Risks to the Blood Supply of the Talus with Four Methods of Total Ankle Arthroplasty

A Cadaveric Injection Study

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Background: Despite the use of contemporary total ankle arthroplasty implant designs, clinical outcomes of total ankle arthroplasty continue to lag behind those of other joint replacement procedures. Disruption of the extraosseous talar blood supply at the time of ankle replacement may be a factor contributing to talar component subsidence—a common mechanism of early failure following ankle replacement. We evaluated the risk of injury to specific extraosseous arteries supplying the talus associated with specific total ankle arthroplasty implants.

Methods: Sixteen fresh-frozen through-knee cadaveric specimens were injected with latex and barium sulfate distal to the popliteal trifurcation to visualize the arteries. Four specimens each were prepared for implantation of four contemporary total ankle arthroplasty systems: Scandinavian Total Ankle Replacement (STAR), INBONE II, Salto Talaris, and Trabecular Metal Total Ankle (TMTA). Postoperative computed tomography scans and 6% sodium hypochlorite chemical debridement were used to examine, measure, and document the proximity of the total ankle arthroplasty instrumentation to the extraosseous talar blood supply.

Results: All four implant types subjected the extraosseous talar blood supply to the risk of injury. The INBONE subtalar drill hole directly transected the artery of the tarsal canal in three of four specimens. The lateral approach for the TMTA transected the first perforator of the peroneal artery in two of four specimens. The STAR caused medial injury to the deltoid branches in all four specimens, whereas the other three systems did not directly affect this supply ($p < 0.005$). The Salto Talaris and STAR implants caused injury to the artery of the tarsal canal in one of four specimens.

Conclusions: All four total ankle arthroplasty systems tested posed a risk of injury to the extraosseous talar blood supply, but the risks of injury to specific arteries were higher for specific implants.

Clinical Relevance: The risk of injury to the blood supply of the talus during total ankle arthroplasty presents theoretical risks of aseptic loosening and implant failure due to talar osteonecrosis. Knowledge of the blood supply and specific surgical anatomy may lower these risks.

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Total ankle arthroplasty has evolved over the past decade, with a number of recent U.S. Food and Drug Administration (FDA) approvals of total ankle arthroplasty systems[1]. Different methods and designs of ankle replacement require various surgical approaches, osteotomies, bone resections, and drilling paths that lie in intimate proximity to the blood supply of the talus.

Pooled results have shown total ankle arthroplasty implant survivorship of 80% to 95% at eight to twelve years[2], with

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clinical results equivalent to those of ankle arthrodesis at the time of intermediate to long-term follow-up[3-8]. Complications such as subsidence and aseptic loosening after total ankle replacement have been well documented[9-15]; however, the precise reasons for these complications remain unclear.

The purpose of this study was to evaluate four contemporary total ankle arthroplasty systems in relationship to the extraosseous arterial blood supply of the talus with use of a cadaveric latex-injection model and preoperative and postoperative computed tomography (CT) analysis. The hypothesis was that the prevalence of injury to specific extraosseous arteries of the talus is higher for specific total ankle arthroplasty implant systems.

Materials and Methods

Four FDA-approved total ankle arthroplasty systems were selected for evaluation: INBONE II Total Ankle System (Wright Medical Technology, Arlington, Tennessee), Salto Talaris Total Ankle Prosthesis (Tornier, U.S., Edina, Minnesota), Scandinavian Total Ankle Replacement (STAR; Small Bone Innovations, Morrisville, Pennsylvania), and Trabecular Metal Total Ankle (TMTA; Zimmer, Warsaw, Indiana). All four companies consented to participation with knowledge of the study aims and protocol, and all donated instrumentation and sent product representatives and/or design engineers to guide the cadaveric surgical procedures. All surgical and debridement procedures were performed in the orthopaedic skills and anatomy laboratories of a single institution. The study was exempted from institutional review board approval.

A pilot study, of two specimens, was initially undertaken to evaluate the effect of surgical manipulation before and after the latex-with-barium injection technique described below. The specificity of vessel anatomy and injury identification was superior when the injection was performed prior to a surgical procedure due to the leakage of latex from surgical incisions and bone cuts.

