CHAPTER 29

Preload Arthrodesis Technique: A Corrected Position, Bone-Preserving, and Realigning Procedure

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INTRODUCTION

Arthrodesis is a durable and reliable means of resolving foot and ankle joint disease and dysfunction. Arthrodesis procedures can be generally categorized by their utility as either in situ or realigning based upon the need to correct deformity. Categorically, realignment arthrodesis is more demanding as it carries the inherent and additional objective of deformity correction. Once joint surfaces are resected, this objective is typically accomplished through additional bone removal. Removing bone twice (during resection and realignment maneuvers) commonly produces untoward and varied consequences of reduced segmental length. Limb and digital length inequality, metatarsalgia and parabola issues, transfer pain, floating or contracted digits, shoe fit issues, and chronic pain are some of the sequelae following significant loss of bone length. Every preserved millimeter of bone length reduces the likelihood of these sequelae.

The purpose of this article is to present a precise, bone-preserving realignment arthrodesis technique that reliably corrects deformity and allows 100% apposition of bleeding bony surfaces in single bone cuts. Likewise, this article will review technique recommendations for specific arthrodesis sites, the background, utility, and detail how this preload technique works.

The term preload, meaning to load beforehand, was selected as an appropriate descriptor for this technique as a whole. The act of preloading refers to the first, most important step of this technique whereby the arthrodesis site is correctly positioned prior to cutting joint surfaces. Simply stated, the preload arthrodesis technique is performed in 4 steps: 1) Placing fusion surfaces in a corrected position (preloading); 2) Minimally cutting reduced fusion surfaces in parallel (sectioning); 3) Removing sectioned surfaces (resecting) and preparing fusion surfaces; and 4) Reducing the resected fusion surfaces for fixation.

The over-riding principle of this technique is to minimally resect joint surfaces based upon a correctly positioned arthrodesis site. Once sectioned, the initial preloaded position immediately becomes the final position with full contact of apposed surfaces. This preload technique is similar to wedge resection, wherein, joint surfaces are sectioned based upon the desired final position, and deformity is corrected in one step (during sectioning) to create en bloc fusion surfaces. Dissimilar from wedge resection, deformity is reduced prior to sectioning and bone length is preserved through narrow parallel bone cuts using this technique. The preload arthrodesis technique differs from other resection techniques wherein deformity correction and fusion site apposition is typically achieved through post-resection (bone removing) modifications.

PRELOAD ARTHRODESIS TECHNIQUE GUIDE

The preload technique is a precise method for performing realignment arthrodesis. Obtaining an initial corrected position and subsequently performing precise sectioning bone cuts (based upon this initial position) are crucial to successfully performing this technique.

Step 1. Preloading

The verbal command of this step is "Put the joint where you want it." Following soft tissue dissection, deformities emanating from the arthrodesis site are preloaded in the correct position for the sectioning phase. All barriers to correct positioning must be nullified prior to sectioning (Figure 1A). The goal of this first step is to obtain anatomic realignment of the arthrodesis site with maximally apposed fusion surfaces. Obtaining the initial corrective load may involve a single plane, manually applied, and manually maintained force or a multi-planar derotation that may be best maintained by temporary reduction pins

Most realignment arthrodesis procedures require multiple corrective maneuvers that are difficult to manually maintain throughout sectioning. Temporary reduction pins are recommended to retain initial correction when addressing multiple joints, multiple planes, and levels of deformity, and sites with significant resistance to reduction. Pinning has proven to be particularly useful when surgical assistants are inexperienced with performing either corrective maneuvers and/or precise sectioning cuts (Figure 1B).

Following application of temporary reduction pins, placement of parallel sectioning guide pins enhance precision during parallel sectioning. Inserted while manually reduced or with temporary reduction pins in place, these guide pins are positioned to mirror the corrected joint line. Each sectioning guide pin (0.8-1.25 mm) is positioned in the same plane of the proposed sectioning cut and 4-5 mm from the terminus of the articular surface. Ideally, each pin

Figure 1A. Lateral bony impingement of the proximal first metatarsal. As a requirement, all soft tissue and osseous barriers to correct positioning are eliminated.

