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Original Article

Anatomic research and clinical significance of the articular surface of the first/second tarsometatarsal joint

Chun-Guang Li, Guang-Rong Yu, Yun-Feng Yang, Bing Li

Department of Orthopaedics, Tongji Hospital, Tongji University, Shanghai 200065, China

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Abstract: Objective: To investigate the characteristics and damage area of the articular surface of the first/second tarsometatarsal joint to improve the treatment of the Lisfranc injury. Methods: Twenty fresh foot specimens of normal adults were dissected and divided into two groups. Results: In the group with one screw penetration, the ratio of damage area to distal articular surface of the first metatarsal and medial cuneiform bones were 5.11% and 4.65%, respectively; the ratio of damage area to distal articular surface of the second metatarsal and the middle cuneiform bones were 7.44±0.86% and 9.41±0.45%, respectively. In the group with two screw penetration, the ratio of damage area to distal articular surface of the first metatarsal and medial cuneiform bones were 10.22±0.67% and 9.30±0.32%, respectively, and the ratio of the damage area to the articular surface of the second metatarsal and middle cuneiform bones were 7.44±0.86% and 9.41±0.45%, respectively. For six feet, the ratio of the damage area caused by the screw through the second metatarsal base and middle cuneiform bones to the distal articular surface were 13.32 + 0.38% and 17.48 + 0.84%, respectively. Conclusion: The articular area of medial cuneiform bone is larger than that of the first metatarsal, and the articular area of the middle cuneiform bone is slightly smaller than that of the second metatarsal. The screw guide pin should be implanted successfully for the first time in the treatment of tarsometatarsal joint injury, because repeated adjustment may cause serious injury to the articular surface.

Keywords: Tarsometatarsal joints, joint surface, applied anatomy, screw fixation

Introduction

Simple dislocation or fracture dislocation is common symptoms of tarsometatarsal joint injury. As the range of motion of the medial and middle columns of the tarsometatarsal joint is smaller than that of the lateral column, the first and second tarsometatarsal joints are frequently injured [1]. Tarsometatarsal joint injury often leads to foot swelling and pain. Anatomical reduction has been an important factor that affects the outcome of tarsometatarsal joint injury. This injury has often been treated by open reduction and internal fixation. For internal fixation, 3.5 mm cortical bone screws or 4.0-4.5 mm hollow screws are often applied [2, 3]. Postoperative joint degeneration and chronic pain are the complications of most surgeries for tarsometatarsal joint injury, and inappropriate treatment is likely to lead old injury that is difficult to treat [4]. In the operation, the articular surface damage caused by screw penetration is an important factor to cause joint degeneration [5]. This research observed and investigated the surface area of the first and second tarsometatarsal joints and the ratio of the damage area caused by the screw to the articular surface to improve the treatment.

Materials and methods

Materials

Fresh foot specimens of twenty adults were included, of which fifteen cases were from the department of anatomy of medical school of Tongji university and five from the patients with traumatic amputation. The ratio of male to female was 13/7; that of left to right feet was 1/1; and the average age of the donors was 59.3, ranging from 25.0-73.0 years. The specimens were cryopreserved at the -20°C.

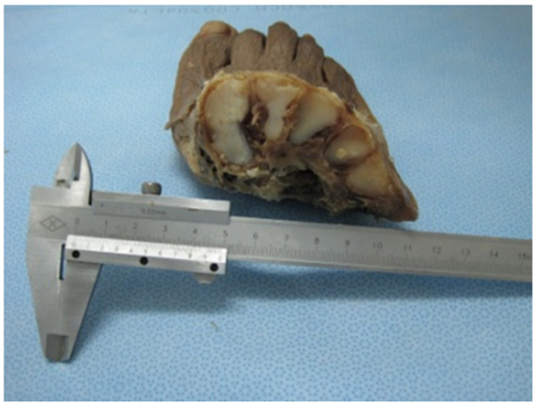

Figure 1. The detached first/second metatarsal articular surface.

