ANATOMIC APPROACH TO PREPARATION AND FUSION OF THE INTERPHALANGEAL JOINT

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INTRODUCTION

The complex combination of deformities grouped under the umbrella "hammertoes" is a very common complaint seen in foot and ankle clinics across the world. The prevalence of this malady is a function of the number of conditions that can impact either development or function of the lower extremity musculature. Certain genetic disorders can result in digital contracture, as can trauma, infection, arthritis, and neuropathy. While not uncommon, collectively these causes likely contribute to a very low percentage of the overall prevalence of the condition when compared to biomechanical abnormalities of the leg and foot. Despite a more proximal cause, it is the dysfunctional interphalangeal joint that often becomes symptomatic, and therefore is generally addressed in the treatment of the disorder.

Dozens of conservative treatment options are available to those who report the symptoms associated with these digital contractures, including splinting, taping, padding, and modifications of shoegear or activities. However, a large number of individuals fail these measures and eventually seek professional treatment. Very often definitive treatment rests with surgical intervention that is designed to alleviate the contractures and prevent recurrence.

PATHOLOGY DEVELOPMENT CONSIDERATIONS

Upon clinical evaluation, the appearance of "hammered" toes range from mild, fully reducible and only functionally symptomatic to rigidly dislocated, multiple-joint deformities. The compound hammertoe deformity generally begins with soft tissue imbalance of the flexor and extensor tendons as they cross over the metatarsophalangeal and interphalangeal joints dorsally and plantarly. The force exerted by these structures creates a sagittal plane buckling, generally towards plantarflexion at the proximal interphalangeal joint level. The distal interphalangeal joint may either contract into plantarflexion or remain neutral, depending on the long flexor influence. Over long periods of time and after prolonged or sustained contraction of the tendons, other periarticular structures either stretch (dorsally) or contract (plantarly) under this influence. This process of joint adaptation leads to the rigidity seen in many situations. At this point the joint has little movement, and the likelihood of reverting back to normal joint architecture and function even with removal of the deforming influence of the tendons is neglible. This is the basis for functional orthotic failure in treating hammered digits.

SURGICAL MANAGEMENT

The fundamental procedures for addressing hammered toes include arthroplasty and arthrodesis. Generally the choice for one type of procedure over the other rests with the extent of deformity, likelihood of recurrence, patient expectation, and other perioperative factors. Arthrodesis requires more time, dexterity, instrumentation, and manipulation, and that generally translates to a more complicated postoperative course. It is important to know that the joint approach is essentially the same for both, and sometimes a surgical plan is for one procedure and the other is carried out instead, given the common disarticulation technique. Between the two interphalangeal joints of each toe, the proximal joint is more often addressed surgically and therefore the discussion will center on this joint.

The interphalangeal joints are characterized as synovial hinge joints. Structurally, the head of the proximal phalanx is saddle shaped, having a medial and lateral flare to the condyles (Figure 1). The base of the middle phalanx has a

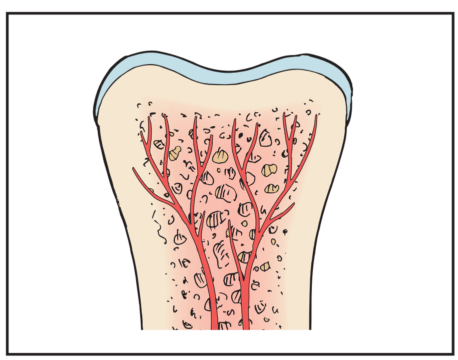


Figure 1. Representation of the head of the proximal phalanx. Note the flare of the condyles and central depression characteristic of a saddle joint.

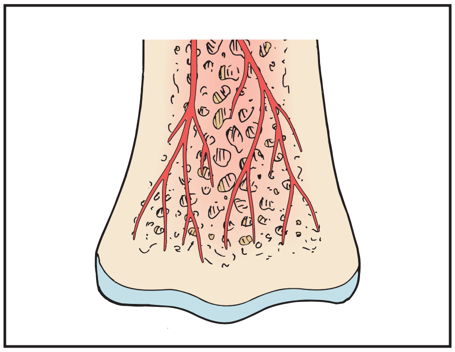


Figure 2. Representation of the base of the middle phalanx. Lateral depressions with central crista for centering the phalanx at the articulation.

