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Defining a Safe Zone for Percutaneous Screw Fixation of Posterior Malleolar Fractures

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ABSTRACT

Posterior malleolar fractures require fixation to confer stability to the ankle. Although some have suggested that fractures involving less than 25% of the articular surface require no intervention, estimation of malleolar size on plain imaging is inaccurate. Some posterior malleolar fractures may be particularly suitable for posterior-to-anterior percutaneous screw fixation of the posterior malleolus via a posterolateral approach. We hypothesized that there may be a safe zone in the posterolateral ankle, identifiable with reliable anatomic landmarks, that might allow safe percutaneous screw placement for fracture fixation. The study protocol involved Step 1, in which multiple Kirschner wires were used in a single cadaveric specimen to attempt to identify a safe zone entry point in the posterior ankle, and Step 2, in which a single wire was used in each of six additional cadaveric specimens to test the ability to safely replicate the use of that entry point. In Step 1, a safe zone entry point was identified, located immediately lateral to the Achilles tendon and 1 cm above the level of the tip of the medial malleolus, when visualizing the posterior ankle. In Step 2, using these landmarks and an image intensifier, single wires were then successfully placed in the other six specimens without injury to any significant structure. If confirmed in clinical studies, the safe zone entry point that we have identified could potentially be used to facilitate posterior-to-anterior percutaneous fixation in patients with posterior malleolar fractures for whom open reduction may not be required or may be contraindicated.

Ankle fractures are common and often involve the posterior malleolus (1,2). However, isolated posterior malleolar fractures (PMFs) are uncommon, accounting for only 1% to 4% of all ankle fractures (3,4). It has been reported that 7% to 44% of all ankle fractures involve a PMF as a part of the fracture (5-7). Ankle fractures that involve a PMF are often associated with poor functional outcomes (5,8,9). Although the traditional treatment for PMFs has been surgical fixation, optimal management remains a matter of debate, in part because clinical outcomes after treatment of these fractures have been less than satisfactory (2,8,10).

The management of ankle fractures requires a broad knowledge of the normal anatomy as well as the various patterns of injury that can occur (11,12). Over time, the understanding of the crucial role that the posterior malleolus plays in ankle stability and the outcome of ankle fractures has increased. Consequently, when ankle fractures include a PMF, fixation is now commonly performed, in order to both confer stability and reduce the likelihood of degenerative arthrosis developing in the ankle (11).

One broadly accepted indication for fixation of a PMF is an estimated posterior malleolar fragment size that is more than 25% of the bone's articular surface, as measured on a lateral plain radiograph (5,9). However, evidence has emerged that the estimation of posterior malleolar fragment size using plain radiographs may be inaccurate, and that fracture stability and overall outcomes may not depend on fragment size alone (13). So, it may be that surgical fixation should be considered for all posterior malleolar fragments, particularly if an important goal when treating PMFs is to create optimal stability. Despite that, formal open reduction and fixation may not be necessary for all PMFs. So, it

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may be preferable to think of treatment options for PMFs as occupying a spectrum, ranging from open reduction and fixation, to fixation with percutaneous screw placement, to no fixation at all.

When considering fixation for PMFs, there is little doubt that use of a plate is biomechanically superior to use of screws (5). However, screw fixation alone has also demonstrated acceptable outcomes, particularly for PMFs with small fragment sizes (14,15). For screw fixation, evidence suggests that a posterior-to-anterior (PA) screw is biomechanically stronger than an anterior-to-posterior (AP) screw, in part because the former provides more control and greater compression of the fracture (5,14,16,17).

For a direct open reduction and fixation of PMFs, either a posteromedial or a posterolateral approach can be used (18,19). For a percutaneous approach to the posterior aspect of the ankle, recent studies involving posterior ankle arthroscopy have led to a greater understanding of where potentially safe portals of entry and passage might be (18,20,21). When considering percutaneous screw fixation involving the blind passage of a screw, the posteromedial approach to the ankle is not suitable, because the neurovascular bundle passes posteromedially, posing a substantial risk of neurovascular damage (20). The posterolateral approach is more appropriate for percutaneous screw fixation (22,23). This is because the sural nerve, its branches, and the short saphenous vein, which descend obliquely running medially to laterally, along with the lateral aspect of the Achilles tendon, form the borders of a potentially safe window of access for blind screw placement.