Figure 2. The fracture on the articular surface of middle cuneiform bone after a 1.0 mm trocar and a 4.0 mm hollow nail were used to penetrate through the first/second tarsometatarsal joint in the same direction twice.

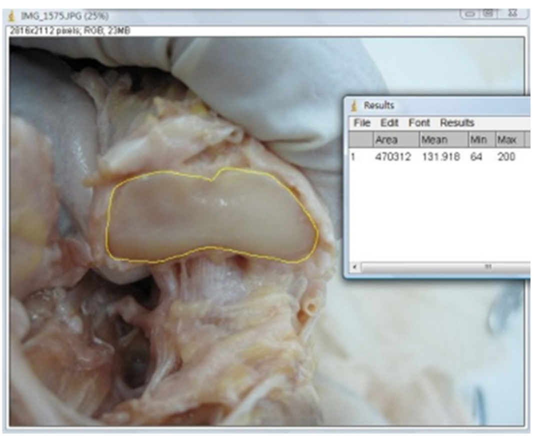

Figure 3. Joint surface area analyzed by Image J software.

Inclusion criteria: no injury of the foot bone joint. Inclusion criteria: X-ray imaging was used to exclude the cases with bone and joint degeneration, metabolic diseases, tumors, deformity, bone abnormalities and other conditions. This study has been approved by the hospital ethics committee, and five patients have signed informed consent.

Instruments of measurement

For dissecting, we used scalpels, forceps, retractor, dissecting scissors, dissecting forceps, bone knife, electric drill, Kirschner wire, screws etc. We also used vernier caliper (with an accuracy of 0.02 mm), deep hypothermia specimens freezer (China, Haier, DW-40W100), and digital camera (China, Canon, ixus95).

Methods

The tarsometatarsal joint was dissected and separated from foot specimens carefully to maintain the integrity of surface cartilage. The articular surface of the first/second metatarsal bones and the distal article surface of medial and middle cuneiform bones were carefully cleaned to eliminate adipose and soft tissue (**Figure 1**). The amputated specimens were divided into two groups according to random number table, ten cases in each group. To simulate the fixation method in surgery completely, the first/second tarsometatarsal joints in the first group were penetrated with a 1.0 mm trocar in the metatarsal cuneiform direction, and the a 4.0 mm hollow nail was screwed. After it was firmly fixed, the screw guide pin was extracted and the damage to the articular surface of tarsometatarsal joint was investigated. The first/second tarsometatarsal joint in the second group was penetrated with a 1.0 mm trocar and then a 4.0 mm hollow nail in the same direction; the nail tunnel was different from the first time. After fixation, the screw guide pin was extracted and the damage of the articular surface of the tarsometatarsal joint was also investigated (**Figure 2**).

Observation project

The image data was analyzed by the Image J software, and the articular surface area of the base of the 1/2 metatarsal bone and the distal articular surface of the medial and middle of the cuneiform bone were calculated (**Figure 3**). Screw penetration caused damage to the base of the first/second metatarsal bone and the distal medial and middle cuneiform bone. We

Table 1. The measurement of articular surface area of the first/second tarsometatarsal joints

Subjects	Results (cm^2)	*P* value
Articular surface area of the first metatarsal	3.13±0.32	<0.01
The distal articular surface area of the medial cuneiform bone	3.44±0.40	
Articular surface area of the second metatarsal	2.15±0.31	<0.01
The distal articular surface area of middle cuneiform bone	1.70±0.30	

also observed the ratio of the damage area to the corresponding articular surface.

Statistical methods

SPSS 14.0 was used for statistical analysis. Data are shown as the mean and standard deviation (SD) and are compared with paired t test. A *P* value less than 0.05 was considered statistically significant.