Twenty-five through-knee-amputation cadaveric fresh-frozen specimens from seventeen adult human cadavers were obtained from a private body donation program (Anatomy Gifts Registry, Hanover, Maryland). The mean age of the donors at the time of death was fifty-eight years (range, fifty-two to sixty-five years). Cadavers with evidence of prior foot or ankle trauma, surgery, or deformity were excluded. It was not known if any of the donors had had a history of ankle injury or pain. The specimens were obtained frozen and allowed to thaw overnight in preparation for the initial latex-plus-barium injection. Skin incisions were made in the dorsal web space of each toe at the level of the proximal phalanx. Cannulations with size-8 French single-lumen catheters of the anterior tibial, posterior tibial, and peroneal arteries were performed just distal to the popliteal trifurcation at the knee. Saline solution was injected manually into the catheter until the flow from the distal incisions at the toe web spaces was clear[16,17]. A suspension of barium sulfate powder in water (ratio, 1:2) was mixed with blue latex (Ward's Science, Rochester, New York) (one part suspension, two parts latex). This mixture was then injected into the three proximal cannulae in a fashion similar to the technique for injecting the saline solution. The specimens were taken on the same day of the injection for fine-cut (0.4-mm) CT scans for preoperative evaluation of the native vasculature and integrity of the injection itself. An ankle-foot orthosis (AFO) jig was used to position the specimens at neutral ankle dorsiflexion in the CT scanner. Specimens were carefully labeled and kept in separate marked plastic bags for future identification and then frozen until the time of surgery for each of the four implant groups (between six days and six weeks for different specimen groups).

Preoperative CT scans of the study specimens were analyzed with particular attention paid to the vascular anatomy of the talar blood supply. The specimens were classified according to the visibility of vessels of interest on the preoperative scans. Groups of specimens with clearly visible vasculature, including anterior tibial, posterior tibial, and peroneal artery sources, were allocated to be randomly assigned to one of the four surgical implant groups. Twenty specimens were deemed adequate for randomization, with the intention of allocating four surgical specimens and one back-up specimen to each implant group.

Surgical procedures were carried out on four separate days, one for each implant study group. All surgical procedures using an implant from a given manufacturer were performed on the same day. On each day, five specimens were allowed to thaw at room temperature for twenty-four hours. Surgical procedures were carried out in direct accordance with the surgical technique guide for each implant[18-21], with use of a large c-arm fluoroscopy unit for guidance (see Appendix). All surgical procedures were performed by an orthopaedic foot and ankle fellow (J.N.T.) during the second half of training and were supervised by one of the three senior authors (P.P., J.F., and A.A.). Representatives from each implant manufacturer (Tornier, Wright Medical Technology, Small Bone Innovations, and Zimmer) were present on the day of experimentation with use of that manufacturer's product to guide the entirety of the surgical procedures. Although some blue barium-latex-filled vessels were apparent both intraoperatively and on fluoroscopic examination, the surgical technique was not altered on the basis of vessel visibility. The specimens were positioned with 10-lb (4.5-kg) beanbags around the calf for implant systems that did not include use of an intraoperative frame. No final total ankle arthroplasty implants were placed; however, trial implants were placed as necessary for performance of final implant cuts. Only the skin was closed, with use of a running nonabsorbable suture, to restore superficial anatomic relationships. The site of the fibular osteotomy required for the TMTA was repaired with use of a nonabsorbable suture through two drill holes in the lateral fibular cortex, away from arterial structures. The specimens were fixed in a fiberglass AFO at neutral ankle dorsiflexion with use of one Steinmann pin through the AFO and posterior aspect of the calcaneus and a second pin through the AFO and proximal part of the tibia. Gentle traction was applied across the ankle joint during fixation for slight distraction to approximate the anatomic position of an implant in the joint space. The specimens were frozen in position in the AFOs and marked bags until all four surgical sessions were completed.