We postulated that there may be some smaller, non-displaced PMFs that can be reduced indirectly with fixation of other components of the injury or with dorsiflexion and ligamentotaxis, and that these types of fractures might be particularly suitable for PA percutaneous screw fixation of the posterior malleolus via a posterolateral approach. Our hypothesis was that there may be a safe zone entry point in the posterior ankle through which percutaneous screw fixation of some PMFs may be safely accomplished. In order to test this hypothesis, we performed a series of cadaveric dissections using Kirschner (K)-wires to determine whether a safe zone entry point in the posterior ankle could be identified and then subsequently used with repeated success.

Materials and Methods

Ethical approval and informed consent were deemed unnecessary because this study was undertaken using specimens provided during an instructional course conducted by the Zimmer Biomet Institute (Palm Beach Gardens, Florida, U.S.A.) in Sydney, Australia (24). The study protocol involved Step 1, in which a single cadaveric specimen was used to identify a safe zone entry point in the posterior ankle, and then Step 2, in which six additional cadaveric specimens were used to test the ability to safely replicate that entry point.

Specimens and Surgeons

This investigation was carried out in August 2017 on seven healthy, fresh, adult cadaveric specimens. Information about the gender and detailed past medical history of the specimens was unknown. None of the specimens had evidence of foot or ankle injuries or surgery. One author (NW, third-year Orthopedic registrar) passed all wires, under the direct supervision of the senior author (SP, 12 years' experience as an Orthopedic Foot and Ankle surgeon). Each of these authors was also present for the subsequent ankle dissections, and each independently assessed whether any ankle structures had been injured. There were no disagreements between the two authors in these assessments.

Step 1

The first cadaver was used to attempt to establish an optimal safe zone entry point that could be used for percutaneous placement of a PA screw in a patient with a PMF. To do this, we used a series of 1.6 mm Kirschner (K-)wires, which were each inserted into the skin along the lateral border of the Achilles tendon and at varied caudal-cephalad skin levels that would allow for some trajectory variation as the wires were being advanced, with the goal of mimicking a safe and satisfactory fixation.

In this step, 4 K-wires were passed posterolateral to anteromedial along the distal tibia of the specimen, all starting just lateral to the Achilles tendon. The wires were started within a limited caudal-cephalad skin spread pattern, then passed on slightly inferior trajectories, representing that which would typically traverse a PMF, based on the experience of the senior author (Figs. 1 and 2). Fluoroscopy with an image intensifier was used to ensure appropriate and consistent wire trajectories in the sagittal plane as the wires were being advanced.

Fig. 1. Step 1. Photo image of the cadaveric posterior ankle, in which 3 of 4 Kirschner wires have been introduced posterolaterally at different caudal-cephalad skin levels.

From the posterolateral skin entry point, each wire was passed anteromedially to reach the posterior malleolus, noting that the body habitus of the specimen contributed to determining the initial path of the wire from skin to bone. A similar trajectory was then followed through the bone. Because the transmalleolar axis can vary with the degree of ankle rotation, resulting in a variation in the trajectories needed to achieve satisfactory bicortical fixation, specimen ankles were placed into external rotation as the wires were advanced. We used direct feedback via the wire driver to ensure bicortical wire placement. Axial imaging could have been used for this step, but we did not have this available and our goal was to establish an optimal safe zone entry point for percutaneous wire placement using only a clear understanding of the posterior ankle anatomy and fluoroscopic guidance.

After the 4 K-wires had been placed, the ankle of the specimen was explored through a posterior midline incision, and a detailed dissection was done to assess the pathway of each of the K-wires and the proximity of each K-wire to significant structures (Fig. 3). The significant structures that were identified during the dissection included the sural nerve, flexor hallucis longus, short saphenous vein, and Achilles tendon. K-wires considered to be too close to any of the significant structures (within 5 mm) were regarded as unsafe and so were removed. A single remaining K-wire was observed to be 5 mm away from all significant structures. This was the most distal wire and it was the wire that was closest to the ankle joint line; it was deemed to be the safest and so it was retained.

