Accurate determination of screw position in treating fifth metatarsal base fractures to shorten radiation exposure time

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ABSTRACT

Introduction: This study aimed to identify anatomical markers for determining the optimal lag screw location during surgery for internal fixation of fifth metatarsal base fractures, in order to reduce radiation exposure.

Methods: A total of 50 patients undergoing oblique foot radiography in the lateral position were randomly selected, and the angles between the fifth metatarsal axis and the cuboid articular surface were measured to determine the optimal lag screw placement relative to anatomical markers.

Results: The line connecting the styloid process of the fifth metatarsal base with the second metatarsophalangeal (MTP) joint intersected the fifth metatarsal base fracture line at an angle of 86.85° ± 4.37°. The line connecting the fifth metatarsal base styloid with the third and fourth MTP joints intersected with the fracture line at angles of 93.28° ± 4.22° and 100.95° ± 4.07°, respectively. The proximal articular surface of the fifth metatarsal base intersected with the line connecting the styloid process of the fifth metatarsal base with the second, third and fourth MTP joints at angles of 24.02° ± 3.77°, 30.79° ± 3.60° and 38.08° ± 3.58°, respectively.

Conclusion: The fifth metatarsal base styloid and third MTP joint can be used as anatomical markers for lag screw placement for fractures involving the fifth tarsometatarsal joint. The connection line, which is normally perpendicular to the fracture line, provides sufficient mechanical stability to facilitate quick and accurate screw placement. The use of these anatomical markers can help reduce the need for unnecessary radiation exposure among patients and medical staff.

Keywords: fifth metatarsal fracture, internal fixation, radiation
INTRODUCTION
Fracture of the fifth metatarsal base is a common injury; it accounts for 45%–70% of all metatarsal fractures.\(^1\) When the foot is in plantar flexion and ankle inversion, the peroneus brevis muscle or plantar fascia contract strongly, resulting in fifth metatarsal styloid avulsion.\(^2\) If the bone fragment is not displaced or only mildly displaced, the injury can be treated by wearing hard-soled shoes or using cast fixation for a few weeks. However, if the bone is displaced more than 3–5 mm or if the rotational displacement is greater than 10°, surgery will be required.\(^3,4\) The choice of surgical method and fixation material varies. Commonly used fixation materials include Kirschner wires, tension bands, cancellous bone screws and intramedullary screws, while commonly used surgical methods include fixation with 4.5-mm ankle screws and transplantation of cortex-cancellous bone following removal of sclerotic bone from the medullary cavity. These methods have high success rates.\(^5\) Using lag screws provides additional mechanical advantage, as they are stronger than single screws.\(^6\)

Due to the very small fragments associated with proximal fractures, it is rare to have more than one screw placement opportunity. Thus, almost all operations are performed using a C-arm X-ray image intensifier to ensure correct screw positioning.\(^6,7\) This, however, exposes both the medical staff and the patient to radiation. A recent survey revealed that more than 75% of medical staff underestimate the potential risk of exposure to radiation.\(^8\) Between 1980 and 2006, X-ray-assisted surgery increased by 47%.\(^9\) Despite the low single doses that are routinely used, the accumulated radiation dose has been reported to have increased by 727%.\(^9\) In a survey conducted by Fazel et al, more than 655,000 (69%) of 950,000 adult patients seeking medical treatment within two years have been exposed to a radiation procedure.\(^10\) Furthermore, cancer prevalence is five times greater among orthopaedic surgeons as compared to other medical staff.\(^10,11\)
As orthopaedic surgeons are familiar with the anatomical characteristics of the musculoskeletal system, using anatomical markers to guide internal fixation would help make surgical procedures safer (as the radiation exposure would be reduced) and more convenient. The centre of the metatarsophalangeal (MTP) joints are the most commonly used anatomical marker in foot surgeries to guide Kirschner wire placement; intraoperatively, passive movement can be applied to determine the centre of the MTP joints. The present study investigated which MTP joint is optimal for use as an anatomical landmark in cases of fifth metatarsal intra-articular fractures (type II) surgeries. This could help to guide the accurate positioning of internal fixation screws and reduce radiation exposure among the patients and medical staff.

**METHODS**

A total of 50 patients who underwent foot radiography at the Huashan Hospital of Fudan University, Shanghai, China, between 2010 and 2011, were selected for inclusion in the present study. All patients were confirmed to be free of mid- and forefoot deformities before being enrolled in the study.

Stewart reported that true Jones fractures were transverse fractures at the junction of the diaphysis and metaphysis, without extension to the fourth and fifth intermetatarsal articulations.\(^{(12)}\) Thus, cases of genuine Jones fractures were excluded from the study because the main focus of the study was intra-articular fifth metatarsal fractures. In the study, the patients were positioned in a simulated lateral surgical position prior to oblique foot radiography. Pelvic fixation was used to prevent the body from shaking. The contralateral lower limb was flexed between 60° and 70°, and a padded cushion was placed between the patient’s legs, with the injured limb placed on the cushion. The hip joint on the injured side was placed in a neutral position, the knee was flexed 15°, and the ankle was made to be in
slight plantar flexion and pronation and perpendicular to the ground. The calcaneocuboid joint was used to mark the centre that was used for oblique foot radiography (Fig. 1).