Postoperative CT scans were performed on all sixteen specimens after they were allowed to thaw for twenty-four hours in the AFOs. Image analysis was performed with use of image viewing software (OsiriX; Pixmeo, Bernex, Switzerland). Vessel boundaries were manually segmented from the CT images collected at 0.4-mm-slice spacing. The vessels of interest included the posterior tibial artery, anterior tibial artery, dorsalis pedis artery, first perforator of the peroneal artery, artery of the tarsal canal, artery of the tarsal sinus, and deltoid branches where present in the anatomy and visible on the CT scan. Additionally, total ankle arthroplasty osteotomies, saw cuts, and drill paths were identified postoperatively. Both the proximity to and the number of direct injuries to the arterial vasculature were measured on these segmented postoperative CT scans. Coronal and sagittal plane images were both used for measurement of vessel proximity to the surgical cuts, and preoperative images were consulted as necessary to locate the vessels of interest. Proximity to the posteromedial deltoid branches was measured with reference to the distal edge of the medial articular facet of the talus. The distance from the medial articular facet edge to the most distal medial saw cut on the talus was determined. Distal medial cuts above the medial articular facet edge were assigned positive values, and those below were given negative values (Fig. 1). Measurement means and standard deviations were statistically compared among implant groups through use of one-way analysis of variance (ANOVA).

Chemical debridement was used for direct visualization and qualitative assessment of the proximity and direct injury noted on the CT scans. In groups of four, specimens were thawed for twenty-four hours. The Steinmann pin at the heel was removed, and the skin and subcutaneous tissues were sharply dissected away. The specimens, in the AFOs, were submerged in 6.0% sodium hypochlorite solution for four to six hours, with refreshment of the solution once after two to three hours. The chemical debridement was paused when soft tissues about the ankle were debrided, leaving the latex vessel casts as well as the ligamentous and osseous structures in place. Careful examination of vascular anatomy, visualization of relationships of vessels to surgically manipulated tissue and bone, and photography were performed. Each talus with its vessel latex casts was then carefully

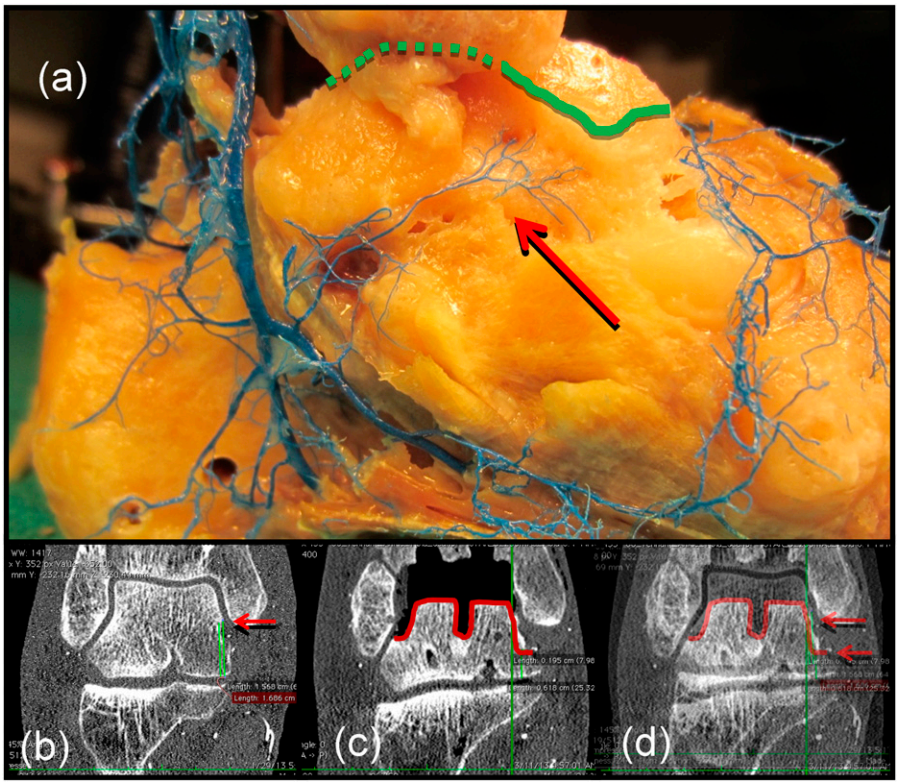

Fig. 1

Deltoid branches of the medial aspect of the talus (arrow) insert below the medial articular facet of the talus (line) (**Fig. 1-A**). Measurement of medial injury referenced the medial articular facet on the preoperative CT (**Fig. 1-B,** arrow), and the medial cut was noted on the postoperative CT at the same coronal cut (**Fig. 1-C**). Overlay of the two images (**Fig. 1-D**) showed the measurement to be above (positive) or below (negative) the medial articular facet. In this example, a value of −6.00 mm was measured.

disarticulated, followed by an additional one to three hours of separate chemical debridement to remove remaining soft tissue. Examination and photography were again performed on the isolated tali at this final stage.