The ankle skin was then closed and with the chosen wire still in place, the location of the single safe zone entry point relative to surface anatomy landmarks was carefully noted. Based on the location of the remaining K-wire, the safe zone entry point was determined to be 1 cm above the distal aspect of the medial malleolus, immediately lateral to the Achilles tendon, when visualizing the posterior ankle (Fig. 4).

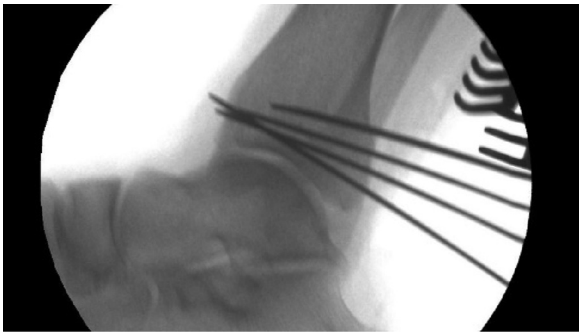

Fig. 2. Step 1. Image intensified lateral radiographic image of the four Kirschner wires passed posterolaterally to anteromedially through cadaveric left ankle.

Fig. 3. Step 1. Photo image demonstrating positions of four Kirschner wires and adjacent significant structures after dissection performed on cadaveric left ankle. The most distal (caudal) wire was ultimately identified as the safest wire and so retained.

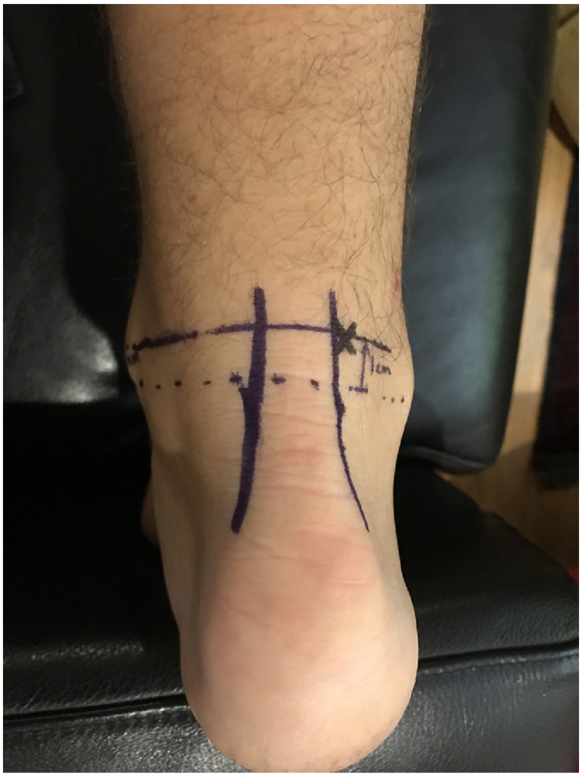

Fig. 4. Anatomical landmarks and safe zone entry point. Photo image of skin markings on posterior right ankle of live model, showing safe zone entry point (black X) just lateral to Achilles tendon (2 solid blue vertical lines), line extending horizontally from distal aspect of medial malleolus (dotted blue horizontal line), and line extending horizontally from 1 cm above the distal aspect of the medial malleolus (solid blue horizontal line).

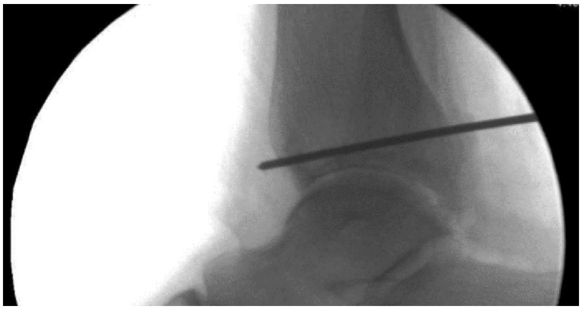

Fig. 5. Step 2. Image intensified lateral radiographic image demonstrating single Kirschner wire passed posterolaterally to anteromedially through cadaveric right ankle.

