Early Radiographic Outcomes of Vascularized Pedicle Bone Grafting in Foot: A Case Series

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Abstract

Background Navicular nonunion and talar avascular necrosis may result from limited blood supply predisposing to injury and impaired healing. Vascularized pedicled bone grafting is a promising adjunct to treat these challenging conditions, offering the susceptible diseased site structural and vascular support. We report the early radiographic and clinical outcomes of vascularized pedicled bone grafting in patients with navicular nonunion, talonavicular fusion nonunion, and talar avascular necrosis.
Methods Patients with navicular nonunion, talonavicular fusion nonunion, or talar avascular necrosis who underwent vascularized pedicled bone grafting at our institution from January 2014 to February 2019 were retrospectively identified. Radiographic evidence of healing was monitored postoperatively as defined by: progression toward union on CT for nonunion and absence of disease progression on MRI or CT for avascular necrosis. Surgical complications and need for additional surgeries were documented.
Results Eight patients were included who underwent vascularized pedicled bone grafting for navicular nonunion ($N = 5$), talonavicular fusion nonunion ($N = 1$), and talar avascular necrosis ($N = 2$). Average clinical follow-up was 10.8 months (range 4–37). All patients had 4 or more months postoperative radiographic follow-up with MRI or CT. Seven of eight patients demonstrated evidence of radiographic healing. One patient required additional surgery due to external fixator pin site infection. No other complications were reported.
Conclusion Our results corroborate prior case series suggesting vascularized pedicled bone grafting is a safe and reliable procedure for treating navicular nonunion, talonavicular fusion nonunion, or talar avascular necrosis with potential to spare or delay need for salvage procedures in the younger patient population.
Level of Evidence The evidence level is Level V.

Keywords
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The navicular and talus are clinically challenging, as limited vascular supply impairs healing and increases susceptibility to fracture nonunion, osteonecrosis, and impaired fusion. While treatment options for navicular nonunion and talar avascular necrosis (AVN) include core decompression, vascularized and non-vascularized bone grafting, total talar replacement, open reduction internal fixation, and arthrodesis, the deficient vascularity that led to the original bony injury still remains.[1] Further, existing treatment options for the two conditions are unreliable, as conservative treatment fails in one-third of patients and surgical interventions involving joint-sacrifice are not desirable, as patients are typically younger and more active.[1,2] Even when the joint is sacrificed, as in arthrodesis, the insufficient vascular supply can lead to impaired joint fusion and nonunion.[3]

A potential surgical alternative is the use of vascularized pedicle bone grafting (VPBG) to replace the diseased bone with revascularized, viable bone from the cuboid or cuneiform. The technique was developed out of Duke University whose two small case series showed promising results.[4,5] In a cohort of 13 patients who received VPBG of the cuboid for talar AVN, 11 (85%) patients required no additional surgery at a mean follow-up of 6 years.[5] In a cohort of eight patients who received VPBG to the navicular, four (50%) patients required no additional surgery at a mean follow-up of 5 years.[4]

To date, there is only one published study in English literature reproducing these results and two other studies in Chinese literature that replicate Nunley and Hamid findings.[3,6,7] However, these three studies relied primarily on patient-reported outcomes and did not consistently report outcomes from postoperative advanced imaging, which gives insight into the healing status of the repaired bone.

With enhanced blood supply to the navicular or talus via VPBG, healing ability is potentially increased. However, reproduction of these results at other institutions is lacking in English literature. Thus, the purpose of this study is to report on early radiographic outcomes of VPBG in the progression toward union in navicular nonunion or talonavicular fusion nonunion and prevention of disease progression in talar AVN. We also report on the clinical outcomes of VPBG as defined by complications, need for reoperation, and donor site morbidity.

Materials and Methods

This study was performed after obtaining approval from the Institutional Review Board at our academic medical center and all patients provided informed consent. The patients were identified through Current Procedural Terminology code search for patients who had undergone VPBG to the navicular or talus from either the cuboid or medial/lateral cuneiform bones at one institution between 2014 and 2019. VPBG was performed by three fellowship-trained microvascular surgeons (Duretti T. Fufa, Daniel A. Osei, and Lloyd B. Gayle). Patient contact information was obtained from the Foot and Ankle Registry, which contains demographic information, operative notes, imaging studies, and clinical outcome scores. If the patient was not identifiable in the Registry, contact information was obtained from the electronic medical record. Each patient was contacted by telephone to request participation in the study. For minors, parental permission was obtained first followed by minor's assent.