Figure 1B. Use of temporary reduction pins allows unencumbered clinical and radiographic assessment of correct positioning prior to sectioning.

is placed parallel to both the corrected articular plane and the neighboring pin. Intraoperative imaging is then used to assess both correct positioning and sectioning guide pin placement (Figure 1C).

Step 2. Sectioning

Power saw instrumentation is used to create minimal parallel sections of each pre-loaded fusion surface. Sectioning cuts are made parallel to and between the pins. Typically, 2-mm sections are created from the apex of each articular surface. Large foot types, large joint surfaces, and concave surfaces may require slightly wider sections (up to 3 mm) of one or both surfaces. If subtle sectioning errors occur, they are directed towards deformity correction. The preferred result of corrective sectioning is to expose bleeding en bloc bone surfaces for arthrodesis that mirror the corrected joint line, and isolate both the articular surface and the entire subchondral bone plate for subsequent removal.

Throughout sectioning, awareness of the corrected joint line's orientation is imperative. Parallel sectioning may be performed while the joint is manually reduced (using the visibly corrected joint line as a reference) or unreduced (using corrective guide pins as a reference). When using the temporary reduction and guide pin method, sectioning can be initiated with all pins in place (Figure 2). Temporary fixation is then removed, and with fusion surfaces now unreduced, sectioning is completed using both initial bone cuts and guide pins as a reference. Cutting guide pins short to allow for unencumbered use of power instruments is a useful maneuver.

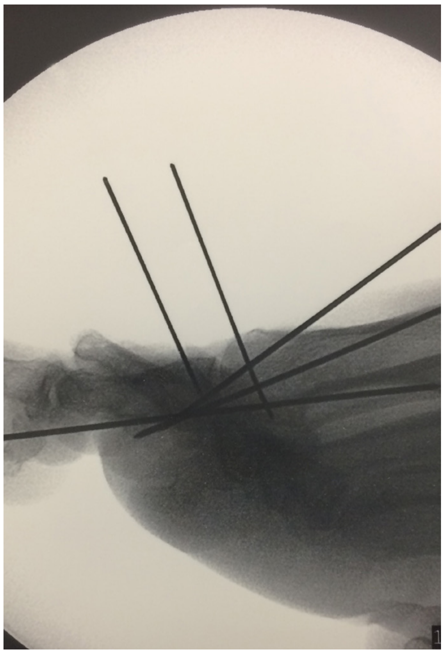

Figure 1C. Sectioning guide pins are ideally placed parallel to the corrected articular plane. Pins may not be exactly parallel, and are used as a reference for sectioning each surface in parallel.

Step 3. Resecting and Preparing

The next step is to resect sectioned surfaces and prepare the fusion surfaces. Removal of intact sections from interphalangeal joint (IPJ) and first metatarsophalangeal joint (MTPJ) fusion sites is performed with simple manual traction. For larger joints under substantial load and those

Figure 2A. Parallel sectioning is initiated with reduction pins in place and performed where excursion and advancement of the saw blade is allowed.

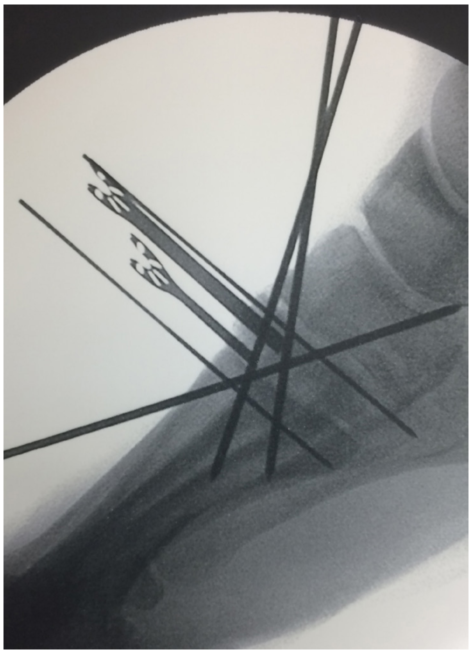

Figure 2B. (C-arm photo). When sectioning longer articular surfaces, initial use of a short saw blade followed by a long blade improves precision. (Long blade is for illustrative purposes only).

with persistent soft tissue attachments or difficult access, use of a specialized joint distractor with 2.0 mm pins is recommended. These pins can be placed at sites where temporary and/or final fixation is planned. When possible, removal of intact-sectioned surfaces is preferred as this allows for evaluation of bone cut precision (Figure 3).

