Use of Three Dimensional Titanium Trusses For Arthrodesis Procedures in Foot and Ankle Surgery: A Retrospective Case Series

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Statement of Purpose

Titanium inter-body spinal trusses packed with bone graft are considered to be the gold standard for treatment of severe degenerative disc disease, restoring alignment and disc height. This same principle can be applied to foot and ankle, using standard or custom titanium trusses manufactured using a 3D printer to fill voids of large segmental osseous defects. 3D printing is different from typical manufacturing techniques. It is founded on the principle of "additive manufacturing", or depositing materials layer by layer. The customizable nature of 3D printing provides surgeons with the ability to tailor the fabrication to an individual patient's anatomy, theoretically restoring joint congruity with concomitant structural integrity promoting successful consolidation.

Literature Review

Periarticular osseous defects pose a challenge when considering arthrodesis in foot and ankle surgery for limb or ray salvage. Resection of large areas of bone is often necessary for treatment of certain pathologies such as avascular necrosis, osteomyelitis, non-union, post-traumatic, and Charcot neuroarthropathy (1,2,3,4,5,6,7,8). These defects often require some type of structural support to restore length, overall cubic content, anatomic alignment, and skin tension. Failure to restore anatomic length transfers pressures to adjacent joints altering foot biomechanics causing compensatory gait disturbances and placing stresses on proximal joints such as the hip, knee, and spine. (18,19,20,21,22) Options for surgical management for these clinical scenarios include end-to-end arthrodesis without structural interpositional grafting, arthrodesis with interpositional autogenous or allogenic bone graft, bone transport utilizing an external fixator, Masquelet's induced membrane technique, osteomyocutaneous flaps of the fibula, or amputation (1,8,9,10,11,12,13,14,15). However, each of these techniques has their disadvantages and inconclusive results have been noted throughout the literature.

End-to-end arthrodesis procedures without structural interpositional grafts have higher documented fusion rates compared to arthrodesis with interpositional autogenous or allogenic bone graft, as it has fewer bone interfaces required to heal. However, it does not restore anatomic length, and causes indirect effects such as decreased skin tension and destruction of normal musculotendinous function.(1).

Studies in the literature on tibiocalcaneal arthrodesis after talectomy without structural interpostional grafts, have reported an average limb length discrepancy of 1.5 to 3.5 cm, altering gait mechanics, and placing stresses upon proximal joints. (18, 19, 20, 21, 22) Additionally, studies have also shown that there is an increase in oxygen consumption, along with patient perceived exertion with limb length discrepancies greater than 2.0 cm in adults. (16, 17)

In contrast, arthrodesis procedures with interpositional structural bone grafts restore anatomic length. However, disadvantages include variable fusion rates ranging between 58% and 93%, additional bone interfaces that are necessary to heal, slow host incorporation, and the potential for delayed graft collapse. (1,9,24,25)

Procedure

Titanium trusses were manufactured from pre-operative CT scans prior to surgery. Incision planning was based upon the anatomic location of the joint for which the truss was to be implanted. The joints were prepared using standard joint preparation techniques, until all joint surfaces were remodeled, and a healthy cancellous substrate was developed for arthrodesis. Sizers were placed and evaluated under image intensification to ascertain the most appropriate size truss. The selected truss is then packed with the bone graft material.

Methodology

Three patients (patients 1, 4, and 5) underwent implantation of a custom titanium truss at the ankle joint. Patients 1 and 4 underwent the procedure for failed index tibiotalocalcaneal arthrodesis procedures. Patient 5 underwent implantation of the custom truss for a failed total ankle arthroplasty. Two patients (patient 6, patient 7) had standard prefabricated titanium trusses implanted for posttraumatic osteoarthritis and malunion of the subtalar joint. One patient (patient 2) had a nonunion following two attempted first metatarsal phalangeal joint arthrodesis procedures with secondary first ray shortening. One patient (patient 3) underwent a first tarsal metatarsal arthrodesis with implantation of a prefabricated titanium truss for a shortened and elevated first ray.