Patient Selection

Patients were included in this study if they were at least 16 years old at the time of surgery, treated operatively with VPBG for navicular nonunion, talonavicular fusion nonunion, or talar AVN, and had a minimum of 3 months postoperative advanced imaging. Three months was felt to be sufficient time for advanced imaging because of Kodama et al's finding that Hawkin's sign—an indication of replacement of necrotic bone in the subchondral area of the dome of the talus—appeared at least 2.5 months postoperatively.[3] Eight feet in 8 patients were included in the series.

Operative Technique

Surgical techniques varied slightly in each case based on clinical application. The surgeries were performed with patients lying in supine position with the use of regional anesthesia. The first surgical approach was made to the affected bone or joint, often localized using intraoperative fluoroscopy. After preparation of the recipient site by clearing fibrous nonunion or dysvascular material, the pedicled graft was dissected. For the navicular nonunion cases, the bone graft harvest site over the lateral or medial cuneiform was approached following the terminal vascular branches of the dorsalis pedis. For talus procedures, the graft was taken from the cuboid. Once suitable vascular pedicles were identified going to bone, osteotomes were used to harvest a bone graft and intact cortical periosteal sleeve with similar dimensions to the recipient cavity. The vascular pedicle was then carefully dissected free and traced back to the main dorsalis pedis artery terminal branch. Adequate swing distance allowed the bone graft to be freely rotated into the nonunion or dysvascular site. Measures to prevent compression and vasospasm of the pedicle were utilized (►**Fig. 1**).

Postoperative Management

Patients were immobilized in plaster splints and instructed to remain non-weightbearing for 2 weeks after surgery, at which time the splint was replaced with a non-weightbearing cast. At 4 weeks postoperatively, the cast was replaced with a removable boot and patients began physical therapy for active and passive range of motion exercises. Typical postoperative follow-up included clinic visits and plain radiographs at 2 weeks, 6 weeks, 3 months, and 6 months following surgery. Progression to weight bearing was dependent on imaging findings, where a CT was typically obtained around 8 to 10 weeks postoperatively to assess the graft and surgical site. A patellar-tibial brace was used to allow gradual advancements in weight bearing.

Radiographic Evaluation

Preoperative and postoperative imaging studies were compared and reviewed for all patients. Advanced postoperative imaging via CT ($n = 6$) or MRI ($n = 2$) was conducted at a