Fusion surfaces are then inspected for exposure of trabecular bone. Residual patches of cartilage (due to articular contours) may be present and are removed using hand or power instruments. Care is taken to preserve bone length and avoid overt gouging. Rarely, when sub-optimal sectioning cuts have been created, a supplemental planar sectioning cut may be required to remove larger surfaces of persistent subchondral tissue.

Provided all chondral elements have been removed, fusion surfaces are additionally prepared by shingling with an osteotome. These actions disrupt the uniform surface created by power instrumentation, assure additional exposure of bleeding bone, and increase exposure of deeper osteocytes to the fusion site. Although thermal injury to bone associated with power instruments appears to be negligible in foot surgery (1), these preparations are also performed with the intent of counteracting potential thermal injury upon surface osteocytes.

Step 4. Reduce Fusion Surfaces and Place Fixation

The arthrodesis site is reduced and temporary fixation is placed. Alignment is then assessed clinically and radiographically. When sectioning is precise, this prefixation alignment mirrors the preloaded position attained in the

Figure 3. Precision of sectioning can be assessed through removal of intact surfaces.

first step with 100% bone-to-bone apposition. Final fixation is then applied (Figure 4).

In cases where the corrected position was not initially attained or sectioning was not optimal, residual deformity or incomplete apposition is noted when provisionally fixated. In these cases, minimal reciprocal planing may be necessary to correctively align deformity or incongruities (2). The temporary construct is taken down, the deformity

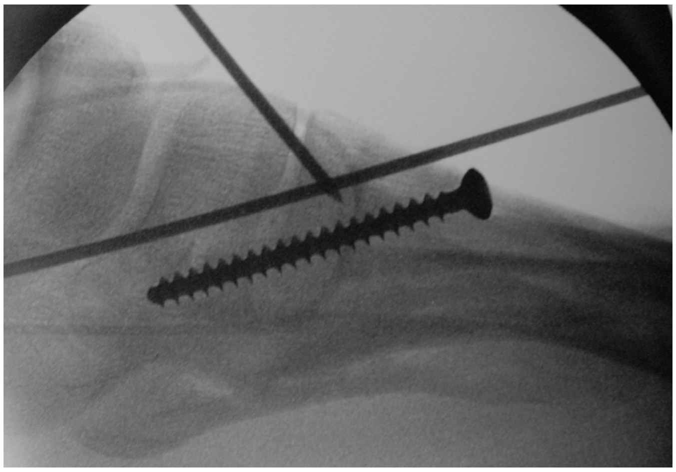

Figure 4A. As most fusion sites are under significant tension, 2-3 points of sturdy temporary fixation are maintained throughout the fixation process to neutralize displacement forces and ensure correct alignment.

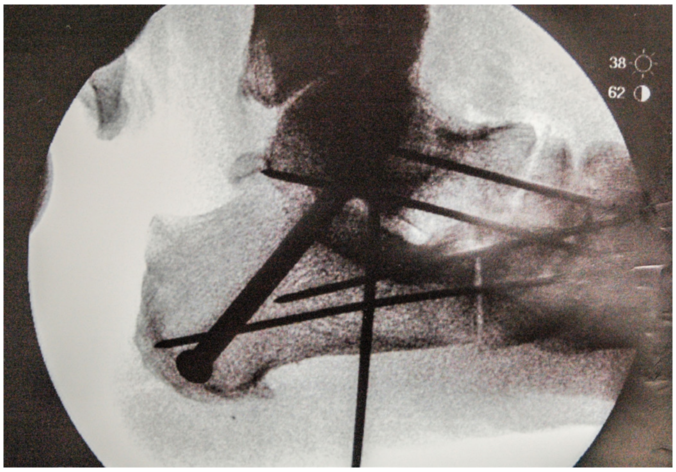

Figure 4B. View of final fixation.

is manually reduced, reciprocal planing is performed, and the temporary fixation construct is reapplied and reassessed.