Step 2

To determine whether use of the safe zone entry point determined in Step 1 would yield reproducible results, the ankle of each of the remaining six specimens was transfixed with a single K-wire, based on the surface anatomy and the safe zone entry point. In each case, fluoroscopy with an image intensifier was used to guide the caudal/cephalad trajectory of the K-wire as it was directed posterolateral to anteromedial (Fig. 5). Direct feedback via the wire driver was also used to ensure satisfactory bicortical wire placement. Each of the ankles was then dissected, identifying the various significant structures, to determine if the K-wire had transfixed or was in close proximity to any significant structures (Fig. 6).

Statistical Methods

A binomial distribution model was used to compute the probability of observing a specified number of "successes" when the K-wire insertion was repeated a specific number of times, and when the outcome for a given specimen was either success or failure. In this case, success was defined as there being no significant damage sustained by any ankle structures (nerves, tendons, or vessels) during K-wire insertion, when using the

Fig. 6. Step 2. Photo images of right cadaveric ankle after dissection, demonstrating position of single Kirschner wire and no visible transfixed or proximate adjacent structures.

anatomical landmarks and the safe path entry point determined in Step1. Statistical significance was defined at the 5% ($P \leq 0.05$) level.

The following statistical hypotheses were tested:

Null hypothesis (H_0): The event of success is random, ie, Probability of success (P) equals 0.5.

Alternate hypothesis (H_1): The event of success is not random, ie, Probability of success (P) is greater than 0.5.

Results

Dissection of each of the six specimen ankles showed that with the use of the same standard safe zone entry point identified in Step 1 for K-wire insertion, there was no evidence of injury to any significant structure, including the sural nerve, short saphenous vein, and the Achilles tendon (Fig. 7).

Based on the fact that the K-wire was placed with success in all six specimens, the estimator of the proportion of success rate was 1.0. Under the null hypothesis, the number of successes in n = 6 trials follows a binomial distribution with a probability of success (P) of 0.5. Therefore, the probability mass function of number of successes can be calculated using the binomial probability distribution formula:

$$P(x) = {}_nC_x\, p^x (1-p)^{(n-x)},$$

where **P** = probability of success (0.5 for H_0 in this study), ${}_nC_x$ **= n!/(x![n-x]!), n** = number of successes (6 in this study), and **x** = number of trials (6 in this study). For this study, ${}_6C_6 = 6!/(6![6\text{-}6]!) = 1.00$, and so the final formula calculation is: $P(x{=}6) = 1.00{*}0.5^{6}{*}(1\text{-}0.5)^{(6\text{-}6)} = 0.016$.

Under the assumption that the null hypothesis is true and based on this calculation, the probability of six successful events would be p= .016 (ie, obtaining six successes in six trials would be very rare). With statistical significance defined at the 5% ($P \leq 0.05$) level, the null hypothesis is not supported and must be rejected. Thus, the number of successful K-wire insertion events using the safe zone entry point identified in Step 1 of this study was unlikely to be a random occurrence. This statistical analysis suggests that K-wire placement using the safe zone entry point identified by this study is likely to have a high success rate in avoiding damage to significant ankle structures.

Discussion

In 2006, Haraguchi published a classification system that was considered helpful in determining the best treatment approach for PMFs (11). He and his colleagues described three categories of PMF: type I is a fracture with a single, wedge-shaped posterolateral fragment and is the most common; type II is a transverse fracture with the fracture line parallel to the bimalleolar line and extending to the posteromedial side of the distal tibia, and it can include more than one fragment; and type III is a small, shell-type fracture with little joint surface involvement, usually occurring laterally, but can have medial extension of lip fragments (25). Then in 2015, Mangnus and colleagues used 3-dimensional computed tomography (CT)-modeling to correlate fracture mapping with the Haraguchi classification system (Fig. 8). They concluded that Haraguchi type I and III fractures actually represent a continuous spectrum of oblique fractures, while type II fractures have different fracture line orientations and are inherently unstable (26).