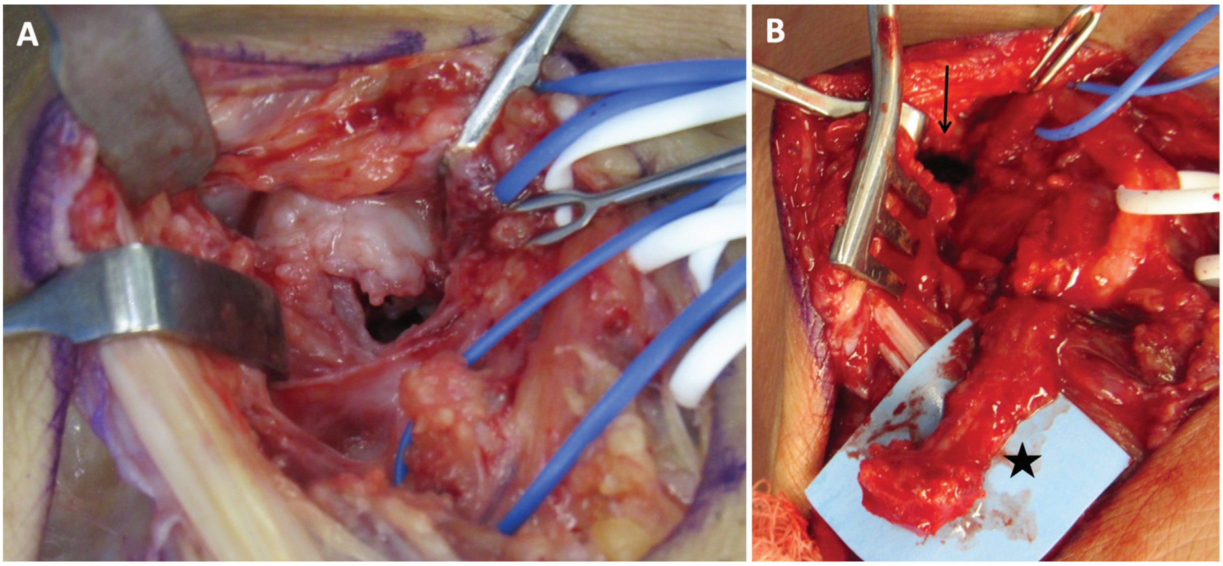

Fig. 1 Case 2, a 38-year-old male with right talar AVN with large anterolateral, cystic defect (**A**). Vascularized pedicled graft from cuboid isolated on transverse branch of lateral tarsal artery (*star*) before rotation into defect (*arrow*) (**B**). AVN, avascular necrosis.

minimum of 3 months and an average of 9.4 months (range 5–23 months) postoperatively. The timing of imaging was case dependent.

CT images were acquired using a high sampling frequency to allow optimal spatial resolution. Given the small body parts and small burden of hardware, a small focal spot was also able to be utilized to optimize spatial resolution. Images were acquired using the smallest detector element at 0.625 mm and post processed into the sharpest kernel available (for fine bony detail) as well as in a soft tissue algorithm. A 20 to 30% iterative reconstruction technique was employed to mitigate dose. Images were generated in all three planes by the technologists for the radiologist's review. Additionally, all source images were post processed on the PACS workstation using commercially available multiplanar reformations to allow for more precise orthogonal interrogation.

MR images were all acquired on 1.5T, high to premier gradient systems. Proton density sequences were performed in all three planes at high in plane and through plane resolution. Frequency and phase encoding steps were set at $512 \times (320–384)$ and slice thickness from 3 to 3.5 mm. Inversion recovery pulse sequences were obtained in one or two planes. As necessary receiver bandwidth was elevated to 62 to 82 kHz, depending on the nature of the hardware employed. No additional metal artifact reduction sequence was employed.

Advanced imaging was reviewed by a single fellowship-trained musculoskeletal radiologist for: (1) CT evidence of progression toward bony union in navicular or talonavicular fusion nonunion, graded in quartiles (25, 50, 75, or 100% evidence of union) (►**Fig. 2**); (2) MRI evidence of prevention of disease progression in talar AVN by assessing bony architecture in comparison to preoperative imaging, graded in quartiles (25, 50, 75, or 100% revascularized) (►**Fig. 3**). All imaging were also reviewed for the presence of articular collapse or loss of joint congruity, cystic changes, adjacent joint degeneration, and donor site morbidity (fracture, penetration into adjacent joints or bones, infection, adjacent precipitous degenerative changes, or heterotopic ossification).

Results

Eight patients who underwent VPBG from a cuneiform or cuboid for the treatment of navicular nonunion ($N = 5$), talonavicular fusion nonunion ($N = 1$), or AVN of the talus ($N = 2$) were identified. All eight patients were men with a mean age of 28 (range, 16–48) years at the time of surgery. Patients underwent an average of 1.5 prior ipsilateral foot surgeries (range: 1–3) (►**Table 1**).

For patients with navicular nonunion, the graft was obtained from the medial ($N = 3$) or lateral ($N = 3$) cuneiform on a branch of the distal lateral tarsal artery. For patients with talar AVN and talonavicular fusion nonunion, the graft was obtained from the cuboid on the proximal lateral tarsal artery.

Radiographic Follow-Up

Advanced imaging was obtained postoperatively for all eight patients. The mean radiographic follow-up was 9.4 (range 5–23) months. Complete radiologic findings are found in ►**Table 2**. No cystic changes or collapse were seen within the navicular or talus in any of the eight patients. Mild loss of joint congruity was seen in five patients. Evidence of early degenerative changes in adjacent joints, including tibiotalar, talonavicular, naviculo-cuneiform, or calcaneous-navicular-cuboid articulations, was present in four of the eight patients. The one patient who underwent talonavicular fusion demonstrated over 50% union.

For the two patients with the diagnosis of talar AVN, neither had evidence of collapse of the talar dome preoperatively or postoperatively. Review of postoperative MRI studies revealed partial (50% in case 1) and extensive (> 75% in case 2) revascularization of the talus with return of marrow signal and reconstitution of a more normalized appearance. Neither of the patients had evidence of donor site morbidity.