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Results

All four implant types posed a risk of injury to the extraosseous talar blood supply. A level of risk to each extraosseous arterial supply was assigned to each implant system on

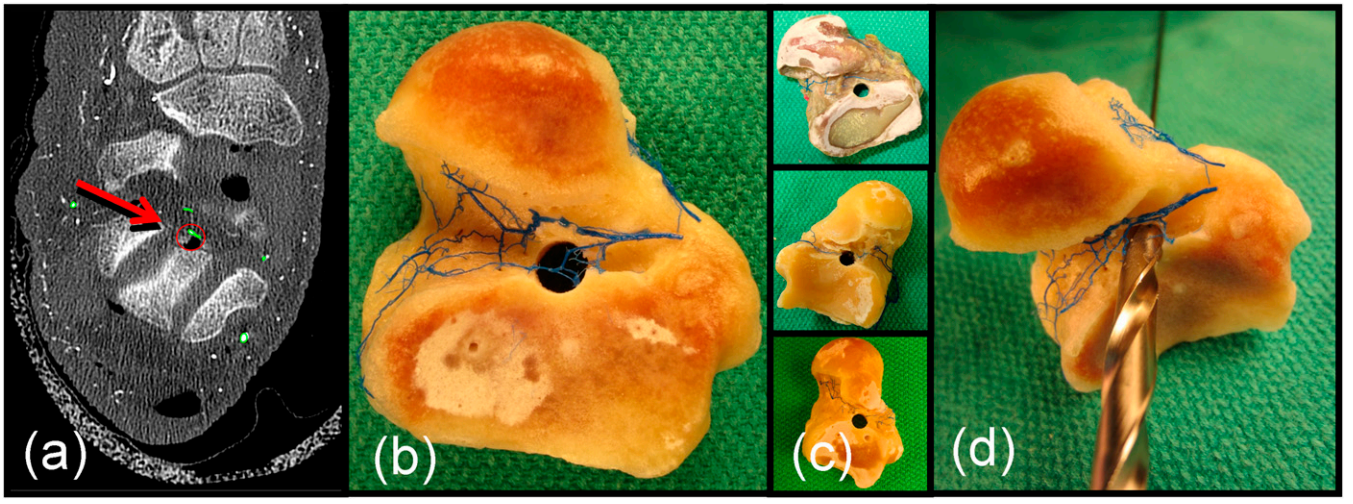

Fig. 2

INBONE II specimen showing injury to the artery of the tarsal canal (arrow indicating drill hole) on the CT scan (**Fig. 2-A**), as was observed in three of the four specimens. The drill holes are seen on the plantar aspect of four tali (**Figs. 2-B and 2-C**), and a specimen is seen with a 6-mm drill bit in place (**Fig. 2-D**).

TABLE I Injury to Extraosseous Blood Supply of the Talus by Total Ankle Implant Type

	INBONE (N = 4)			Salto Talaris (N = 4)		
		Direct Injury			Direct Injury	
	Proximity* *(mm)*	No.	Risk	Proximity* *(mm)*	No.	Risk
Artery of tarsal canal	0.16 ± 0.31	3 (6-mm subtalar drill bit)	Very high	4.4 ± 5.2	1 (dorsal-to-plantar Kirschner wire)	Mod.
1st perforator of peroneal artery	Ant. approach avoids substantial lateral dissection	0	Low	Ant. approach avoids substantial lateral dissection	0	Low
Artery of tarsal sinus	Ant. approach avoids substantial lateral dissection	0	Low	Ant. approach avoids substantial lateral dissection	0	Low
Dorsalis pedis artery (artery itself)	Ant. approach allows lateral retraction of dorsalis pedis artery	0	Low	Ant. approach allows lateral retraction of dorsalis pedis artery	0	Low
Medial talar neck and head supply vessels from dorsalis pedis artery	Cut with ant. incision	4	High	Cut with ant. incision	4	High
Posteromedial deltoid branches (cut of talus above medial articular facet)	1.80 ± 3.11	0	Low	6.18 ± 2.85	0	Low
Posterior tibial artery at distal part of tibia	4.7 ± 1.57†	0	Mod.	4.7 ± 1.57†	0	Mod.

