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ORIGINAL ARTICLE

Minimally invasive surgery versus an arthroscopic procedure for the first metatarsophalangeal arthrodesis: A comparative study of the effectiveness and safety profile

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Abstract

Introduction First metatarsophalangeal (MTP) arthrodesis is a common procedure for treating degeneration in the MTP joint. Open arthrodesis is a conventional procedure that provides acceptable results but is more invasive than minimally invasive or arthroscopic arthrodesis. However, little is known about the different outcomes between minimally invasive surgery (MIS) and arthroscopic surgery (AS) for MTP arthrodesis. This study was performed to compare the outcomes of the first MTP joint preparation for arthrodesis regarding the effectiveness of articular surface preparation and safety between MIS and the arthroscopic procedure in cadaveric specimens.

Methods Sixteen cadaveric feet were collected in this study from eight cadavers. The potential exclusion criteria were significantly decomposed or deformed joint. All feet were randomly allocated into two groups, eight feet for the MIS (under fluoroscopic control) group and eight feet for the arthroscopic group. One foot in the AS group was excluded because the position of an arthroscopic portal was incorrect. All feet were operated on by four fellowship-trained foot and ankle orthopedic surgeons who also had prior clinical experience with the arthroscopic and minimal invasive procedure. Following a complete procedure in each specimen, all feet were dissected and the areas of joint preparation on the metatarsal and phalangeal sides were recorded via photography and the ImageJ program. Injury to the adjacent structure was noted in each specimen. All data were analyzed via the IBM SPSS program version 22 and GraphPad to compare the outcomes between the two groups.

Results The average age of the cadavers was 68.6 ± 12.3 years. The average areas of joint preparation on the metatarsal and phalangeal sides were 136.97 and 99.08 mm^2, respectively. The average areas of joint preparation on the metatarsal sides were 154.26 and 117.21 mm^2 in the MIS and arthroscopic groups, respectively (p value = 0.353). The average areas of joint preparation on the phalangeal sides were 82.46 and 118.08 mm^2 in the MIS and arthroscopic groups, respectively (p value = 0.151). Regarding the ratio of prepared area/mean estimated fusion contact area, there was no significant difference of a ratio on metatarsal side with p value as 0.285. However, a higher level of ratio on phalangeal side was found in the arthroscopic group with p value as 0.085. For the safety profiles, the rate of adjacent injury was insignificantly higher in the MIS group (37.5%) than the arthroscopic group (0%) (p value = 0.20). All injuries were found at the extensor hallucis longus tendon.

Conclusions There were no significant differences of the effectiveness of articular surface preparation between the MIS and arthroscopic groups. However, the arthroscopic procedure seemed to provide higher rate of prepared surface area on phalangeal side and be safer to the adjacent structures than MIS for this arthrodesis.

Keywords Minimally invasive surgery · Arthroscopy · arthrodesis · First metatarsophalangeal joint

Introduction

The first metatarsophalangeal (MTP) arthrodesis is the gold standard treatment for severe arthritis of the MTP joint. Open arthrodesis provides reliable and satisfactory outcomes but is associated with more invasiveness and significant postoperative pain [1]. Regarding the conventional

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open arthrodesis procedures for the first MTP joint, bone-surface preparation occasionally requires an extensive surgical approach, which might induce postoperative pain and improper healing [1]. Arthroscopic arthrodesis is a less invasive emerging technique for MTP arthrodesis [2]. Regarding a previous review, in the authors' experience, patients may have less swelling and faster recovery after arthroscopic first MTP arthrodesis as compared with open procedure [3]. In addition to the above techniques, minimally invasive surgery (MIS) for MTP arthrodesis is also newly proposed technique because it also has the benefit of being less invasive and returning a satisfactory rate of union [4]. However, little is known about the different outcomes following MIS and arthroscopic procedures for the first MTP arthrodesis. The present study was conducted to report a comparison in the effectiveness of articular surface preparation and the risk of adjacent structure injury between MIS and arthroscopic procedures for the first MTP arthrodesis.

