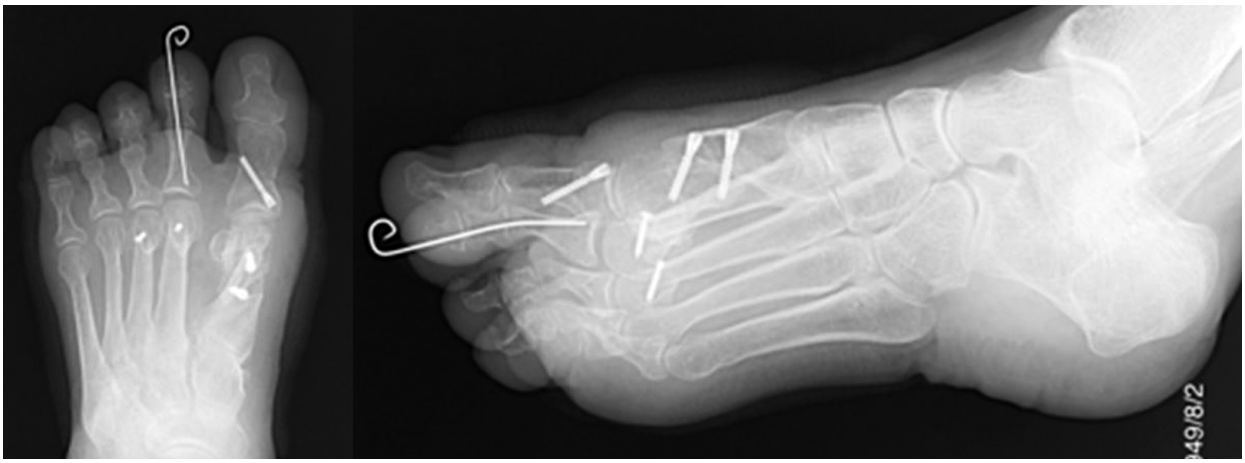

Fig. 10 AP and lateral radiographic views of the left foot on the first postoperative day

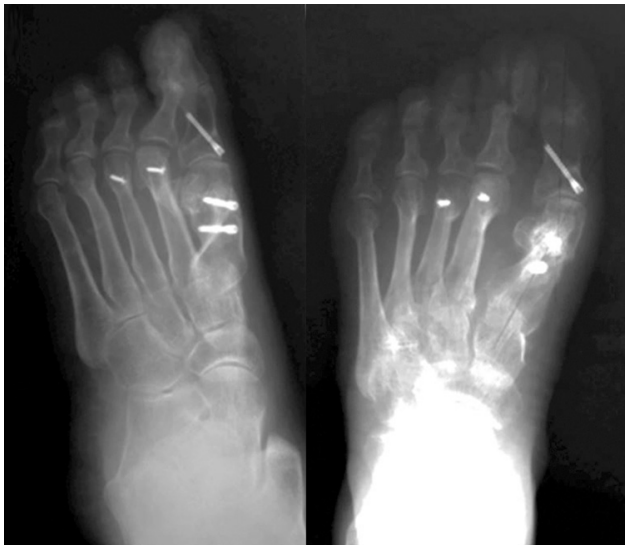

Fig. 11 Radiographs of the left foot at 12-month follow-up

Fig. 12 Appearance of the left foot at 12 months of surgical treatment

DISCUSSION

The minimally invasive forefoot surgery [35] is a revival of an old technique that was widely practiced several decades ago [36]. The present study confirms the hypothesis that minimally invasive surgery can compete with open surgery. The findings of the study suggest that minimally invasive osteotomy can be safe for correction of forefoot deformity with short pulse drilling at lower speed. Irrigating the drill with saline intraoperatively was shown to reduce the temperature and minimize thermal tissue damage. Drilling at a higher speed can cause injury to neurovascular structures [37]. The potential risks of minimally invasive surgery can be accommodated by lower levels of pain in the early and late postoperative period that can be associated with an incision in the open procedure. However, the level of pain was identical at a long term, as evidenced by the VAS FA score. The lower pain score was likely to be associated with higher PGIC satisfaction scores in the minimally invasive group. A comprehensive analysis indicated the advantage of the minimally invasive technique regarding pain with the technique causing a large intraoperative radiation load.