*The mean distance (and standard deviation) of the injury site to the implant system. †The mean for all twelve specimens.

the basis of both the mean proximity of the system to the supply among the specimens in each group and the number of direct injuries visualized on CT scans (Table I).

The INBONE II subtalar drill hole directly transected the artery of the tarsal canal in three of the four specimens (Fig. 2). In the single INBONE specimen without direct injury, such injury was avoided by 0.62 mm as determined with CT measurement.

The TMTA lateral approach transected the first perforator of the peroneal artery in two of the four specimens at the fibular osteotomy site (mean proximity [and standard deviation], 2.19 ± 1.24 mm, with transections considered to equal 0.00 mm for the

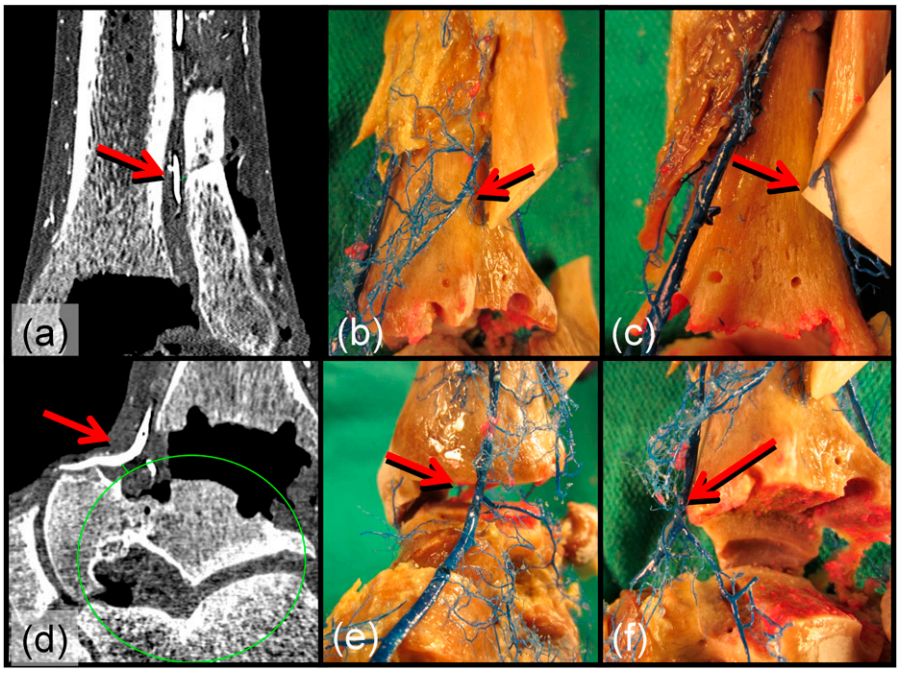

Fig. 3

TMTA specimens showing injury to the first perforator of the peroneal artery and the proximity of the TMTA system to the dorsalis pedis. **Fig. 3-A** Postoperative CT scan showing the first perforator of the peroneal artery (arrow) adjacent to the fibular osteotomy. **Fig. 3-B** An intact first perforator of the peroneal artery (arrow). **Fig. 3-C** Injury to the first perforator of the peroneal artery (arrow), as was seen in two of the four specimens. **Fig. 3-D** Sagittal postoperative CT scan showing proximity of the dorsalis pedis artery (arrow) to the anterior sweep of the high-speed burr used for tibial and talar resection. Anterior (**Fig. 3-E**) and lateral (**Fig. 3-F**) views of postoperative specimens demonstrating the proximity to the dorsalis pedis (arrows).

TABLE I (*continued*)

STAR (N = 4)			TMTA (N = 4)		
	Direct Injury			Direct Injury	
Proximity* *(mm)*	No.	Risk	Proximity* *(mm)*	No.	Risk
5.55 ± 4.71	1 (dorsal-to-plantar Kirschner wire)	Mod.	5.64 ± 2.53	0	Low
Ant. approach avoids substantial lateral dissection	0	Low	2.19 ± 1.24	2	High
Ant. approach avoids substantial lateral dissection	0	Low	8.08 ± 1.98	0	Mod.
Ant. approach allows lateral retraction of dorsalis pedis artery	0	Low	0.66 ± 0.94 (high-speed burr for tibia and talus)	0	Mod.
Cut with ant. incision	4	High			
−5.96 ± 3.29	4	Very high	6.00 ± 1.12	0	Low
4.7 ± 1.57†	0	Mod.	4.7 ± 1.57†	0	Mod.

calculation) (Fig. 3). The artery was cut at the distal anterior aspect of the fibular osteotomy in both injured specimens. The high-speed burr used for tibial and talar resection was noted to be very close to the dorsalis pedis artery, although no direct injuries were visualized. The mean proximity of the burr to the dorsalis pedis at the closest measurement was 0.66 ± 0.94 mm.