Methods

Sixteen cadaveric feet from eight cadavers were collected for this study. All specimens were randomly allocated into two groups, an MIS group (eight feet) and an arthroscopic group (eight feet). All feet were operated on by four fellowship-trained foot and ankle orthopedic surgeons who also had prior clinical experience with the arthroscopic and minimal invasive procedure. The potential exclusion criteria were significantly decomposed or deformed joint. There was no excluded foot due to the reported criteria. The outcomes were measured following the procedure for articular surface preparation, using the ImageJ program for the area analysis and adjacent tissue injury events. The distance between the device portals to the adjacent structures was measured using vernier caliper measurement.

The MIS group was operated in accordance with the reported technique of Bauer et al. [5]. Dorsomedial and dorsolateral portals were created just medial and lateral to the extensor hallucis longus (EHL). Third portal as suggested by Bauer et al. (for MIS group) or Vaseenon et al. (for arthroscopy group [6]) was not used in this study due to our awareness that additional third portal might create more morbidity with significant more injury to the soft tissues and it was more cumbersome to perform the three portals procedure. The minimally invasive burr was introduced through these two portals consecutively to denude and decorticate the chondral and subchondral layers of the phalangeal and metacarpal surface with traction over the hallux. Resections of cartilage and superficial layer of subchondral bone over the metacarpal and phalangeal surfaces were performed under fluoroscopic control. Bony debris was carefully removed. Over-jealous resection might lead to risk of bone loss usually on the metatarsal head and must be avoided, otherwise the primary stability of the arthrodesis would be compromised. All joint surfaces were denuded until subchondral bones were exposed. The average depth of denuded area was around 1–2 mm. The arthroscopic group was operated in accordance with the technique used by Vaseenon et al. [6]. The nick-and-spread technique was used to create the arthroscopic portals. The device portals were created in the same way as the portals in the MIS technique were made. An arthroscopic shaver and acromionizer were introduced through both portals consecutively to denude and decorticate the chondral and subchondral layers of the joint. Both dorsolateral and dorsomedial portals were used interchangeably for visualization and instrumentation. There was no need to use fluoroscopy in this group. Resections of cartilage and superficial layer of subchondral bone over the metacarpal and phalangeal surfaces were performed under arthroscopic control. All joint surfaces were denuded until subchondral bones were exposed. The average depth of denuded area was around 1–2 mm. Once the articular surface preparation has been accomplished to the satisfaction of the surgeon for each foot, open dissection was performed to examine the area of surface preparation. One foot in the arthroscopic group was excluded because the position of an arthroscopic portal was incorrect. Photography was performed at an approximate distance of 10 cm from a surface of each joint by a resident physician who was not involved in the procedure. The photograph was analyzed by another fellow surgeon who was not involved in the procedure (Fig. 1), using the ImageJ program to report the measurement of area of the articular surface preparation on each side. Other outcomes

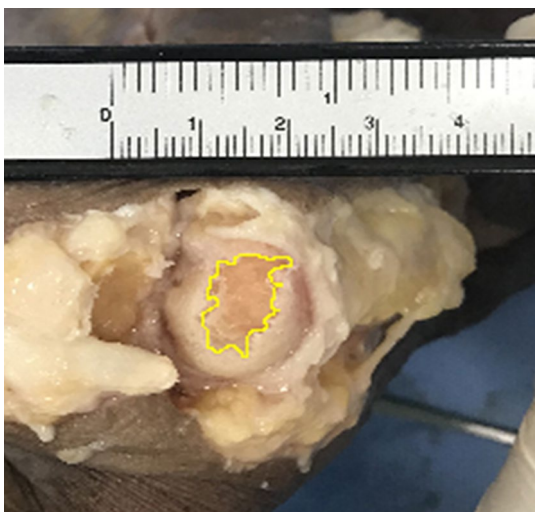

Fig. 1 The demonstration of the measurement using the ImageJ program to report the area of the articular surface preparation on the first metatarsal side of left foot. The yellow line outlined the area of the articular surface preparation which was measured by the ImageJ program

were mainly collected by resident physicians who were not involved in the procedure.