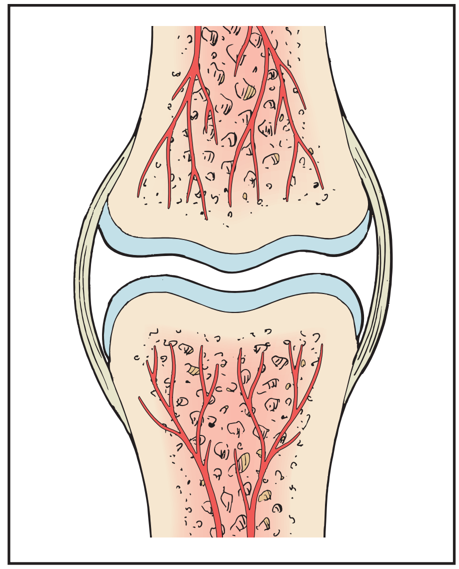


Figure 3A. Collateral ligaments assist in maintaining transverse plane alignment and normal sagittal plane joint tracking.

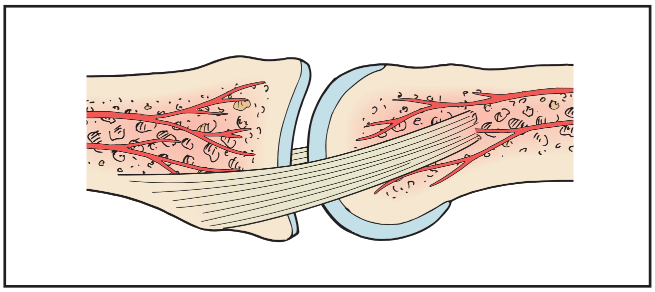


Figure 3B. Collateral ligaments help maintain transverse plane alignment.

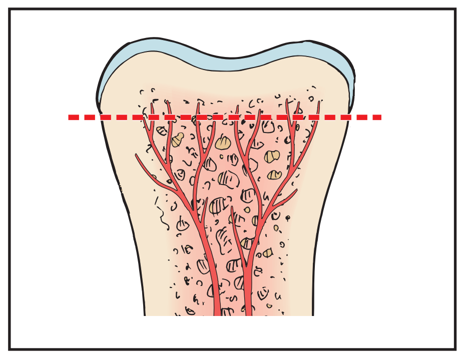


Figure 4. The typical resection includes the entirety of articular cartilage back to the flare of the metaphysis on the respective sides of the proximal and middle phalanges as depicted by the red lines.

central projection that tracks within the groove formed by the proximal phalangeal condyles (Figure 2). This arrangement, along with the presence of a pair of collateral ligaments that run on either side of the joint restricts movement to just the sagittal plane (Figure 3).

Anatomic access to the joint begins with transverse sectioning of the extensor tendon and capsule over the dorsum of the joint. This palpable landmark translates to the proximal ridge of the bone-cartilage junction on the head of the proximal phalanx. The medial and lateral collateral ligaments are then divided, completing the disarticulation and exposing the head of the proximal phalanx. A small amount of further dissection of the capsular attachments and adjacent periosteum may be required for full degloving in preparation for joint ressection. This leaves a small flap of tissue over both the head of the proximal phalanx and base of the middle phalanx. These are usually clamped and retracted with a mosquito hemostat.

Arthrodesis requires cartilage removal from adjacent sides of the joint, removal of the subchondral bone plate, and approximation and rigid fixation throughout the phases of bone healing. When performing an arthrodesis there are a few general principles to follow. First, exposure of the cancellous bone material is critical to fusion. Incomplete tissue removal during the operation is possibly the leading cause of nonunion. However, aggressive bone resection can leave a digit short or render the tendinous structures unable to move the toe, resulting in a flail toe. The digital length should represent a parabola, or unbroken arc with respect to adjacent digits. Second, joint apposition is critical to successful osseous bridging. The prepared joint ends must be in contact, preferably along the entire surface of the bone ends, to achieve fusion. Third, anatomic alignment is important for both function and cosmesis. The fusion should leave the toe neutral on the frontal plane, neutral to slightly flexed on the sagittal plane, and parallel with adjacent digits on the transverse plane. Finally, the choice of fixation must make sound biomechanical sense, maintaining the bone ends in alignment against the two main deleterious forces: distraction and plantarflexion. Use of poor fixation methods or failure to maintain bone apposition for long enough will likely result in postoperative complications.