The metatarsal axis was determined according to the method described by Shima et al.(13) that is, the line connecting the midpoint of proximal articular surface and the centre of the distal articular surface was taken to provide the most accurate axis. A second line, which is perpendicular to the fifth metatarsal axis, was determined on the oblique view. The line begins at the most distal point of the joint, formed by the fourth and fifth metatarsal base, and its intersection point with the lateral cortex of the fifth metatarsal was defined as point A (Fig. 2). A third line was drawn to connect point A to the medial articular surface of the fifth tarsometatarsal (TMT) joint (i.e. point B). The line AB indicated the extent of the fifth metatarsal base protrusion and roughly corresponded to the tuberosity avulsion fracture line with articular involvement (Fig. 2). The styloid tip of the fifth metatarsal base was determined as point C (Fig. 3). The midpoint of the articular surfaces of the second, third and fourth MTP joints are shown as points D, E and F in Fig. 3. Lines CD, CE, and CF represent the directions of guide wires.

Angles $d_1$, $e_1$, and $f_1$ were formed by the intersections of the proximal bevel of the fifth metatarsal (i.e. line BC) with CD, CE and CF, respectively (Fig. 3), while angles $d_2$, $e_2$, and $f_2$ were formed by the intersections of AB with CD, CE and CF, respectively (Fig. 4). Each of the angles was measured by two radiologists and two orthopaedic surgeons using a computer-assisted design software. Measurements were repeated and mean values were calculated.

RESULTS

The line connecting the fifth metatarsal base styloid with the second MTP joint intersected with the fifth metatarsal base fracture line at an angle of $86.85^\circ \pm 4.37^\circ$ (Table I). The line connecting the fifth metatarsal base styloid with the third and fourth MTP joints intersected with the
fracture line at the angles of $93.28^\circ \pm 4.22^\circ$ and $100.95^\circ \pm 4.07^\circ$, respectively. The proximal articular surface of the fifth metatarsal base intersected with the line connecting the fifth metatarsal base styloid with the second, third and fourth MTP joints at the angles of $24.02^\circ \pm 3.77^\circ$, $30.79^\circ \pm 3.60^\circ$, and $38.08^\circ \pm 3.58^\circ$, respectively.

**Table I. Angle measurements.**

<table>
<thead>
<tr>
<th>Angle (°)</th>
<th>Mean ± SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>d1</td>
<td>86.85° ± 5.44°</td>
<td>75.97°–99.20°</td>
</tr>
<tr>
<td>e1</td>
<td>93.28° ± 5.24°</td>
<td>83.19°–104.28°</td>
</tr>
<tr>
<td>f1</td>
<td>100.95° ± 5.00°</td>
<td>90.73°–111.54°</td>
</tr>
<tr>
<td>d2</td>
<td>24.02° ± 4.77°</td>
<td>15.47°–35.75°</td>
</tr>
<tr>
<td>e2</td>
<td>30.79° ± 4.53°</td>
<td>22.20°–42.43°</td>
</tr>
<tr>
<td>f2</td>
<td>38.08° ± 4.54°</td>
<td>28.94°–49.65°</td>
</tr>
</tbody>
</table>

*SD: standard deviation*

**DISCUSSION**

The aim of the present study was to identify anatomical markers that can be used to define optimal lag screw location during surgery for internal fixation of fifth metatarsal base fractures, in order to reduce exposure to radiation. Our results show that the fifth metatarsal base styloid and the third MTP joint can be used as anatomical markers for screw placement for fractures involving the fifth TMT joint. The connection line, which is normally perpendicular to the fracture line, provides sufficient mechanical stability to facilitate quick and accurate screw placement. The use of these anatomical markers can help reduce radiation exposure among patients and medical staff.

The pathological mechanism, diagnosis and treatment of fifth metatarsal base fractures are controversial.\(^6\) Generally, the articular surfaces of the proximal fourth and fifth metatarsal bases have been used to distinguish between extra-articular (type I) and intra-articular (type II) fifth metatarsal fractures.\(^14\) In the present study, the metatarsal axis was determined according to the method described by Shima et al.\(^13\) In that method, the line connecting the midpoint of proximal articular surface and the centre of the distal articular surface was taken to be the most
accurate metatarsal axis. A second line perpendicular to the fifth metatarsal axis was
determined on the oblique view. This line, which begins at the most distal point of the joint
formed by the fourth and fifth metatarsal base, intersects with the lateral cortex of the fifth
metatarsal; this intersection point is named point A in the present study (Fig. 2). A third line
was then drawn to connect point A to the medial articular surface of the fifth TMT joint (i.e.
point B); the line AB indicated the extent of the fifth metatarsal base protrusion and
simulated an approximation for the tuberosity avulsion fracture line with articular involvement
(Fig. 2).