Regarding the overall procedures, successful operations were accomplished in eight joints for the MIS group and seven joints for the arthroscopic group. In the latter group, one joint was excluded because the position of the arthroscopic portal was incorrect.

The present study was approved by the ethical committee of the author's institution. Statistical analyses were performed using IBM SPSS version 22 and GraphPad. Statistical significance was considered as a p value less than 0.05.

Results

The mean age of cadavers was 68.6 ± 12.3 years. The mean areas of articular surface preparation on the metatarsal and proximal phalangeal sides were 136.97 and 99.08 mm^2 respectively. As shown in Table 1, the mean areas of articular surface preparation on the metatarsal side were 154.26 and 117.21 mm^2 in the MIS and arthroscopic group, respectively (p value = 0.353). The mean areas of articular surface preparation on the proximal phalangeal side were 82.46 and 118.08 mm^2 in the MIS and arthroscopic group, respectively (p value = 0.151). The data of whole surface area on each joint was not available in this study. However, this study was in effort to calculate the ratio of prepared area (from this study)/mean estimated fusion contact area (from Vaseenon's study [6]) instead to delineate the additional data. The results showed that there was no significant difference of a ratio on metatarsal side with p value as 0.285. However, a higher level of ratio on phalangeal side was found in the arthroscopic group with p value as 0.085. Therefore the preparation of articular surface was more favor on the arthroscopic group than the MIS group on the phalangeal side.

For the safety profiles, iatrogenic injury of the adjacent structure was insignificant higher in the MIS group (37.5%) than the arthroscopic group (0%), p value = 0.20). All injuries were found at the EHL tendon. The mean distances between the device portals and the corresponding structures were reported in the MIS and arthroscopic group (Table 2). No distances were significant between the MIS and arthroscopic group (p values > 0.05).

Table 1 The mean areas of articular surface preparation on the metatarsal and proximal phalangeal sides

Techniques		Metatarsal side (mm^2)	Phalangeal side (mm^2)
MIS	Mean	154.26	82.46
	S.D	85.38	31.15
	N	8	8
Scope	Mean	117.21	118.08
	S.D	59.04	57.17
	N	7	7
p values		0.35	0.15

S.D. standard deviation, *N* number of specimens with available data, scope, arthroscopic procedure, *MIS* minimally invasive surgery

Discussion

The present study highlighted the effectiveness of articular surface preparation for the first MTP arthrodesis and the risk of adjacent structure injury during the MIS versus arthroscopic procedure. Based on the results, there were no statistically significant differences between the two groups in terms of the prepared area of the articular surface, iatrogenic injury, or the distances between the device portals and corresponding structures. The number of specimens was limited in this study to demonstrate the significant differences of the

Table 2 The mean distances between device portals and adjacent structures on the first metatarsophalangeal area

Techniques		Distance: DLP and DLN	Distance: DLP and EHL	Distance: DMP and DMN	Distance: DMP and EHL
Scope	Mean (mm)	3.00	3.57	2.57	3.35
	S.D	2.39	2.57	1.61	2.42
	N	7	7	7	7
MIS	Mean (mm)	3.31	3.12	2.68	3.25
	S.D	1.66	3.43	1.64	1.96
	N	8	8	8	8
p values		0.77	0.78	0.89	0.92
Total	Mean (mm)	3.16	3.33	2.63	3.30
	N	15	15	15	15

Scope, arthroscopic procedure, *MIS* minimally invasive surgery, *DLP* dorsolateral portal, *DLN* dorsolateral hallucal nerve, *DMP* dorsomedial portal, *DMN* dorsomedial hallucal nerve, *EHL* extensor hallucis longus, *S.D.* standard deviation, *N* number of specimens with available data

results between both techniques. Further study with larger number of specimens or participants was needed to clarify the difference of outcome between these two techniques.