The Salto Talaris implant caused injury to the artery of the tarsal canal in one of the four specimens, with a 2.0-mm pin

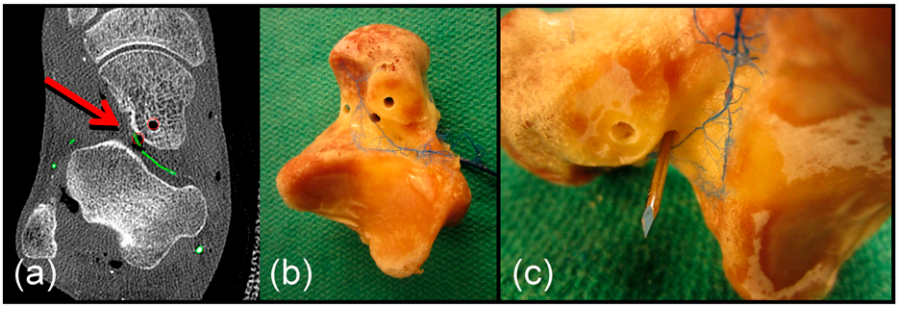

Fig. 4

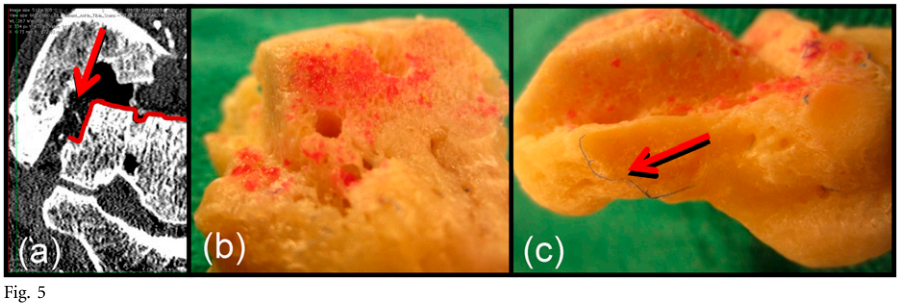

Fig. 5

Fig. 4 Salto Talaris specimen showing the single injury (arrow) to the artery of the tarsal canal from the 2.0-mm pin on a CT scan (**Fig. 4-A**), on the plantar aspect of the postoperative talus (**Fig. 4-B**), and with the dorsal-to-plantar pin in place (**Fig. 4-C**). **Fig. 5** Postoperative CT scan of a STAR specimen showing the medial talar cut at the previous insertion of the main deltoid branch (**Fig. 5-A,** arrow). Anteromedial (**Fig. 5-B**) and medial (**Fig. 5-C**) views of a postoperative specimen; a remnant of the deltoid branch is visible (arrow).

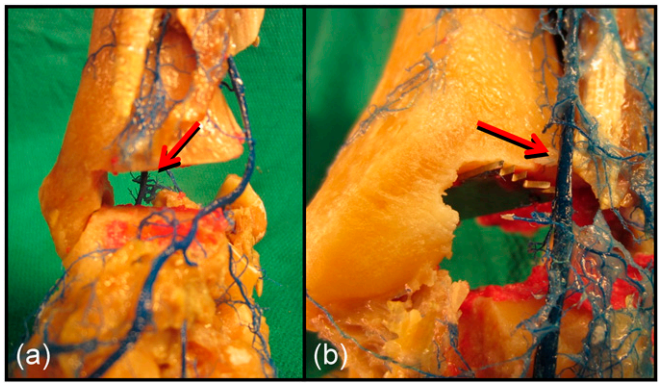

Fig. 6

Proximity of the posterior tibial artery (arrows) to the distal medial tibial saw cut was noted in all twelve specimens (mean proximity for the twelve specimens, 4.7 mm). Anterior (**Fig. 6-A**) and posterior (**Fig. 6-B**) views, with the saw blade in position at the completion of the cut.