Results

Surface areas of the first and second metatarsal joints were 3.13±0.32 cm^2 and 2.15±0.31 cm^2, respectively. The distal surface areas of the medial and middle cuneiform bone were 3.44±0.40 cm^2 and 1.70±0.30 cm^2, respectively. The surface area of the medial cuneiform bone was slightly larger than that of the base of the first metatarsal bone, and the surface area of the middle cuneiform bone is was slightly smaller than that of the base of the second metatarsal bone (**Table 1**).

For the ten cases in the first group, the damage of the articular surface of the first/second metatarsal bones and that of the medial and middle cuneiform bone was the holes caused by the diameter of screws, and the articular surface around the holes were undamaged and no fracture was observed. The ratios of the injury area caused by screw penetration to the articular surface of first and second metatarsal bones were 5.11±0.26% and 7.44±0.86%, respectively. The ratios of injury area to distal articular surface of the medial and middle cuneiform bone were 4.65±0.58% and 9.41± 0.45%, respectively.

For the ten cases in the second group, the damage to the articular surface of the first metatarsal bones and that of the medial cuneiform bone was the holes caused by the diameter of screws, and the articular surface around holes were undamaged and no fracture was observed. The ratio of injury area to the articular surface of the base of the first metatarsal bone was 10.22±0.67%. The ratio of injury area to the distal articular surface of the medial cuneiform bone was 9.30±0.32%. For 6 cases, the damage to the articular surface of the base of the second metatarsal bone and the medial cuneiform bone just fitted with the diameter of screw holes, and the articular surface around the holes were intact and no fracture existed. The ratios of injury area to the articular surface of the base of the second metatarsal bone and that to the distal articular surface of the middle cuneiform bone were 13.32±0.38% and 17.48±0.84% respectively. For four cases, the articular surface damage area of the base of the second metatarsal base and the middle cuneiform bone were larger. For them, besides the holes caused by the diameter of the screw, fractures and fissures of articular cartilage surface existed. The ratios of damage area to the articular surface of the base of the second metatarsal bone and the middle cuneiform bone were 16.45±0.57% and 20.07±0.84% respectively. Articular fracture of the foot all occurred in the specimens with second tarsometatarsal joint of a smaller articular area.

Discussion

It is difficult to treat the tarsometatarsal joint injury. Anatomic reduction and stable fixation of the joint is the key to obtain good outcome [6, 7]. Foot joint degeneration and pain could be caused by malreduction. Because of the limited mobility of the first/second tarsometatarsal joints, stable fixation is also needed to ensure the repair after successful reduction. For internal fixation, fixation screws, steel plate, Kirschner wire staples, rivet, etc. can be used. The fixation of the tarsometatarsal joint with screws have the advantages such as high fixation strength, little damage to soft tissue, a low rate of postoperative incision infection, good recovery, etc. Therefore, this research investigated the characteristics of first/second tarsometatarsal joint surface injury to provide evidence for the clinical choice of fixation in the relevant parts.

Complications and anatomical analysis of screw fixation of tarsometatarsal joint injury

The articular degeneration caused by trauma has been common in patients with intra-articular fracture or dislocation, and is also the complications caused by penetration of internal fixator. Open reduction and internal fixation can facilitate the repair of the first tarsometatarsal joints [8]. Kuo et al. [3] found that tarsometatarsal joint injury of 15/48 patients was purely ligamentous injury, and among the 15 patients, 40% could progress to tarsometatarsal joint degeneration. Recently, Ly and Coetzee et al. [9] carried out a prospective randomized study, in which early joint fusion obtained a better efficacy than open reduction and internal fixation for patients with simple ligament injury of tarsometatarsal joint. Twenty patients underwent open reduction and internal fixation, and joint degeneration was observed in fifteen patients during short-term follow-up. These results indicate that the fixation of the articular surface is an important factor that may affect the progress of articular degeneration.