Traditionally, cartilage resection is carried out with a powered saw or side cutting bone forceps and possibly a rongeur. High speed oscillating and sagittal saws are more commonly used for this procedure. Their use requires careful retraction of neurovascular structures. Since there is no jig or guide to aid the surgeon, the instrumentation demands meticulous positioning of the saw blade in all three cardinal planes when sectioning both sides of the joint (Figures 4- 8). This will ensure precise apposition of the joint ends to achieve fusion. Hand instrumentation is also used to remove the cartilage from the proximal phalanx, as well as the middle phalanx in the case of arthrodesis. A side cutting forceps is used in this instance, and the cartilage and subchondral plate of the phalangeal head is removed piecemeal until the head is fully denuded of cartilage. A rongeur is used on the base of the middle phalanx, in a scraping or gouging motion. Use of this method eliminates the problem of frictional heat generated with high speed saws. The surgeon also has precise control over how much bone is removed, which is especially important in cases of revision and nonunion, where substantial length problems can arise. Hand instruments permit very precise adjustments

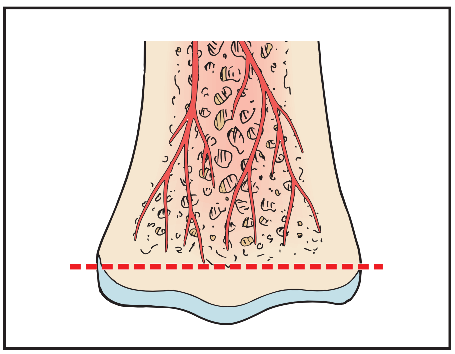


Figure 5A The resection is ideally 90 degrees to the long axis of the phalanx, or to the long axis of the foot if correcting for malunion.

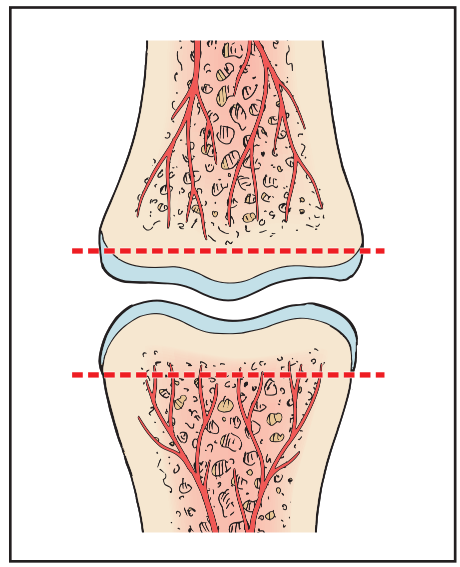
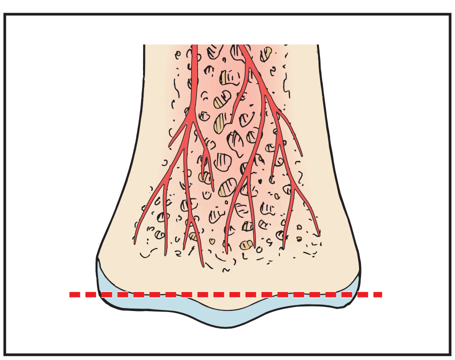


Figure 5B. The resection angle is the same for each phalanx to achieve uniform joint apposition and a rectus digit upon approximation.



Figures 6A. Often, the level of resection is an estimate of the depth of subchondral plate on the middle phalanx. This is due to incomplete visualization of the metaphyseal flare.

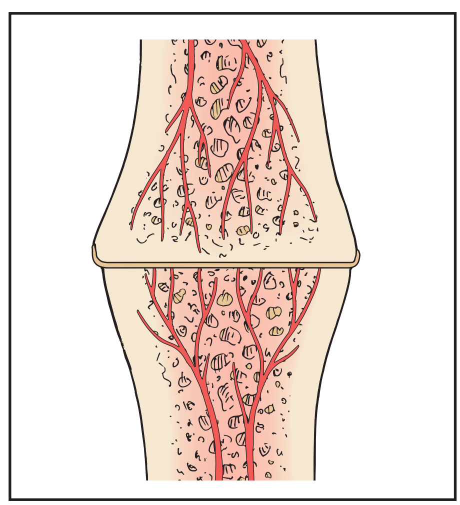


Figure 6B. The resultant apposition after the resection depth of Figure 6A. The intact subchondral plate or remaining articular cartilage will impede full bridging.