placed from dorsally to plantarly to secure the talar resection guide intersecting the course of the artery of the tarsal canal (Fig. 4). The mean proximity of the closest pin track in each specimen was 4.4 ± 5.2 mm. The STAR was also found to have caused injury to the artery of the tarsal canal in one specimen, in a manner similar to that seen with the Salto Talaris implant. A single dorsal-to-plantar talar cutting guide pin for the STAR implant intersected the artery of the tarsal canal (mean proximity in the STAR group, 5.55 ± 4.71 mm).

The STAR implant caused medial injury to the deltoid branches in all four specimens, whereas the other three systems did not directly affect this supply ($p < 0.005$) (Fig. 5). On the basis of the reference measurement from the distal edge of the medial articular facet of the talus, the medial resection used for the STAR implant was −5.96 ± 3.29 mm (below the articular surface edge as indicated by the negative value). The medial resection used for the other three implant systems was above the articular surface edge (indicated by positive values in Table I).

Common to all implant types was proximity of the distal tibial saw cut or high-speed-burr cut at the posteromedial aspect of the distal part of the tibia to the course of the traversing posterior tibial artery (Fig. 6). The mean proximity in all specimens was 4.72 ± 1.57 mm, with no significant difference detected among implant groups.

All implants that were placed through an anterior approach (STAR, Salto Talaris, and INBONE) caused injury to a portion of the talar head and neck arterial supply from the dorsalis pedis artery. Although difficult to determine on the CT scans, the injury risk was assessed on the basis of the location of the surgical dissection over the talar head and neck. The dorsalis pedis itself was not injured in any of the twelve specimens from the three anterior-approach groups.

Discussion

The surgical anatomy demonstrated and measured in this study highlights the inherent risk to the talar extraosseous arterial vascular supply during total ankle arthroplasty performed with use of four current implant methods. All of the studied implant systems were associated with a risk of injury.

The blood supply of the talus previously has been described in detail[16,22-25]. The artery of the tarsal canal is considered to provide the major blood supply to the talar body; the artery of the tarsal sinus and the deltoid branches provide minor supplies to the talar body; and the supply from the dorsalis pedis talar head and neck branches and the posterior tubercle vessels are less important[16]. The first perforator of the peroneal artery serves as a source of much of the lateral talar blood supply. With 70% of the talus covered by articular cartilage, the talar blood supply is uniquely sensitive to insult given its dependence on limited contributions for its vascularity[26].

There are avoidable and unavoidable risks to the extraosseous talar blood supply with the current total ankle arthroplasty implant systems. The risk of injury by the distal tibial saw cut to the posterior tibial artery would be mitigated by avoiding overperforation of the posterior tibial cortex. For the TMTA implant, which is inserted through a lateral approach, careful retraction should avoid injury to both the dorsalis pedis and the posterior tibial artery from the high-speed resection burr. Injury to the artery of the tarsal canal by the pins for the talar cutting guides of the Salto Talaris and STAR implants might be avoided by placing the pins to, but not through, the plantar cortex of the talar neck, a point not previously emphasized in the described techniques. However, direct approaches to each region of the talus are also likely to involve some vascular damage: resection of the medial aspect of the talus with resultant injury to the deltoid supply, drilling through the tarsal canal and its artery, and associated vascular compromise with anterior or lateral approaches are all risks that are unavoidable with specific current implant designs.

It is important to emphasize that this is not a clinical study; long-term clinical follow-up studies are needed to determine if there are clinical correlations with our findings in cadavers. In addition, injury to specific vessels, no matter their relative importance to the supply of the talar body, may not lead to clinically relevant talar osteonecrosis. In fact, rich extraosseous and intraosseous anastomoses may prevent blood supply disruption in vivo[16]. The importance of the extraosseous blood supply of the talus for total ankle arthroplasty is also amplified when considering that the network of intraosseous anastomoses in the talus decreases with age[27]. Moreover, the arterial injury associated with total ankle arthroplasty is a more controlled and limited vascular insult than an injury such as a displaced talar neck fracture, which is known to be associated with a risk of osteonecrosis[28-30].