RECOMMENDATIONS APPLIED TO SPECIFIC ARTHRODESIS SITES

"Putting the joint where you want it," is the key step of this technique, and everything follows from this. As the deformity of each arthrodesis site differs, so do the techniques of preloading. The fundamental technique of preloading is to simultaneously reduce all deformities emanating from the fusion site and to maximally appose articular surfaces. Methods for obtaining the initial corrected position and special considerations for specific fusion sites are detailed below. Based upon preference and exposure, guide pins and sectioning cuts can be performed in planes other than described.

The maneuvers for each fusion site are performed in sequence and then stabilized. Once preloaded and temporary reduction pins/sectioning guide pins are applied, intraoperative imaging is performed to verify alignment. The arthrodesis site is then sectioned, resected, prepared, and preloaded again prior to final fixation.

First MTPJ

Manually reduce the first intermetatarsal angle (IMA), reduce lateral hallux deviation, derotate valgus/varus deformity, and finally correct the sagittal plane. Apply two or three 1.25-mm temporary reduction pins, load the foot plantarly with a plate to assess tri-planar alignment and hallux purchase, and apply parallel sectioning guide pins from dorsal to plantar.

First Tarsal Metatarsal Joint (TMTJ)

This technique is similar to the first MTPJ but it involves the additional physiological load of the windlass mechanism. Utilized to reduce other proximal medial column fusions, this action stabilizes and maximally apposes fusion surfaces in a nonpronated position.

The sequential actions for first TMTJ are to reduce the first IMA, reduce lateral hallux deviation, derotate valgus/varus deformity, and finally dorsiflex the hallux. Placing a circumferential self-adhesive wrap is a useful hand-freeing technique for maintaining reduction of the first IMA. Placed to capture the distal one-third of the metatarsals and to allow for procedural access to the first TMTJ, this forefoot-binding wrap is applied while an assistant manually adducts the hallux and reduces the first IMA. After placement, the hallux is manually aligned as described, and three 1.6-mm first TMTJ temporary reduction pins are used to counteract displacement forces. Sectioning guide pins are driven dorsal to plantar and sectioning cuts are made in the same direction parallel to the pins.

In the very flexible forefoot, significant dorsal excursion of the second metatarsal may be noted during first IMA reduction maneuvers. This is most visibly evident distally, as a pronounced dorsal displacement of the transverse metatarsal arch with the apex at the second metatarsal. This intra-operative dorsal extrusion of the second metatarsal relative to the first metatarsal is both a barrier to first IMA anatomic positioning, and may be associated with recurrent first IMA splaying.

The corrective action is to apply a distal plantarflexory force to the second metatarsal while the first TMTJ is manually reduced. With the metatarsals satisfactorily aligned in the sagittal plane, a basilar first metatarsal to second metatarsal pin is applied followed by placement of first TMTJ temporary reduction pins. Associated with recurrence of the first IMA, supplemental fusion of the first and second metatarsal bases is indicated in this foot type (Figure 5). In addition to this foot type, placement of a basilar first metatarsal to intermediate cuneiform pin and/or a distal first to second metatarsal transverse pin may be a useful adjunct to correct positioning of the first TMTJ. As a matter of sequence and to not impede preloading, these pins are applied while the first TMTJ is manually reduced and fully apposed.

While difficult to quantify, the author qualitatively links sizable dorsal excursion of the second metatarsal as a sign of medial intercuneiform instability. This excursion is discoverable preoperatively in the evaluation of IMA1 reducibility. Intraoperative assessment of medial intercuneiform instability may be verified with the hook test (3).

The hook test is performed after temporary reduction first TMTJ pins are placed, the self-adhesive wrap and first and second metatarsal pin(s) are removed, and a medially directed force is applied upon the distal lateral surface of the first metatarsal. An increase in the first IMA is a positive test and signifies intercuneiform instability. Presumably, this instability occurs due to progressive, chronic attenuation forces of a high first IMA upon the medial and intermediate cuneiform ligament complex. Routine basilar first and second metatarsal fusion (spot-welding) is indicated to prevent first IMA recurrence when intermetatarsal splaying occurs with testing (Figure 5).