These 2 important reports demonstrate the extent to which PMFs are a heterogeneous group of fractures (25,26). It is not surprising then that there is currently no consensus about the optimal method for repair of PMFs (2,7,8,10). However, there is general agreement, supported by the literature, that fixation should be considered for all PMFs, in order to provide patients with the best stability and the least risk of future degenerative changes in the ankle (6,7,11,13). These 2 reports also suggest that fracture patterns exist for which open reduction may not be required (25,26). In addition, open reduction may be relatively contraindicated in some patients, including those who are elderly, medically compromised, or dealing with circulatory issues related to diabetes or peripheral vascular disease (27). In such cases, percutaneous PA fixation is an alternative option that may aid the surgeon in adequately stabilizing a broad range of ankle fractures, including tri-malleolar fractures.

Percutaneous fixation avoids the considerable dissection necessary for open reduction, leading to less pain and a faster recovery (27). It also avoids the higher rate of complications (eg, poor wound healing, infection, and neurovascular injury), as well as the longer hospital stays and recovery times, associated with open reduction (27,28). On the other hand, the indirect PA percutaneous approach poses some risk of damage to the neurovascular bundle (including the sural nerve) and the flexor hallucis longus, and the quality of reduction is potentially inferior to that achieved with an open approach (28,29). Ultimately, the

Fig. 7. Safe Zone Entry Point. Illustration of posterior right ankle, demonstrating location of safe zone entry point (green circle) and significant adjacent structures (sural nerve, short saphenous vein, and Achilles tendon).

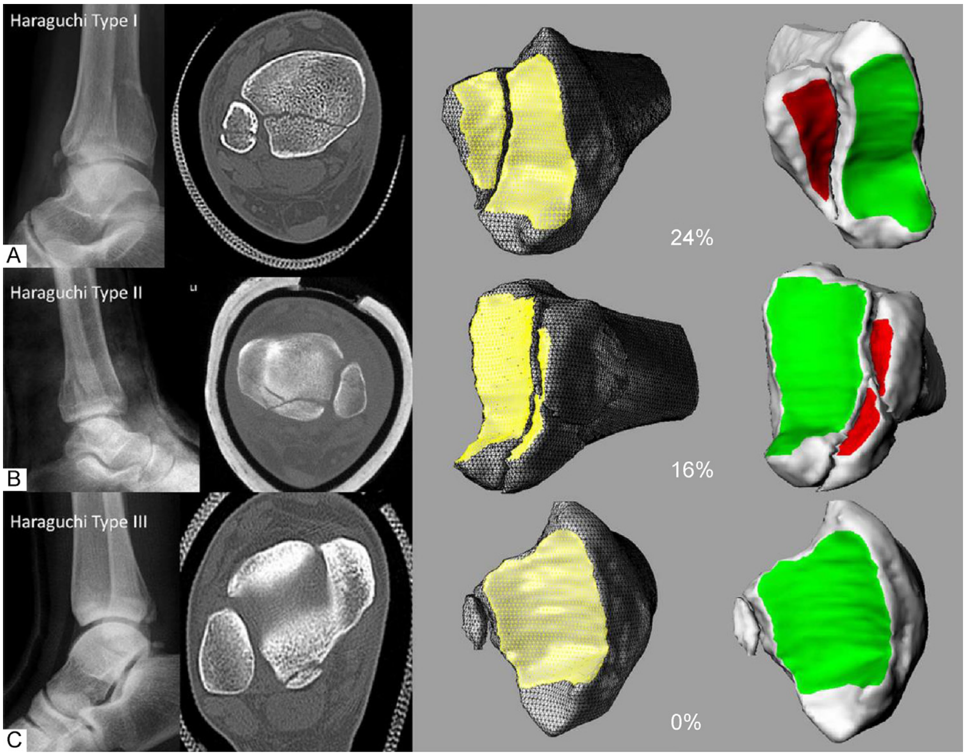

Fig. 8. Haraguchi Classification System. ***Left:*** Plain lateral radiographic images and transverse CT images of ankle fractures, based on the original Haraguchi anatomic classification system of posterior malleolar fractures (25); ***Right:*** 3-dimensional CT-modeling images of ankle posterior malleolar fracture morphologies (showing percentages of articular surface involved in fracture) corresponding to the Haraguchi classification system, as described by Mangnus and colleagues (26). For both series of ankle images, A is right, B is left, and C is right.