Clinical studies have demonstrated failures of talar components caused by aseptic loosening and implant subsidence. Glazebrook et al.[13] systematically evaluated twenty studies on total ankle arthroplasty complications and found subsidence (8.7%) and aseptic loosening (10.7%) to be the most commonly reported. In a systematic review of ten studies, Haddad et al.[7] noted a 7% revision rate for total ankle arthroplasty, with 28%

of the revisions performed because of loosening or subsidence. Neither review differentiated between tibial and talar component loosening or subsidence.

Because the STAR system has a longer history of use than the other implants in our study, it is the only prosthesis in our study for which intermediate and long-term results have been published. Brunner et al.[12] recently reported a revision rate of 38% (twenty-nine of seventy-seven) for the STAR prosthesis at eleven to fifteen years, with twenty-three of the twenty-nine revisions involving the talar component and required because of loosening, subsidence, or cyst formation. The authors hypothesized that degeneration at the bone-prosthesis interface may have been the source of the problem. Similar results were noted by Anderson et al.[11], after a three to eight-year follow-up of fifty-one patients treated with the STAR prosthesis; five of twelve revisions were performed because of talar component problems. Studies of implant systems that we did not include in our study demonstrated a 3%[31] and 10%[32] prevalence of talar osteonecrosis after total ankle arthroplasty, and talar component subsidence has been quantified by radiostereometric analysis[33]. Only recently, if at all, have early outcomes begun to be reported for the three newer implant systems in our study (Salto Talaris, INBONE, and TMTA)[34].

In our current anatomic study, we experienced minimal difficulty with preservation of the arterial structures and debrided latex casts in a surgical setting. Few latex-injection techniques described in the literature have been used to specifically evaluate postsurgical anatomy[35], and no studies to our knowledge have investigated a latex-injection technique for evaluating total ankle arthroplasty or have used chemical debridement after surgery. On the basis of our pilot study, we deemed preoperative injection superior to postoperative injection. We did not think that intraoperative manipulation and retraction substantially compromised the integrity of the barium-latex cast-defined vascular anatomy. The latex casts at room temperature allowed flexibility that did not induce obvious false-positive findings of injuries and did not hinder soft-tissue manipulation. Moreover, preoperative injection provided visualization of baseline anatomy, which was an important quality control for our specimens as well as an aid in postoperative anatomic comparisons.

A limitation of our study is the relatively limited scope of our testing. Our use of only sixteen specimens presents inherent variability due to anatomic variations among the specimens. Despite the small number of specimens, we believe that our preoperative CT vascular assessment allowed us to select and ultimately test specimens with vasculature within a normal anatomic range[16,35]. Our study was also limited in that we tested only four implant types, all FDA-approved implants that are currently used or have been used at our institution. We expect that some of our observations could apply to other implant designs, but additional anatomic testing with other implants is required. Our goal was not to catalog talar vascular anatomy; rather, we sought to identify clinically relevant risks of total ankle arthroplasty that have not been previously identified in the literature.

In light of the risks defined in this study, implant selection and implant design have clinical implications. A surgeon may consider choosing a total ankle arthroplasty implant on the basis of a patient's known talar vascular anatomy as shown by preoperative imaging. While we would not consider routine preoperative angiography for all patients undergoing total ankle arthroplasty, patients with previous surgical procedures, trauma, or suspicion of congenital vascular anomalies might be considered for further evaluation. A patient whose talus relies on an abnormally limited blood supply should be considered for an implant associated with protection of that supply. Furthermore, those developing iterations and future concepts of total ankle arthroplasty implant design should continue to consider protection of the vascular anatomy about the talus.

In conclusion, injury to specific arteries providing the extraosseous blood supply of the talus can be expected with specific current total ankle arthroplasty implant systems. Knowledge of the surgical and vascular anatomy may allow some, but not all, arterial injuries to be prevented. Correlation with clinical outcomes and additional investigative study is needed to verify that the arterial injuries expected from total ankle arthroplasty would affect the prevalence of talar component complications from osteonecrosis. The design and clinical application of total ankle arthroplasties have implications with regard to the minimization of risk to the blood supply of the talus.

Appendix

(eA) A figure showing fluoroscopic visualization during the total ankle arthroplasties in the cadavers is available with the online version of this article as a data supplement at jbjs.org. ■

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