Fig. 2 CT scan of case 6, a 16-year-old male with navicular nonunion preoperatively (**A**) and postoperatively (**B–D**) with evidence of healing. Preoperative image (**A**) shows chronic non-united navicular fracture with prior ORIF. After VPBG, images (**B–D**) show bone formation (**B**) and fracture fusion (**D**). ORIF, open reduction internal fixation; VPBG, vascularized pedicle bone grafting.

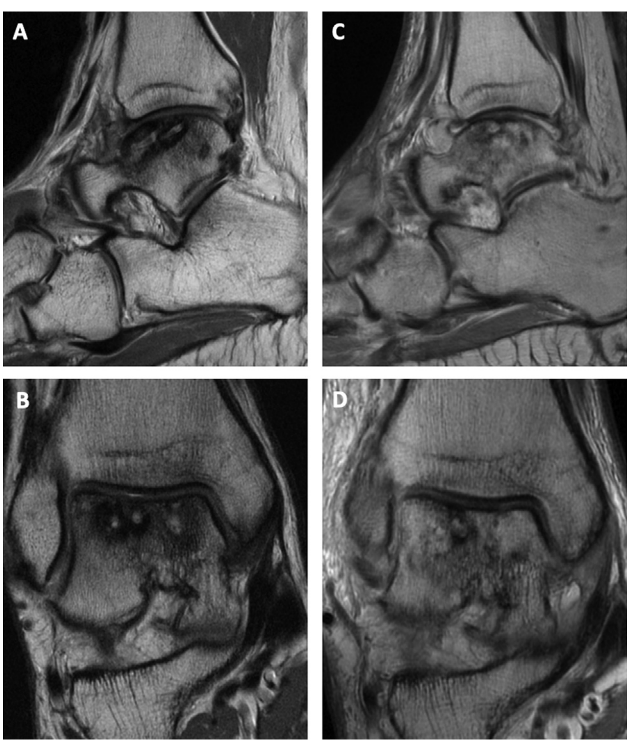

Fig. 3 Proton density MRI of case 2, a 38-year-old male with talar AVN preoperatively (**A, B**) and postoperatively (**C, D**) with evidence of healing. Sagittal view (**A, C**) shows normalized bone architecture with decreased sclerosis in the talus (**C**). Coronal view (**B, D**) shows decreased cystic change and sclerosis. AVN, avascular necrosis.

For the five patients with the diagnosis of navicular nonunion, four had 75% or greater evidence of union while one had 25% evidence of union. Three patients had evidence of donor site morbidity in the form of small amounts of heterotopic ossification ($n = 2$) and slight extension into the intermediate and lateral cuneiform ($n = 1$).

Clinical and Patient-Rated Outcomes

Average clinical follow-up was 12.4 months (range 4–37 months) from the date of surgery to the most recent clinic visit. At the time of most recent clinical evaluation, no patient had failure of treatment or progression to total ankle replacement. Only one patient required an additional operation due to pin site infection from an external fixator.

Postoperative outcome surveys were completed by five of the eight patients. Surveys were completed on average 32.2 (range, 12–63) months postoperatively. Average postoperative pain was reported as 0.6 out of 10 (range, 0–2) for current pain and 1 out of 10 (range, 0–3) for worst pain. Patients were either very ($N = 3$) or extremely ($N = 2$) satisfied with their surgery and outcome. Regarding patient-reported complications, two patients reported nerve damage or sensory disturbances in their operative foot/leg and one patient reported pain with hardware. The average FAOS score was 79.6 (range, 69.0–92.9). The SF-12 subscales averages were as follows: mental health component scale (MCS), 52.8 (range, 47.2–61.3) and physical function component scale (PCS), 54.8 (range, 49.7–57.8).