Figure 5. Basilar first and second metatarsal pinning is useful to maintain first intermetatarsal angle reduction. Proximal first and second metatarsal fusion is recommended for intercuneiform instability. (Note: Forefoot is bound to support first intermetatarsal angle reduction).

Naviculo-cuneiform Joint

Activate the windlass mechanism and apply temporary reduction pins. Sectioning guide pins are placed medial to lateral, and oriented with a proximal bias to mirror the apposed joint line. Temporary reduction pins are not typically used, but may be helpful when surgical assistants are inexperienced. Importantly, sectioning is inclusive of at least two-thirds of the naviculo-cuneiform joint and is directed proximally to mirror the proximal lateral orientation of the joint.

Triple/Midtarsal Joint

As an overview, due to the contours of the subtalar joint (STJ), parallel sectioning is not utilized at this fusion site. Once the STJ is resected and correctly positioned as described below, the preload technique is applied to the midtarsal joint utilizing parallel sectioning. Contour preserving and in situ STJ resection is performed first and includes removal of both articular surfaces and corresponding subchondral bone plates. STJ correct alignment is performed by optimally positioning the calcaneus under the leg (typically shifted medial for planus and lateral for cavus). Manual reduction of the STJ is stabilized with a single 5/64-inch or 3/32-inch temporary reduction pin driven from the plantar surface of the calcaneus into the tibia. Each MTJ is then preloaded starting with the talo-navicular joint (TNJ). The TNJ is positioned as follows: correct forefoot to rearfoot alignment, the hallux is then dorsiflexed to axially appose and load the TNJ, finally, 1.6 mm temporary reduction pins and medial to lateral sectioning guide pins are applied. The calcaneocuboid joint (CCJ) is positioned to correct forefoot to rearfoot alignment and axially loaded. Temporary reduction pins, and lateral to medial sectioning guide pins are applied. Prior to TNJ sectioning, resecting the navicular's overhanging medial margin is a useful technique to improve visualization of the articular plane. TNJ sectioning, resecting, and preparing is performed first, followed by the CCJ. Once prepared the MTJ is temporarily fixated in the same sequence. Final fixation is applied in the same order (STJ, TNJ, and CCJ).

BACKGROUND, RATIONALE, AND QUESTIONS

The purpose of this article is to introduce a useful realignment arthrodesis technique with multiple applications in foot and ankle surgery. As such, statistical analysis and outcomes of surgical cases are not within the scope of this article. This discussion section reviews the background, rationale and utility of performing the procedure and addresses primary questions about this procedure.

Where did this originate? This preload arthrodesis technique merges several surgical principles gathered and assimilated from the author's training, personal experience, professional mentors, and friends. The principles are old, but their application is new. Motivation towards improving the realignment arthrodesis experience was provided by personal discontent with current resection techniques. The customary approach of resecting joint surfaces in an uncorrected position maintains this position in the resected joint, and dependably dictates the need for subsequent modifications to both correctively align and appose fusion surfaces. Use of this customary approach was found to be unreliable in reproducibly obtaining the right balance of bone apposition, length, and alignment. This history provided personal incentive to pursue other methods.

This preloading realignment arthrodesis technique has been continually performed and refined by the author for varied foot and ankle fusion sites since 2006. Initially performed with manual reduction (4), the addition of temporary reduction and sectioning guide pins (as described here) improved both the accuracy and reproducibility of the preload technique. The addition of windlass activation during sectioning is a new approach applicable to proximal medial column fusions. Aside from this reference and to the author's knowledge, there have been no published reports that describe sectioning of adjoining arthrodesis surfaces maintained in the corrected position.

One published report described the use of first IMA reduction for partial resection of the first TMTJ. In 2014 Klemola et al described a first TMTJ resection technique utilizing a manually reduced first IMA (5). Initially the first metatarsal base was resected without first IMA reduction. First IMA manual reduction was then performed for resection of only 1 surface – the medial cuneiform. Deformity correction was subsequently achieved through frontal plane eversion of the first metatarsal.