Lui [2] reported the benefit of the arthroscopic procedure for the first MTP arthrodesis in terms of minimal invasiveness and higher union rate compared with the open technique. Schmid and Younger [3] also reported similar benefits of this procedure. Vaseenon et al. [6] reported a satisfactory outcome following an arthroscopic procedure for articular surface preparation in cadaveric specimens. Furthermore, Bauer [4, 5] claimed that benefits of the MIS procedure existed in terms of its minimal invasiveness and high rate of union. They stated that only major bone defects or severe osteoporosis can be considered as contraindications [4]. However, there has been no comparative study to report the different outcomes in terms of the effectiveness and risk of adjacent structure injury between these procedures. The present study demonstrated that there were no significant differences of the effectiveness of articular surface preparation between the two techniques, but there was lower risk of the iatrogenic injury to adjacent structures following the arthroscopic procedure compared with the MIS procedure. Moreover, the preparation of articular surface was more favor on the arthroscopic group than the MIS group on the phalangeal side. The prevalence of injury in the arthroscopic group was much lower than in the MIS group, though this lower rate did not reach statistical significance because of the limited number of specimens. Regarding a previous study about the risk of adjacent structure injury in the MIS at the forefoot area, Dhukaram et al. [7] reported performing a lateral release, a minimally invasive chevron and Akin (MICA) procedure for the correction of hallux valgus, and a minimally invasive distal metatarsal extra-articular osteotomy (DMO). They found that the dorsal medial cutaneous and the plantar interdigital nerves were intact in all specimens. There was no apparent damage to the arterial plexus supplying the first metatarsal head and no flexor or extensor tendon injuries were identified [7]. However, McGann et al. [8] reported a different outcome from the previous study. They proposed that minimally invasive chevron distal osteotomy and medial eminence resection has a high learning curve. The resection of the medial eminence might iatrogenically injure the dorsal medial cutaneous nerve. The incidence was higher in their study than that reported in previous cadaveric studies, and extra care might be warranted to protect vital structures. Although there has been no previous study about adjacent structure injury from MIS for the first MTP arthrodesis, the present study's finding was in consistent with the study from McGann et al. in terms of the existence of a higher risk of adjacent structure injury. There was also similar agreement about the high learning curve of the MIS technique especially in newly inexperienced surgeon there might be misplacement in creating portals that might lead to neurovascular and extensor tendon injury. However, Ling et al. [9] proposed that the arthroscopic procedure in the first MTP provided a minimal rate of damage to the deep peroneal nerve branch (dorsal lateral digital nerve) that lies in the first web because of the improved visualization via arthroscopy and the inside-out sequence of the procedure. Additionally, the extensor hallucis longus might also be injured during the creation of the dorsal–lateral portal; therefore, they recommended that care must be taken to create the portal using the nick-and-spread technique [9]. Although there has been no previous cadaveric study about adjacent structure injury from the arthroscopic procedure for the first MTP arthrodesis, the present study's finding was consistent with the study from Ling et al. [9] in terms of there being a low risk of adjacent structure injury. Furthermore, there was similar agreement about the necessity of the nick-and-spread technique during the arthroscopic procedure.

In addition to these issues, there were some points of difference between the two techniques, such as the MIS procedure needing fluoroscopy but the arthroscopic procedure needing comprehensive arthroscopic images. These may be the limitations in each hospital on a case by case on basis. The surgeons may need to customize their decision whether to use the MIS or arthroscopic procedure on their patients based on their familiarity, skill level, and supporting resources.

There was some limitation in this study because the number of cadaveric specimens were possibly too small to demonstrate statistically significant differences between the two groups. However, the information from this study can be considered a potential platform for further study in a larger number of patients in the clinical setting.

Conclusions

Both MIS and arthroscopic procedures produced comparable outcomes in terms of the effectiveness of articular surface preparation for the first MTP arthrodesis. However, the arthroscopic procedure seemed to produce a substantially higher rate of prepared surface area on phalangeal side and lower rate of adjacent structure injury than the MIS procedure.

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Compliance with ethical standards

Conflict of Interest Dr. Angthong reports grants from Faculty of Medicine, Thammasat University, during the conduct of the study; personal fees from Amgen, personal fees from Phoenix Surgical Equipment (Thailand) Co., Ltd, outside the submitted work.

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