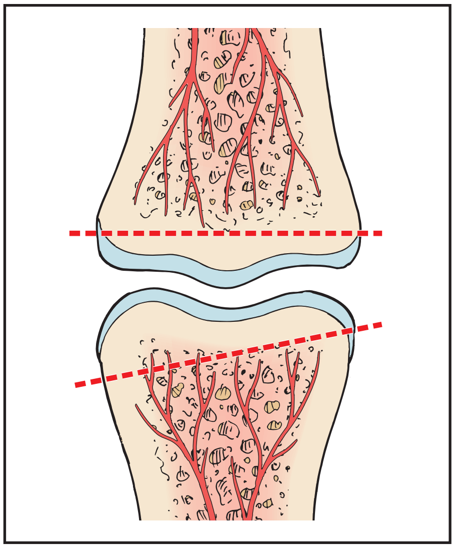


Figure 7A. Deviation of resection angle in the transverse plane can occur on one side as depicted, or to varying degrees on both resection surfaces.

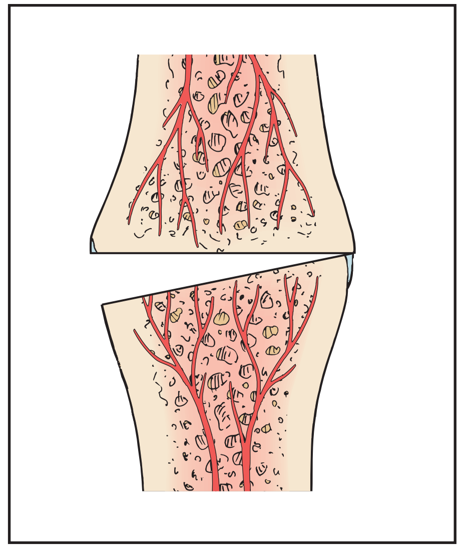


Figure 7B. Apposition of the joint after this type of resection will need revision to achieve uniform joint apposition.

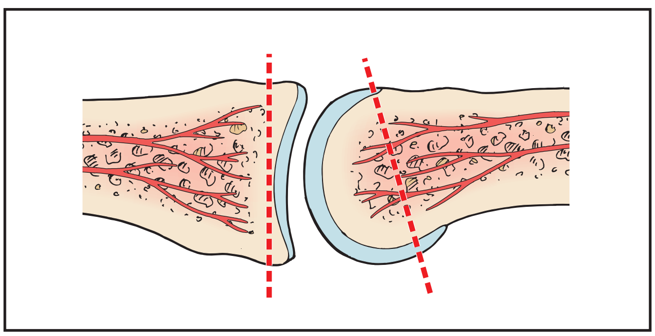


Figure 8A. Deviation of resection angle in the sagittal plane can occur on one side as depicted, or to varying degrees on both resection surfaces.

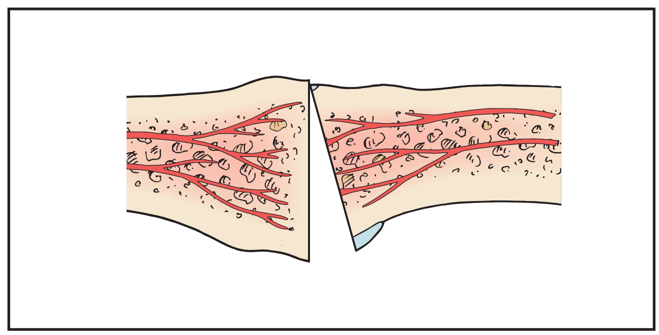


Figure 8B.Apposition of the joint after this type of resection will need revision to achieve uniform joint apposition.

to high and low areas of bone ends that may not be adequately apposed when the joint is fixated (Figures 9-15).

In addition to the technical problems with their use, there are certain deficiencies with these set-ups. Care must be taken with high speed powered saws to minimize prolonged contact with the bone ends and avoid excessive heat generation. This is a function of the relatively large surface area of the side of the blade rapidly moving against the bone surface and generating friction. It is widely known that excessive heat generation can result in bone cell death, and consequently can compromise the intended outcome of the operation. Saw blade depth can also be problematic in the sense that the oscillations carry the square cutting surface through an arc, and consequently the blade edges escape into the soft tissues when cutting the small cylindrical bone.