The occurrence of a floating toe was lower with the minimally invasive technique and could be associated with tenotomies and was high in both groups. The complication was seen in all patients with grade four degree instability of the metatarsophalangeal joint of the 2nd toe and failure of the plantar ligament of the metatarsophalangeal joint. The incidence of the complication was directly proportional to the grade of instability of the metatarsophalangeal joint. The complication was rather associated with additional procedures (Weil osteotomy, distal minimally invasive metatarsal osteotomy) than with major toe interventions.

CONCLUSION

Lack of randomization was a disadvantage of the study. The strength of the study was a single treatment protocol performed by a single surgeon and consistent follow-up. The use of minimally invasive technique in forefoot surgery was characterized by a high level of safety, efficiency and patient satisfaction and facilitated relief of severe pain in the early postoperative period and improvement outcomes for patients with hammertoe deformity. Minimally invasive technique requires the use of special equipment, skills and experience of the surgeon.

REFERENCES

1. Berezhnoi S.Iu., Buriev I.M. Chreskozhnaia khirurgiia tsentralnykh staticheskikh metatarsalgii. *Vestnik Natsionalnogo Medikokhirurgicheskogo Tsentra im. N.I. Pirogova* [Bulletin of the National Medical and Surgical Center named after N.I. Pirogov], 2012, vol. 7, no. 3. pp. 50-53. (in Russian)
2. Bobrov D.S., Shubkina A.A., Lychagin A.V., Sliniakov L.Iu., Drogin A.R., Tselishcheva E.Iu., Iavlieva R.Kh., Rigin N.V., Tuffour-Amirikakh M. Rezultaty khirurgicheskogo lecheniia peregruzochnoi metatarzalgii s ispolzovaniem miniinvazivnykh metodik [Results of surgical treatment of overload metatarsalgia using minimally invasive techniques]. *Kafedra Travmatologii i Ortopedii* [Department of Traumatology and Orthopedics], 2018, no. 4 (34), pp. 7-16. (in Russian)
3. Redfern D.J., Vernois J. Percutaneous Surgery for Metatarsalgia and the Lesser Toes. *Foot Ankle Clin*., 2016, vol. 21, no. 3, pp. 527-550. DOI: 10.1016/j.fcl.2016.04.003.
4. Vernois J., Redfern D.J. Percutaneous Surgery for Severe Hallux Valgus. *Foot Ankle Clin*., 2016, vol. 21, no. 3, pp. 479-493. DOI: 10.1016/j.fcl.2016.04.002.
5. Piclet B. Traitement chirurgical percutané des déformations des orteils latéraux. In: *Chirurgie mini-invasive et percutanée du pied (specialites medicales)*. Paris, Sauramps Médical, 2009, pp. 157-167.
6. White D.L. Minimal incision approach to osteotomies of the lesser metatarsals. For treatment of intractable keratosis, metatarsalgia, and tailor's bunion. *Clin. Podiatr. Med. Surg*., 1991, vol. 8, no. 1, pp. 25-39.
7. Thomas M., Jordan M. [Minimally invasive correction of lesser toe deformities and treatment of metatarsalgia]. *Oper. Orthop. Traumatol*., 2018, vol. 30, no. 3, pp. 171-183. (in German) DOI: 10.1007/s00064-018-0548-6.
8. Roukis T.S., Schade V.L. Minimum-incision metatarsal osteotomies. *Clin. Podiatr. Med. Surg*., 2008, vol. 25, no. 4, pp. 587-607. DOI: 10.1016/j.cpm.2008.05.007.
9. Bauer T. Percutaneous forefoot surgery. *Orthop. Traumatol. Surg. Res*., 2014, vol. 100, no. 1 Suppl., pp. S191-S204. DOI: 10.1016/j.otsr.2013.06.017.
10. De Prado M., Ripoll P.L., Golano P. *Minimally Invasive Foot Surgery: Surgical Techniques, Indications, Anatomical Basis*. Bilbao (Spain), About Your Health. 2009.
11. Frey S., Hélix-Giordanino M., Piclet-Legré B. Percutaneous correction of second toe proximal deformity: Proximal interphalangeal release, flexor digitorum brevis tenotomy and proximal phalanx osteotomy. *Orthop. Traumatol. Surg. Res*., 2015, vol. 101, no. 6, pp. 753-758. DOI: 10.1016/j.otsr.2015.06.009.
12. Tamir E., Finestone A.S., Avisar E., Agar G. Mini-invasive floating metatarsal osteotomy for resistant or recurrent neuropathic plantar metatarsal head ulcers. *J. Orthop. Surg. Res*., 2016, vol. 11, no. 1, pp. 78. DOI: 10.1186/s13018-016-0414-x.