Our research finds that implanting the guide pin and screw twice can increase the area of joint surface damage. After penetration of the articular surface of the second tarsometatarsal joint for internal fixation, we observed fracture of the second metatarsal base and the distal articular surface of the middle cuneiform bone in 40% specimens, and the ratio of the injury to articular surface is more than two times higher than that caused by one-time screw damage. Because of the certain mobility of the first/second tarsometatarsal joints, the joint friction after the injury of the articular surface has an important effect on the degeneration of the joint. In this experiment, the articular surface fracture occurred easily in the second tarsometatarsal joint with two-time penetration and the internal fixation. The primary reason is that the second tarsometatarsal joint is located at the highest point of the transverse arch of the foot, and the surface stress it bears is the greatest. When it is injured, serious secondary damage often occurs. Meanwhile, surface area of the second tarsometatarsal joint is small and the damage proportion is high, which also contributes to fracture. Gaines et al. [10] implanted twice a 4.0 mm hollow screw as the guide pin into the first/second tarsometatarsal joint, and the damage area of the articular surface was greater for the second time. Especially, fracture rate of the second tarsometatarsal joint was as high as 40% when the guide pin was placed for the second time. The conclusion based on our experimental data is consistent with that of the foreign reports. However, the first/second tarsometatarsal joint area of Chinese population is smaller, and the ratio of damage area to articular surface is larger when the screw of the same diameter was used. Therefore, for patients with this injury, to avoid postoperative tarsometatarsal joint degeneration, the times for implanting the guide pin and screw should be reduced as much as possible to obtain the one-time success.

Noninvasive treatment of the articular surface injury of the tarsometatarsal joint

Plate fixation is also widely used in treating Lisfranc damage. The fixation with steel plate is transarticular fixation, which does not damage the joint surface. During the healing process, the steel plate is subject to most of the stress, which is beneficial to the early movement of patients. Alberta et al. [11] demonstrated that the backside steel plate had certain biomechanical strength as the same as the screw. It is recommended that Lisfranc fracture and dislocation could be fixed with 1/4 tubular plate. However, it has some limitations. The placement of the plate requires stripping a lot of soft tissue, which is not conducive to fracture healing. In addition, for the Lisfranc injury patients with dislocation at the metatarsal side, the dorsal plate is unable to obtain the effects of compression and fixation, and it is difficult to place the plate at the plantar side using a plantar approach. Cosculluela et al. [12] recommended medial dorsal bridging plate for the Lisfranc injury with an instable medial column. The screw fixed at the lateral surface could be used to eliminate the instability of the medial cuneiform bone and the second metatarsal base joint. In recent years, locking plate has been applied for the fixation of Lisfranc damage, but the long-term effect needs to be further investigated.

Similar to the steel plate, staples also provide transarticular fixation, which does not damage the joint surface. The staple is small in size, and does not strip soft tissue as much as the steel plate. However, no biomechanical studies have been carried out to compare the fixation strength between the staple and plate, and meanwhile no studies have reported the wide use of staples.

In recent years, a kind of non-rigid suture button (endo-button), which is more consistent with the physiological characteristics of the Lisfranc ligament, has been applied in the treatment of Lisfranc injury. Panchbhavi et al. [13] found that the biomechanical strength of the suture button was as same as the hollow nail. And it can provide non-rigid anatomical reduction, without the need to remove it by another surgery. In Lisfranc ligament damage, button suture is often used to fix the medial cuneiform bone and the second metatarsal base; it can be used to replace the Lisfranc screw. Brin et al. [14] reported the significant short-term curative effect of suture button in treating Lisfranc injury in five patients, among whom AOFAS scores of four were significantly improved. A satisfactory effect was obtained by the suture button in the patients who need revision surgery after the failure of screw fixation.

Therefore, for the effective prevention of joint degeneration caused by screw fixation in tarsometatarsal joint injury, the approaches that cause no damage to the articular surface, such as transarticular steel plates can be selected for surgical treatment.

Disclosure of conflict of interest

None.

Address correspondence to: Guang-Rong Yu, Department of Orthopaedics, Tongji Hospital, Tongji University, Shanghai 200065, China. E-mail: yuguangrong1122@sina.com

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