Hand instrumentation is not without its own deficiencies; the method can be extremely slow due to multiple passes back and forth between the surgical site and a sponge to remove the material from the instrument. In

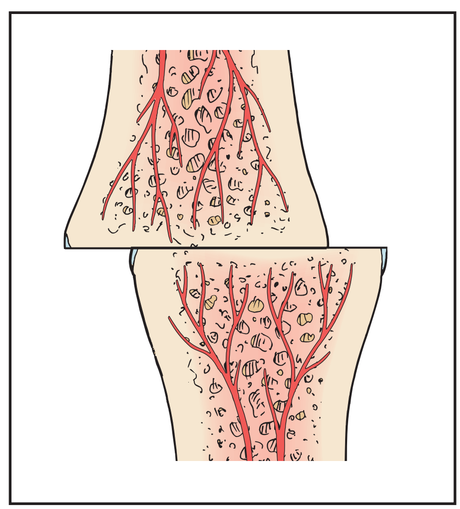


Figure 9. Complete removal of joint surfaces using microsaws leaves uniformly flat surfaces. These can drift, in either the transverse or sagittal planes, or rotate in the frontal plane.

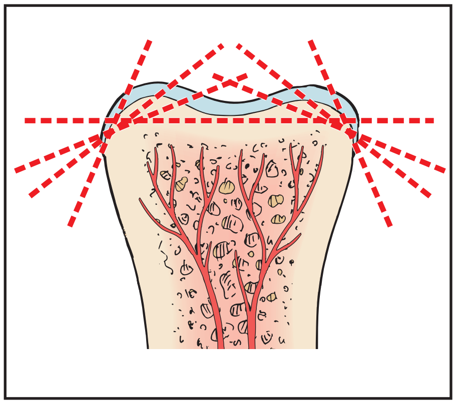


Figure 10A. Anatomic, contoured joint resection of the head of the proximal phalanx.

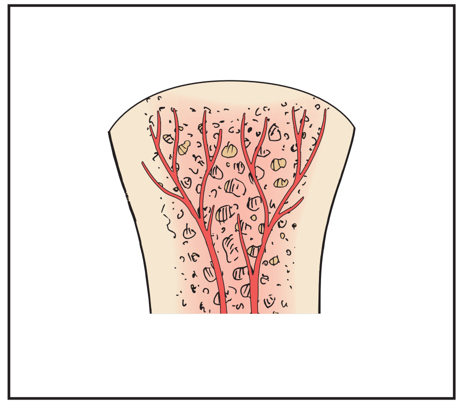


Figure 10B. This technique minimizes bone shortening and increases the surface area available to contact the middle phalanx.

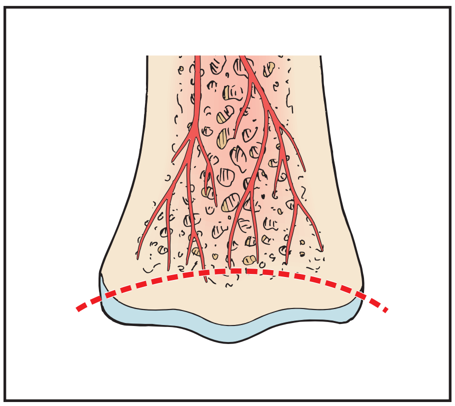
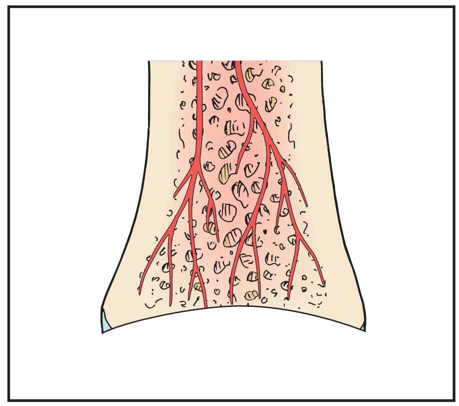


Figure 11A. Anatomic, contoured joint resection of the base of the middle phalanx.