(Fig. 3 from Reference 26; License number 4799701090719, issued Mar 31, 2020, by Wolters Kluwer Health, Inc.)

surgeon must choose the most appropriate approach to these fractures, based on the sound knowledge of anatomy, careful examination of preoperative radiographic images, individual patient characteristics, and a full understanding of the surgical options available.

In this study, we have defined a specific safe zone entry point that could potentially be used for placement of a posterior percutaneous screw in patients with a PMF who may not need open reduction and fixation. The entry point is located immediately lateral to the Achilles tendon and 1 cm above the distal aspect of the medial malleolus, when visualizing the posterior ankle. We identified this safe zone using a series of K-wires, inserting them lateral to the Achilles tendon and then directing them in a posterolateral to anteromedial path, over a level course, along the distal tibia of the initial specimen. After placing the wires, we dissected the initial specimen and removed all wires except the one that had not transfixed or come excessively close to significant anatomic structures.

We were then able to use surface anatomical landmarks and this safe zone entry point to direct a single K-wire into the ankle in six subsequent specimens, and in each case, dissection showed that we successfully avoided injury to any significant anatomic structures. Statistical analysis revealed that the likelihood of achieving successful K-wire positioning in six cases by random chance was very low. The statistical results suggest that the success rate for passage of a K-wire using this approach is likely to be high. They also suggest that safe passage of a K-wire can be replicated by starting with the use of surface anatomical landmarks and locating the safe zone entry point.

If our results are confirmed by clinical studies, the use of this approach may facilitate reliable and reproducible safe passage for screw insertion during a PA mini-open or percutaneous fixation procedure for PMFs. This technique may be ideal for fractures of the posterior malleolus that are suitable for screw fixation, including Haraguchi type I fractures, transverse Haraguchi type II fractures, and oblique Haraguchi type III fractures with medial extension (Fig. 8).

This study has limitations. The number of specimens used was relatively small, which may have reduced the odds of encountering a specimen with variations in ankle anatomy (be those congenital, post-traumatic, or postoperative). In addition, the initial assessment of whether significant structures were avoided in each of the specimens in Step 2 was performed by the surgeon who had placed the K-wires. However, these assessments were confirmed to be accurate by a different surgeon, reducing the risk of evaluator bias. Finally, with the use of cadavers, this study obviously did not allow for the assessment of any clinical outcomes, such as postoperative pain, range of motion, fracture union, or complications.

Whereas we acknowledge the limitations of a cadaveric study like this, others have certainly carried out similar preliminary work in the field of orthopedics. Czerwonka utilized 10 cadavers to determine the risk to anatomic structures utilizing a percutaneous technique for PA screw fixation of PMFs (29). Grandizio et al. used cadavers to assess K-wire trajectories in metacarpal fractures (30). And, Shibata et al. used cadaveric shoulders to measure the distances from K-wire insertion points to the bony landmarks of the clavicle and to determine the shortest distances from those points to the suprascapular nerves and arteries (31). Furthermore, the methodological quality of our cadaveric study seems to be relatively high. When we apply the QUality Appraisal for Cadaveric Studies (QUACS) scale to our study and manuscript, it yields a 92% rating. The QUACS scale has been reported to exhibit strong construct validity when used to assess the methodological quality of observational dissection studies (32). The scale consists of a checklist encompassing 13 items, each of which is scored with either 0 (no/not stated) or 1 (yes/present) point, and the quality rating is expressed as a percentage value.

In conclusion, despite some limitations, we believe this can serve as a pilot study, providing initial support for the use of ankle surface anatomy to determine a specific safe zone entry point for PA percutaneous screw fixation of the posterior malleolus in patients with ankle fractures in whom open reduction and fixation may not be required or may be contraindicated. The results of this study could provide a foundation for implementing this approach in clinical studies in order to confirm our findings. If the safety and reproducibility of this approach can be confirmed in a clinical setting, it would offer surgeons a clearly defined anatomic safe zone that could be used to safely repair certain posterior malleolus fractures using PA percutaneous screw fixation.

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