Financial Disclosures

None

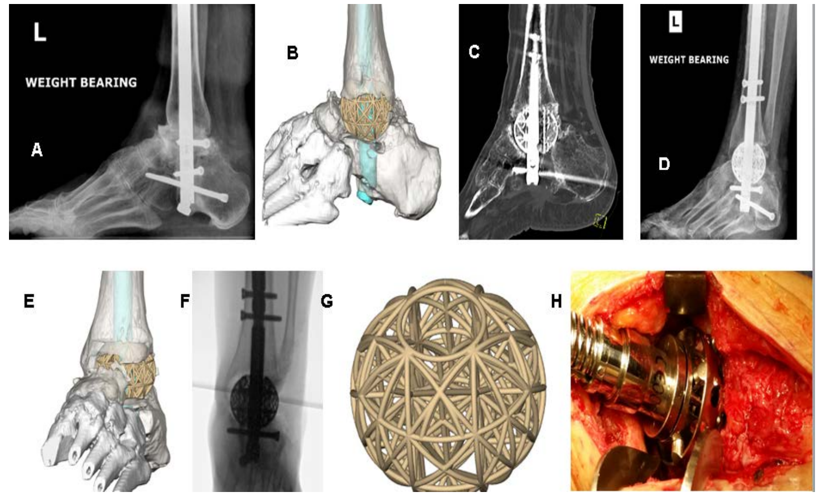

Figure 1. Patient 4 **(A)** Pre-operative lateral radiograph demonstrating the ankle in a rigidly plantarflexed position. **(B)** Schematic of spherical custom titanium truss. **(C)** Sagittal CT scan showing consolidation at 2 months status post-surgery. **(D)** Post-operative lateral oblique ankle radiograph at 10 months status post-surgery. **(E)** Schematic of spherical custom titanium truss. **(F)** Intra-operative image of spherical truss with intramedullary rod fixation. **(G)** Schematic of spherical custom titanium truss. **(H)** Intra-operative photographs of spherical tibial reamer.

	Patient 1	Patient 2	Patient 3	Patient 4	Patient 5	Patient 6	Patient 7
Age	48	33	53	49	46	60	49
Gender	Male	Female	Female	Female	Female	Male	Female
Failed Index Procedure	Tibiotalocalcaneal arthrodesis	First metatarsal phalangeal joint arthrodesis	None	Tibiotalocalcaneal arthrodesis	Total ankle arthroplasty	Treated conservatively with cast immobilization	Subtalar joint arthrodesis
Revision Procedure	Tibiocalcaneal arthrodesis	First metatarsal phalangeal joint arthrodesis	First tarsal metatarsal joint arthrodesis	Tibiotalocalcaneal arthrodesis	Tibiotalocalcaneal arthrodesis	Subtalar joint arthodesis	Subtalar joint arthodesis
Orthobiologics	DBM, allograft cancellous bone chips, autograft from fibula	DBM, autograft from tibia,	DBM	DBM, autograft from talus and tibia, allograft cancellous bone chips	DBM	DBM, frozen femoral head allograft	DBM, frozen femoral head allograft, autograft from tibia,
Follow-up	17.5 months	13 months	12 months	13 months	20.5 months	12 months	14 months
Limb Salvage	Pending	Yes	Yes	Yes	Yes	Yes	Yes
Complications	Non-union of ankle and subtalar joints, hardware failure with break-down of Truss at 14 months post-surgery	Multiple admissions for pain control post-operatively	None	None	None	None	None
Post-operative CT scan	First: Complete union of ankle and subtalar joints at 3.5 months post-surgery. Second: Non-union of ankle and subtalar joints, hardware failure with break-down of Truss at 14 months post-surgery.	Greater than partial fusion at 1 month status post-surgery.	None	No hardware complication	75% fusion at the tibia-truss interface, 50% fusion at the talus-truss interface at 2-months status post-surgery	None	None
Fixation	11 x 200-mm retrograde IM nail with 5 interlocking screw	MTP fusion plate	Locking midfoot plate, 2.7-mm locking screws x3, 3.5-mm non-locking screws x2	11.5 x 250-mm retrograde IM nail with 5 interlocking screws	10 x 150-mm retrograde IM nail with 5 interlocking screws	7.3 mm partially threaded compression screws x 2	7.3 mm partially threaded compression screws x 2