13. Yassin M., Garti A., Heller E., Weissbrot M., Robinson D. [Percutaneous correction of forefoot deformities in diabetic patients in order to prevent pressure sores – technique and results in 20 consecutive patients]. *Harefuah*, 2017, vol. 156, pp. 234-236. (in Hebrew)
14. Uglow M.G. Percutaneous Pediatric Foot and Ankle Surgery. *Foot Ankle Clin*., 2016, vol. 21, no. 3, pp. 577-594. DOI: 10.1016/j.fcl.2016.04.005.
15. Flora M., Diniz P., Neto A.L., Teixeira N., Carvalho P., Pinto F.G. Minimally Invasive Hallux Interphalangeal Joint Arthrodesis for Hallux Varus in Pfeiffer Syndrome: A Case Report. *J. Foot Ankle Surg*., 2018, vol. 57, no. 1, pp. 205-209. DOI: 10.1053/j.jfas.2017.08.003.
16. Bia A., Guerra-Pinto F., Pereira B.S., Corte-Real N., Oliva X.M. Percutaneous Osteotomies in Hallux Valgus: A Systematic Review. *J. Foot Ankle Surg*., 2018, vol. 57, no. 1, pp. 123-130. DOI: 10.1053/j.jfas.2017.06.027.
17. Parrish T.F. Dynamic correction of clawtoes. Orthop. Clin. North Am., 1973, vol. 4, no. 1, pp. 97-102.
18. Jowett C.R.J., Bedi H.S. Preliminary Results and Learning Curve of the Minimally Invasive Chevron Akin Operation for Hallux Valgus. *J. Foot Ankle Surg*., 2017, vol. 56, no. 3, pp. 445-452. DOI: 10.1053/j.jfas.2017.01.002.
19. Kendal A.R., Khalid A., Ball T., Rogers M., Cooke P., Sharp R. Complications of minimally invasive calcaneal osteotomy versus open osteotomy. *Foot Ankle Int*., 2015, vol. 36, no. 6, pp. 685-690. DOI: 10.1177/1071100715571438.
20. Gilheany M., Baarini O., Samaras D. Minimally invasive surgery for pedal digital deformity: an audit of complications using national benchmark indicators. *J. Foot Ankle Res*., 2015, vol. 8, pp. 17. DOI: 10.1186/s13047-015-0073-x.
21. Yassin M., Garti A., Heller E., Robinson D. Hammertoe Correction with K-Wire Fixation Compared with Percutaneous Correction. *Foot Ankle Spec*., 2017, vol. 10, no. 5, pp. 421-427. DOI: 10.1177/1938640016681069.
22. Botezatu I., Marinescu R., Laptoiu D. Minimally invasive-percutaneous surgery – recent developments of the foot surgery techniques. *J. Med. Life*, 2015, vol. 8, Spec. Iss., pp. 87-93.
23. Seki H., Suda Y., Takeshima K., Kokubo T., Ishii K., Nakamura M., Matsumoto M., Niki Y. Minimally invasive distal linear metatarsal osteotomy combined with selective release of lateral soft tissue for severe hallux valgus. *J. Orthop. Sci*., 2018, vol. 23, no. 3, pp. 557-564. DOI: 10.1016/j.jos.2018.02.013.
24. Davidson S.R., James D.F. Drilling in bone: modeling heat generation and temperature distribution. *J. Biomech. Eng*., 2003, vol. 125, no. 3, pp. 305-314. DOI: 10.1115/1.1535190.
25. Haddad S.L., Hsu A.R., Templin C.R., Ren Y., Stewart B., Kohli N.S., Zhang L.Q. Effects of Continuous Irrigation during Burring on Thermal Necrosis and Fusion Strength in a Rabbit Arthrodesis Model. *Foot Ankle Int*., 2014, vol. 35, no. 8, pp. 796-801. DOI: 10.1177/1071100714535767.
26. Ellington J.K., Anderson R.B., Davis W.H., Cohen B.E., Jones C.P. Radiographic analysis of proximal interphalangeal joint arthrodesis with an intramedullary fusion device for lesser toe deformities. *Foot Ankle Int*., 2010, vol. 31, no. 5, pp. 372-376. DOI: 10.3113/FAI.2010.0372.
27. Mo Ts., Rigin N.V., Bobrov D.S., Sliniakov L.Iu. Ankety i shkaly dlia otsenki sostoianiia stopy i golenostopnogo sustava [Questionnaires and Scales for assessing the condition of the foot and ankle]. *Kafedra Travmatologii i Ortopedii* [Department of Traumatology and Orthopedics], 2016, no. 4 (20), pp. 5-11. (in Russian)
28. Rigin N.V. *Khirurgicheskoe lechenie peregruzochnoi metatarzalgii pri elastichnykh deformatsiiakh stop. Diss. kand. med. nauk* [Surgical treatment of overload metatarsalgia in elastic foot deformities. Cand. med. sci. diss.]. M., 2020, 133 p. (in Russian)
29. Cook J.J., Cook E.A., Rosenblum B.I., Landsman A.S., Roukis T.S. Validation of the American College of Foot and Ankle Surgeons Scoring Scales. *J. Foot Ankle Surg*., 2011, vol. 50, no. 4, pp. 420-429. DOI: 10.1053/j.jfas.2011.03.005.