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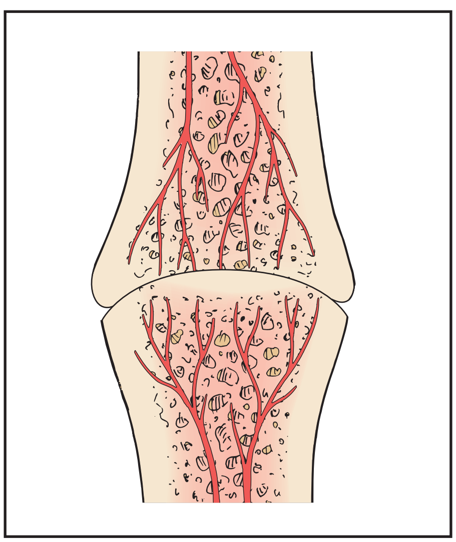

Figure 12. The resultant approximation of the corresponding head and base when the contours are exactly fitted.

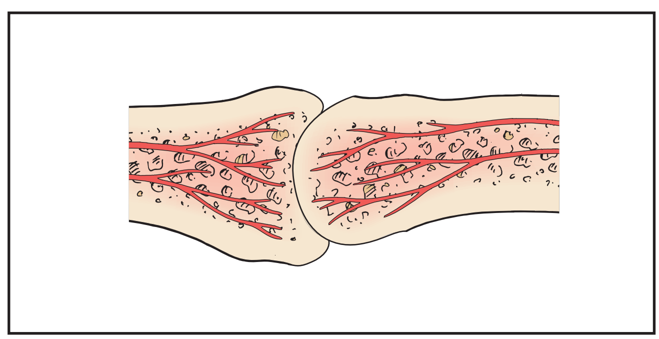

Figure 13. The contoured cup and dome fit allows fine tuning final toe placement on the three cardinal planes, including the sagittal plane for anatomic, flexed fusions.

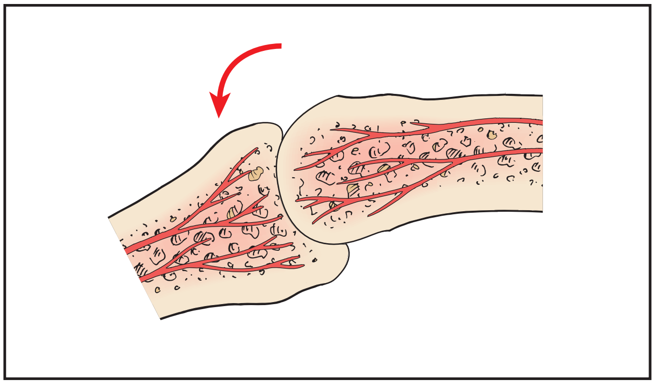

Figure 14. The contoured cup and dome fit.

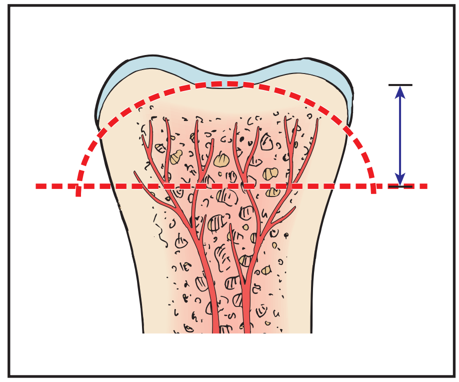

Figure 15. Most digital length is lost in the unnecessarily deep transverse resection of the head of the proximal phalanx. Dome resection of the head of the phalanx achieves the desired tissue removal while minimizing shortening, an important consideration in the maintenance of the anatomic digital parabola and in revision surgery.

addition, the rongeur instrument will often result in incomplete cartilage removal on the middle phalanx, a function of the mismatch between the phalangeal surface and the tip of the instrument. This incomplete tissue removal will lead to osseous union problems.

ANATOMIC APPROACH TO JOINT RESECTION

Joint preparation is very tedious and more often than not imperfect. The ideal operation would be a rapid joint disarticulation, rapid and precise cartilage removal as with hand instruments without excessive soft tissue disruption or heat generation seen with powered instruments, and perfect approximation of the bone ends after cartilage removal. These factors led to the development of a micro-reaming system, one that combines the precision and control of hand instrumentation with the rapid tissue removal of a powered instrument (Figures 16, 17). The instruments reduced operating time, completely and uniformly removed articular tissue, increased surface area of the fusion mass, and reduce total bone loss. The corresponding reamers attach to standard Kirschner wire (K-wire) drivers which run at variable speeds, a function that allows for slow or rapid removal of bone tissue (Figures 18, 19). The devices have a closed periphery, preventing additional soft tissue damage by enclosing the cutting device and restricting tissue removal to the area within a dome. The amount of bone removed can be finely adjusted by the number of revolutions of the cutter on the bone, a function of two variables directly controlled by the surgeon: the speed of the drill and the pressure delivered to the instrument. The dome-shaped cutter leaves behind a rounded edge, eliminating sharp corners in the prepared joint. The instrument also generates very little heat, a function of variable speed tissue removal, extremely sharp cutting edges, and large openings in the cutters to reduce surface area contact of noncutting surfaces with the bone.