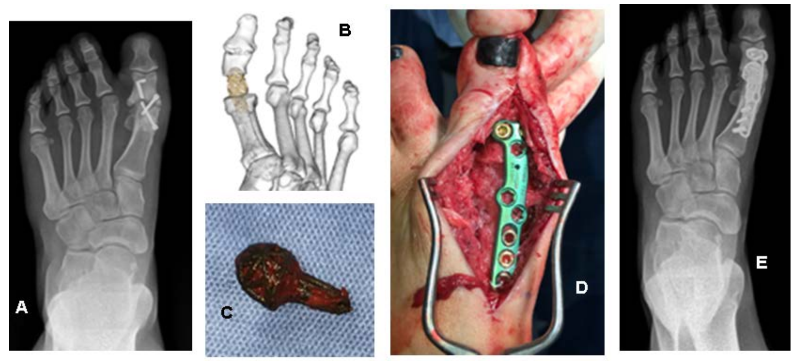

Figure 2. Patient 2 **(A)** Pre-operative AP radiograph. **(B)** Schematic of 1st metatarsal phalangeal joint titanium truss. **(C)** Intra-operative titanium truss with packed bone graft. **(D)** Intra-operative 1st metatarsal phalangeal joint truss with plate. **(E)** Post-operative AP radiograph at 9-months status post-surgery.

Results

Successful arthrodesis with consolidation of the titanium truss occurred in 6 /7 patients (85%). One patient (patient 1) did not achieve successful limb salvage. The patient underwent a tibiotalocalcaneal arthrodesis with a custom titanium truss . A CT scan was performed 3.5 months, and demonstrated near complete consolidation at both the tibial-truss and the calcaneal-truss interfaces. At 14 months status post-surgery, a CT scan demonstrated non-union of both the tibial-truss and the calcaneal-truss interfaces, with lucency and collapse surrounding the intramedullary nail, metallic truss, and distal interlocking screws.

Discussion

Custom or pre-fabricated titanium trusses like those seen in this case series have been used for large osseous defects for arthrodesis procedures within various joints of the foot and ankle, restoring joint congruity with concomitant structural integrity promoting successful consolidation. In this case series, successful arthrodesis occurred in 6/7 patients (85%), making it a viable option for salvage as well as non-salvage arthrodesis procedures with large osseous defects.

Figure 3. Patient 1 **(A)** Sagittal and **(B)** Coronal views of CT scan performed 3.5 months status post revision surgery using a custom titanium truss demonstrates near complete consolidation of the ankle and subtalar joints at the truss-interface. **(C)** Sagittal and **(D)** Coronal views of CT scan performed 14 months status post- surgery demonstrating hardware failure, truss collapse, and non-unions of both the ankle and subtalar joints at the truss-interface.

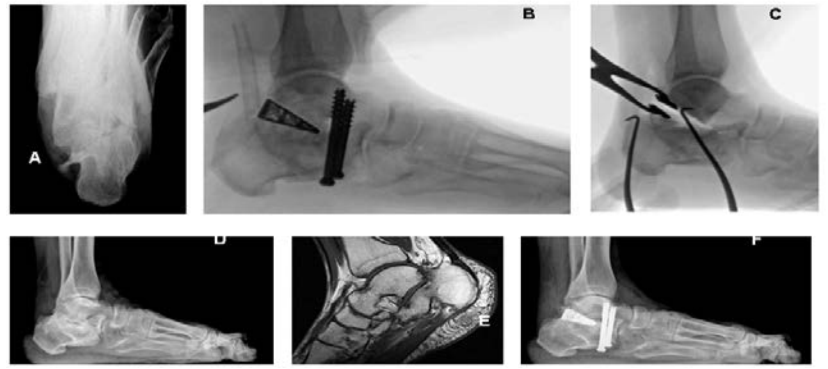

Figure 4. Patient 6 **(A)** Pre-operative calcaneal axial radiograph demonstrating residual rearfoot varus. **(B)** Intra-operative image of titanium truss restoring height of posterior facet of subtalar joint. **(C)** Distraction of subtalar joint prior to insertion of truss. **(D)** Pre-operative lateral radiograph showing depression of posterior facet of subtalar joint. **(E)** Pre-operative sagittal MRI demonstrating subchondral sclerosis of the posterior facet of the subtalar joint. **(F)** Post-operative lateral radiograph at 6-months status post-surgery.

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