Table 1 Patient information: demographic, surgical, and imaging data

Case	Smoking status	BMI (kg/m^2)	Carpal bone	Etiology	No prior surgeries; specifics	Donor pedicle location	Concomitant procedures	Subsequent procedures
1	Former	26.7	Talus	Idiopathic aseptic necrosis	1; ORIF	Cuboid	Osteochondroma excision, ICBG	
2	Former	32.0	Talus	Idiopathic aseptic necrosis	1; “foot surgery”	Cuboid	Distraction ankle arthroplasty, application of external fixator	Debridement of pin sites and external fixator hardware removal (April 19, 2019)
3	Current	23.7	Talus	Osteonecrosis, talonavicular OA	1; talonavicular fusion	Cuboid	HWR, talonavicular fusion, ICBMA, proximal tibial bone-grafting, calcaneal cuboid fusion	
4	Never	25.8	Navicular	Nonunion	3; ORIF and ankle arthroscopy, HWR, ankle arthrotomy and repeat ORIF with ICBMA	M Cuneiform	HWR, ORIF, ICBG, ICBMA	
5	Never	23.8	Navicular	Nonunion	1; tibial bone graft	M Cuneiform	Arthroscopy and debridement, ostectomy tibia/talus, I CBG, ICBMA	
6	Never	20.6	Navicular	Nonunion	2; ORIF, repeat ORIF with ICBG	L Cuneiform	HWR, ORIF, ICBMA	
7	Never	24.4	Navicular	Nonunion	1; ORIF with ICBG	M Cuneiform	HWR, ORIF, ICBG, ICBMA	
8	Never	25.2	Navicular	Nonunion	2; Subchondroplasty, ORIF with calcaneal bone-grafting	L Cuneiform	HWR, ORIF, ICBMA	

Abbreviations: BMI, body mass index; HWR, hardware removal; ICBG, iliac crest bone graft; ICBMA, iliac crest bone marrow aspirate; L, lateral; M, medial; OA, osteoarthritis; ORIF, open reduction and internal fixation.

Table 2 Radiologic outcomes

Case	Navicular or talus	Etiology	Imaging modality	Months post-op	Percent healed/union (quartiles)	Articular collapse or loss of joint congruity (JC)	Cystic changes	Adjacent joint degeneration	Donor site morbidity[a]	Donor pedicle location
1	Talus	Avascular necrosis	MRI	7.00	50%	None	None	None	No evidence	Cuboid
2	Talus	Idiopathic aseptic necrosis	MRI	11.00	75–100%	TT: mild loss of JC	None	None	No evidence	Cuboid
3	Talus	Talonavicular arthritis	CT	9.00	50–75%	Sub-Talar: mild loss of JC CNC: mod loss of JC	None	Sub-Talar: mild–mod. CNC: mod–severe	Areas of bony bridging between navicular and cuboid	Cuboid
4	Navicular	Nonunion	CT	5.00	25%	TN: mild loss of JC	None	TN: mild	Small HO	M Cuneiform
5	Navicular	Nonunion	CT	7.00	> 75%	None	None	None	No evidence	M Cuneiform
6	Navicular	Nonunion	CT	8.00	> 75%	None	None	NC: mild	Small HO	L Cuneiform
7	Navicular	Nonunion	CT	23.00	> 50–75%	TN: mild loss of JC	None	TN: mild–mod NC: mild	No evidence	M Cuneiform
8	Navicular	Nonunion	CT	5.00	75%	TN: mild loss of JC	None	None	Slight extension into intermediate and lateral cuneiform	L Cuneiform

Abbreviations: CNC, calcaneous-navicular-cuboid; Mod., moderate; NC, naviculocuneiform; TN, talonavicular; TT, tibiotalar.
[a]Donor site morbidity includes: fracture, penetration, infection, adjacent precipitous degenerative changes, and heterotopic ossification (HO).

Discussion

Intricate arterial supply to the foot predisposes the navicular and talus to injury, impairs healing, and increases susceptibility to fracture nonunion and osteonecrosis. Thus, navicular nonunion and talar AVN are challenging to treat. VPBG can be considered in cases of navicular nonunion and talar AVN where prior operative management has failed. In line with previous studies, VPBG had promising outcomes in this small case series when treating pathology of the navicular and talus. Patients were provided excellent pain relief and improvements in physical functioning, while only one of eight patients required additional surgery.

While treatment options for navicular nonunion and talar AVN include core decompression, vascularized and nonvascularized bone grafting, total talar replacement, open reduction internal fixation, and arthrodesis, the deficient vascularity that led to the original bony injury remains and clinical outcomes are variable. A systematic review by Gross and colleagues concluded that the treatment pathway for talar AVN should initially be conservative with protected weight-bearing, then progress to core decompression, and, lastly, arthrodesis as a salvage procedure.[8] Moreover, conservative treatment fails in one-third of patients and surgical interventions involving joint-sacrifice are not desirable, as patients are typically younger and more active.[1,2,8] A similar treatment algorithm exists for navicular fractures.[9,10] When treatment or diagnosis are delayed, however, nonunion, delayed union, and osteonecrosis of the navicular are more likely to occur.[9] Thus, using a VPBG to replace the necrotic bone with revascularized, viable bone is a promising treatment alternative.