30. Cöster M.C., Rosengren B.E., Bremander A., Brudin L., Karlsson M.K. Comparison of the Self-reported Foot and Ankle Score (SEFAS) and the American Orthopedic Foot and Ankle Society Score (AOFAS). *Foot Ankle Int*., 2014, vol. 35, no. 10, pp. 1031-1036. DOI: 10.1177/1071100714543647.
31. Pinsker E., Daniels T.R. AOFAS position statement regarding the future of the AOFAS Clinical Rating Systems. *Foot Ankle Int*., 2011, vol. 32, no. 9, pp. 841-842. DOI: 10.3113/FAI.2011.0841.
32. Repo J.P., Tukiainen E.J., Roine R.P., Kautiainen H., Lindahl J., Ilves O., Järvenpää S., Häkkinen A. Reliability and validity of the Finnish version of the Visual Analogue Scale Foot and Ankle (VAS-FA). *Foot Ankle Surg*., 2018, vol. 24, no. 6, pp. 474-480. DOI: 10.1016/j.fas.2017.05.009.
33. Richter M., Zech S., Geerling J., Frink M., Knobloch K., Krettek C. A new foot and ankle outcome score: Questionnaire based, subjective, Visual-Analogue-Scale, validated and computerized. *Foot Ankle Surg*., 2006, vol. 12, pp. 191-199. DOI: 10.1016/j.fas.2006.04.001.
34. Ferguson L., Scheman J. Patient global impression of change scores within the context of a chronic pain rehabilitation program. *J. Pain*, 2009, vol. 10, no. 4, Suppl., pp. S73. DOI: 10.1016/j.jpain.2009.01.258.
35. Bauer T., de Lavigne C., Biau D., De Prado M., Isham S., Laffenétre O. Percutaneous hallux valgus surgery: a prospective multicenter study of 189 cases. *Orthop. Clin. North Am*., 2009, vol. 40, no. 4, pp. 505-514, ix. DOI: 10.1016/j.ocl.2009.05.002.
36. Weinberger B.H., Fulp J.M., Falstrom P., Anavian R.R., Gore A.I., Bazak I. Retrospective evaluation of percutaneous bunionectomies and distal osteotomies without internal fixation. *Clin. Podiatr. Med. Surg*., 1991, vol. 8, no. 1, pp. 111-136.
37. Hosono N., Miwa T., Mukai Y., Takenaka S., Makino T., Fuji T. Potential risk of thermal damage to cervical nerve roots by a high-speed drill. *J. Bone Joint Surg. Br*., 2009, vol. 91, no. 11, pp. 1541-1544. DOI: 10.1302/0301-620X.91B11.22196.

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