The basic treatment principle is to keep the screw perpendicular to the fracture line to
achieve the most secure fixation. Mechanical experiments have shown that screws positioned
vertical to the fracture line and bicortical fixation provide maximum strength. Screw fixation
into the proximal articular surface would involve the fifth TMT joint, whereas distal fixation
would involve the third, fourth or fifth metatarsal proximal joint. The present study showed
that the direction perpendicular to the fracture line provides maximal biomechanical strength,
at an angle of $93.28^\circ \pm 4.22^\circ$ to the third MTP joint. The line projected to the second MTP joint
also intersected with the fracture line at a right angle. However, we do not recommend it as a
guiding marker because its angle with the articular surface of the fifth TMT joint (i.e. angle f2)
is too small if the centre of the second MTP joint is used ($24.02^\circ$ on average). This could cause
the screw to enter the fifth TMT joint or even the proximal articular surface between the fourth
and fifth metatarsals, damaging the articular surface. The line connecting the fifth metatarsal
base point and the fourth MTP joint formed an angle of $100.95^\circ \pm 4.07^\circ$ with the fracture line;
this would reduce mechanical strength and hamper screw fixation into the fifth metatarsal
lateral cortex. In addition, using the second or fourth MTP joint could result in medial or lateral
deviation.
The transverse arch of the foot means that the fifth metatarsal base is closer to plantar side of the foot than to the third MTP joint.\textsuperscript{(15,16)} In our opinion, screws fixed from the styloid of the fifth metatarsal base pointing obliquely to the third MTP joint should be aligned in a sagittal position to avoid the risk of piercing through the plantar or dorsal side (Fig. 5). This surgical procedure, which is supplemented by the use of brief X-ray radiation for verification, was easy to perform, maximised lag screw mechanical strength, and avoided repeated use of Kirschner wires and thus the associated risk of fragmentation of the proximal fractures (Fig. 6). Although the use of the C-arm X-ray is still needed during surgery to ensure correct direction and position of the screw, the radiation dose is substantially lower if anatomical markers, instead of the C-arm X-ray, are used to determine the position of the lag screw.

Patients with fifth metatarsal base fractures should undergo surgery in the lateral position, with the injured limb hip joint placed in a neutral position, the knee flexed to an angle of approximately 15° and the ankle positioned in slight plantar flexion. The connection between the styloid tip of the fifth metatarsal base and third MTP joint can be used to determine the position of the leading guide wire for bicortical fixation screws. The use of this anatomical marker as a reference point provides a reliable method for facilitating surgical repair of fifth metatarsal base fractures and minimises the need for radiation exposure among patients and medical staff. Prospective studies can be conducted to validate this method.
REFERENCES


FIGURES

**Fig. 1** Photographs show (a) the position of the patient intraoperatively; and (b) the direction of the screw placement.

**Fig. 2** Radiographs show (a) point A, which resulted from the intersection of a line, perpendicular to the fifth metatarsal axis, made from the distal point of the articular surface of the joint formed by the fourth and fifth metatarsal bases, and the lateral cortex of the fifth metatarsal; and (b) point B, which is the nearest point of the articular surface of the joint formed
by the fourth and fifth metatarsal bases. The proximal part from line AB is the most common region of the bone fracture of the fifth metatarsal base. Line AB determines the intra-articular fifth metatarsal fractures.

Fig. 3 Radiographs show the determination of the angles between the proximal fifth metatarsal articular surface and screw placement. (a) Line BC marks the proximal articular surface of the fifth metatarsal and line CD is formed by joining the nearest point of the fifth metatarsal base (C) and the midpoint of the fourth metatarsal joint (D). The resulting angle d1 is too large. (b) Line CE is formed by joining the nearest point of the fifth metatarsal base (C) and the midpoint of the third metatarsal joint (E). The resulting angle e1 is suitable. (c) Line CF is formed by joining the nearest point of the fifth metatarsal base (C) and the midpoint of the second metatarsal joint (F). The resulting angle f1 is too small.
**Fig. 4** Radiographs show angles (a) \( d_2 \) between the lines AB and CD; (b) \( e_2 \) between the lines AB and CE; and (c) \( f_2 \) between the lines AB and CF, which help to determine the angles between the proximal fifth metatarsal articular surface and possible screw placement.

**Fig. 5** (a) 3D reconstructed and (b) coronal CT images show the screw placement direction in the midpoint of the third metatarsal joint (arrows).
Fig. 6 Radiographs show the (a) hypothetical and (b) postoperative screw direction, which is pointing to the midpoint of the metatarsal joint (arrow).