VPBG promotes bony union, reduces healing time, and allows for early stability.[11] VPBG has shown favorable outcomes in upper extremity literature for scaphoid nonunion with osteonecrosis with healing confirmed by CT scans,[12,13] as well as in hip preserving surgery for femoral head osteonecrosis where graft viability was confirmed with MRI, CT, or radiographs.[14] In a systematic review evaluating the effectiveness of vascularized pedicle iliac bone grafts for femoral head necrosis, the authors found an average clinical success rate, or prevention of arthroplasty and alleviation of symptoms at midterm follow-up, of 76%.[14] Similarly, our results support existing literature on the use of VPBG for the treatment of navicular nonunion and talar AVN. Three small case series exist in English literature exploring VPBG in treating navicular nonunion ($N = 1$) and talar AVN ($N = 2$). Eighty-five percent of patients who received VPBG of the cuboid for talar AVN required no additional surgery at a mean follow-up of 6 years.[5] Furthermore, all postoperative MRI studies showed partial talar revascularization. In a cohort of eight patients who received VPBG to the navicular, half of the patients required no additional surgery at a mean follow-up of 5 years.[4] Four of eight patients had postoperative CT scans for the evaluation of navicular nonunion, however, the authors do not detail the findings.[4] Lastly, Kodama et al expanded the use of VPBG to promote arthrodesis in 11 of 12 patients with osteoarthritis of the talonavicular joint secondary to talar AVN.[3] Additionally, all patients showed partial revascularization at 6 months postsurgery via MRI.[3] Two other studies published in Chinese literature also replicate Nunley and Hamid findings, both of which reported “good” or “excellent” results in more than 80% of patients, but the studies do not detail radiographic outcomes.[6,7] Thus, our study provides further evidence that VPBG should be considered in cases where prior conservative or operative management has failed.

Additionally, our use of advanced imaging to further elucidate healing in this cohort of patients adds to the literature, as prior studies relied primarily on patient-reported outcomes or reoperation rates to define success.[3–5] For example, Nunley and Hamid and Kodama et al used MRI to generally evaluate the talar dome and marrow signal postoperatively, but did not relate radiographic findings to surgical success.[3,5] Moreover, in Fishman et al’s study, only four of eight patients had postoperative advanced imaging, leading to lack of uniformity in outcomes.[4] In the study at hand, all patients underwent advanced imaging postoperatively, specifically MRI to assess talar revascularization or CT to assess navicular union. For patients aiming to achieve union, five out of six achieved more than 50% union, with four patients achieving more than 75% union. The two patients with talar AVN showed at least partial revascularization at most recent MRI follow-up, which is similar to Kodama et al’s findings.[3] Furthermore, MRI or CT evidence of revascularization or union correlated with clinical outcomes. The one patient with minimal evidence of revascularization on MRI also had the lowest SF-12 MCS and PCS scores. Seven of the eight patients in our series indicated that their postoperative mental and physical functioning were in line with population norms.[15] Low postoperative pain scores, with an average score of 1 out of 10, further reflected the effectiveness of VPBG in this cohort. Lastly, at time of most recent follow-up, no patient had progressed to arthrodesis or had additional surgery on their operative foot.

Our study has several limitations, including its small sample size, lack of control group, and heterogenous cohort. Given how uncommon navicular nonunion and talar AVN are, we combined our patients into one series to report on the outcomes of eight patients. Further, as this was a retrospective review, baseline patient-reported outcome scores were unavailable, limiting the usefulness of postoperative follow-up patient-reported outcomes scores. Moreover, in regards MRI evaluation of talar AVN patients, revascularization was assessed via changes in bony architecture; to truly comment on revascularization, bone biopsies are gold standard. Lastly, the radiographic outcomes were interpreted by one fellowship-trained musculoskeletal radiologist. Validity would be increased with an additional reader.

The study at hand further validates the usefulness of VPBG in treatment of navicular nonunion and talar AVN, specifically in maintaining bony architecture as evaluated by advanced imaging. Using these revascularization procedures and preserving native anatomy, patients may be spared from the need for arthrodesis. As there is a paucity of evidence in the literature regarding the efficacy of this procedure, including radiologic, clinical, and patient-reported outcomes, future studies with larger cohorts should continue to investigate the outcomes of this surgical intervention.

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Conflict of Interest

None declared.

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