How does this preload technique work? In addition to osseous malalignment, articular deformities involve multi-planar and dynamic soft tissue tension that also contributes to malalignment. Fully reducing and apposing the arthrodesis site as a first step, collectively aligns osseous structure and engages soft tissue tension. Sharing features with the Vassal principle in ankle fracture repair, and dependent upon application, corrective soft tissue effects may occur at multiple levels, (i.e., in situ, retrograde, and/or anterograde) (6-9). If the initial preloaded position mirrors the surgeon's desired outcome and parallel sectioning is performed, the initial alignment does not change and will be reproduced in the fixation phase (Table 1).

Reducing the deformity (normalizing anatomy) with fully apposed surfaces is the key step to performing this technique. If you can put it where you want it and cut parallel sections, the preload technique will align segments, appose surfaces, and preserve bone length.

UTILITY AND SUPPOSITIONS OF THE PRELOAD ARTHRODESIS TECHNIQUE

Several parameters for measuring clinical success of arthrodesis procedures are readily achieved through the preload technique (Table 2). As a new surgical approach using minimal resection, there is negligible risk with implementing the preload arthrodesis technique. This technique may be particularly useful to the surgeon who does not have seasoned assistants in the operating room. In addition to preserving length, this technique can be used to shorten bone by simply sectioning larger segments (e.g., when shortening of the first metatarsal is needed to balance the digital and metatarsal parabola). Similarly, this technique is a precise method for performing in situ fusions.

Table 1. Biomechanical effects of preloading maneuvers during sectioning and fixation

- Deformity is corrected at the arthrodesis site
- Both osseous and soft tissues are placed under corrective tension
    - These corrective effects may be retrograde and/or anterograde to the arthrodesis site
- Effects of specific pre-loading maneuvers
    - MTPJ1
        - Manual IMA reduction eases MTPJ1 reduction
        - Corrected MTPJ1 provides retrograde corrective forces upon the IMA
        - IMA1 reduction is maintained following final fixation
    - TMTJ1
        - Combining IMA1 reduction with tri-planar MTPJ1 reduction provides corrective retrograde alignment of TMTJ1 surfaces for sectioning
        - Correct positioning of TMTJ1 along with IMA reduction provides corrective anterograde realignment of MTPJ1
    - TMTJ1/NCJ/TNJ
        - Engaging the windlass mechanism supinates, stabilizes, and maximally apposes the TMTJ1, NCJ, & TNJ surfaces in a non-pronated (and desired) position
    - Triple/MTJ
        - The MTJ is correctly positioned based upon the temporarily reduced STJ

Table 2. Utility of the Preload Technique.

Deformity correction achieved in 1st step
• During sectioning
Minimal to no post-resection modifications
• Bone length is preserved
Uniform exposure of bleeding bony surfaces
100% bone-bone apposition
High rate of fusion & patient satisfaction
Applicable for in situ & realignment fusions
Can be modified to shorten segments
Reproducibility

Admittedly, the author regards certain arthrodesis principles as both axiomatic truths and desirable goals.

Principle 1. Removal of the non-bone forming subchondral plate enhances fusion by exposing bleeding bone surfaces and osteocytes to the entire arthrodesis site. Why should the subchondral plate be removed? Routine resection of the subchondral plate is warranted by its histology. This tissue is not bone, but is a relatively acellular and avascular composite of bone and cartilage. As a non-bone forming tissue, the subchondral plate is an inherent histologic barrier to fusion that not only must be reconciled during the process of healing, but also may inhibit consolidation of the fusion site (10).

How thick of a section is required to remove altogether the cartilage layers and subchondral plate in the foot and ankle? There is a paucity of published information regarding the normal thickness of the osteochondral segment that includes the noncalcified cartilage layer, the calcified cartilage layer, and the subchondral bone plate. Measurement is complicated by many factors including the presence of joint disease, arthritis and osteoporosis, patient size, joint type, joint surface, and the undulating interlocking interface of the subchondral plate itself. Most studies measuring this segment were performed not on normal tissue, but upon patients with joint disease (11-13).

In disease-free joints, the shape of opposing joint surfaces appears to have an impact on the measurable thickness of the subchondral plate. In 1980, using fine detail radiography, Simkin et al (14) measured the subchondral plate in 5 cadavers at 7 disease-free joint sites including the first MTPJ, pretalar, and ankle joints. With the exception of the ankle where the subchondral plate thickness was uniform on both surfaces, they found concave surfaces to have significantly thicker subchondral plates than convex surfaces at all sites. This finding may have surgical implications regarding exposure of osteocytes along concave surfaces.

Histologic measurement is more convoluted. Functionally similar to the shear resistant epidermal pegs and dermal papillae of the epidermal-dermal junction, the subchondral plate is irregularly arranged in crests of bone pegs and troughs of calcified cartilage. At best, subchondral plate measurement is an average of this undulating interface. Only 1 article has attempted to perform histological measurements of the cartilage-bone interface in the foot (10). In their control samples, the measurements obtained for the combined thickness of the noncalcified and calcified cartilage segments were 0.83-mm for first TMTJ and 1.25-mm for the STJ. This thickness did not include the subchondral bone plate. Consequently, if this depth of sectioning were performed, "most if not all of the subchondral plate would remain" (Schuberth JM: personal communication). Anecdotally, a 2-mm sectioning depth from the apex each articular surface has been observed by this author to uniformly expose bleeding bone.

Principle 2. Maximizing apposition of native bone increases the available surface area for fusion and provides the environment for improved fusion rates. Full apposition imparts stability to the construct, and eliminates both surface voids and the need for bone grafting as filler (Figure 6).

Principle 3. Sectioning fusion surfaces to obtain optimal segmental length improves postoperative function. Every millimeter of bone length preserved contributes to reducing the consequences of shortening. For this preloading technique, shortening is abated with single sectioning cuts.

In conclusion, the desirable goals of performing any arthrodesis procedure are correctly aligned and bleeding bony surfaces of optimal segmental length, with 100% bone-to-bone apposition. Attainment of these goals on the day of surgery provides the foundation for good long-term outcomes. The preload arthrodesis technique reproducibly achieves these goals and remains the author's primary method of performing arthrodesis procedures.

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Figure 6A. Uniform and complete bony apposition is an inherent feature.

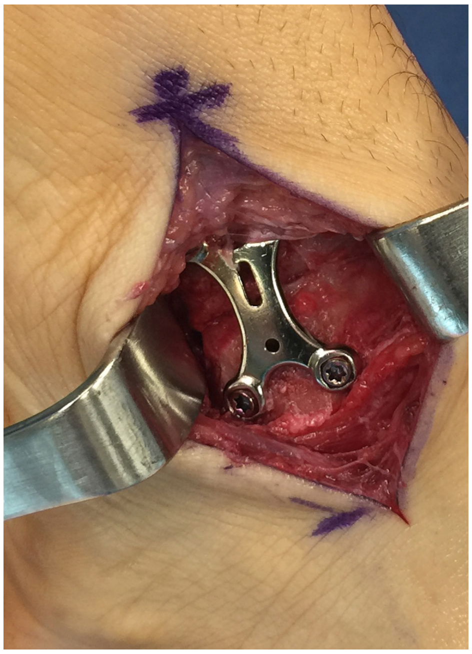

Figure 6B. Uniform bony apposition.

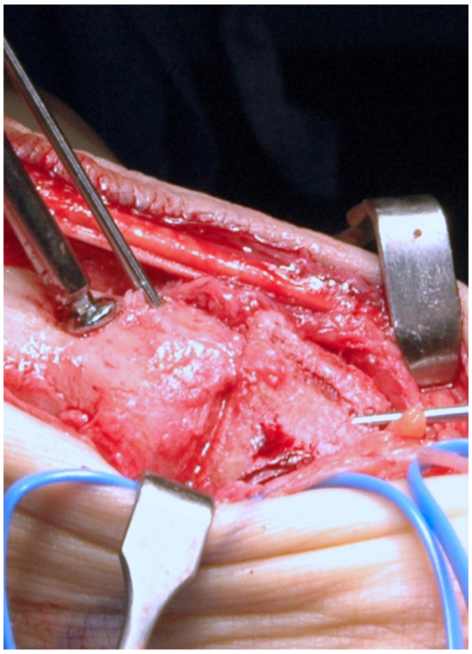

Figure 6C. Complete bony apposition.

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