Anatomic position is critical to the success of the arthrodesis procedure. One of the drawbacks to traditional powered saws is that the freehand cut on two adjacent bones is not connected. It is difficult to visualize the final position of the fused bones while making the osteotomy without approximating and often fixating the bones together. It is common to take the fixation out, and revise the bone cut in order to gain better approximation of the ends. It is likewise difficult to appreciate the hills and valleys on adjacent sides of the prepared joint until the ends are brought together. The dome reamer eliminates this problem. The corresponding cup reamer creates a recess in the middle phalanx with specific geometry for the reamed proximal phalangeal head to seat in. The concavity is just fractionally larger than the convexity. This permits the surgeon to place the toe in any position and have direct contact of bone ends. The process of fixation-assessment-revision-refixation is then avoided, since use of corresponding reamers will always result in direct and complete apposition of bone ends.

The cutting portions of the reamer sit behind a leading trocar-pointed segment of wire. This lead serves three purposes; first, the trocar pointed segment leads the cutter down the medullary center of the cylindrical bone, thus the device is self-centering; second, the lead steadies the bone and the reamer such that when the cutting device actually contacts and begins reaming, the assembly is stabilized against bending and slippage; and third, the pointed lead also predrills for intended fixation, leaving behind centrally located corresponding holes in both the proximal and middle phalanx for placement of fixation.

JOINT FIXATION

The standard technique for interphalangeal joint fixation involves the use of K-wires, placed from within the prepared joint, exiting the toe, then retrograded back into the base of the proximal phalanx. Wire fixation is made easier by predrilling a hole in the proximal phalanx prior to retrograding the wire. This maneuver will centralize the middle phalanx on the proximal phalanx when the bones are approximated as stated above.

The reamer instruments are affixed to a bore of the same dimensions as a traditional K-wire. This bore is the coupling that allows the cutter to connect to the myriad of standardized power instruments. This bore also provides the user with a built in fixation device, once the cutting section of the wire is removed. The remaining wire is the exact diameter of the lead that has already predrilled the bones. Consequently, the surgeon has in his hand a single instrument for cutting and fixating a digital arthrodesis.

CONCLUSION

Digital arthroplasty and arthrodesis are among the most commonly performed operations in foot and ankle surgery. The surgical technique has remained relatively unchanged for many years, despite the fact that the majority of the healing complications are a direct result of poor joint preparation. The benefits of contoured resections of the ankle, subtalar, talonavicular, first metatarsophalangeal joint, and interphalangeal joints have been described in the literature. However, given the inherently rapid nature of the operation on interphalangeal joints contoured resections at this level are not commonly performed, and when they are performed they are imperfect due to the inherent nature of the instruments utilized. A great deal of attention is directed at fixation methods for this procedure, although the ability to enhance fusion rates and patient satisfaction may simply lie in more careful, anatomic preparation of the joint surfaces.

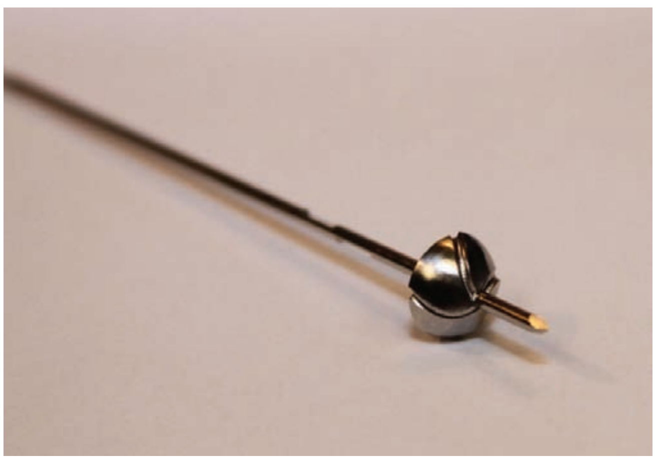

Figure 16.

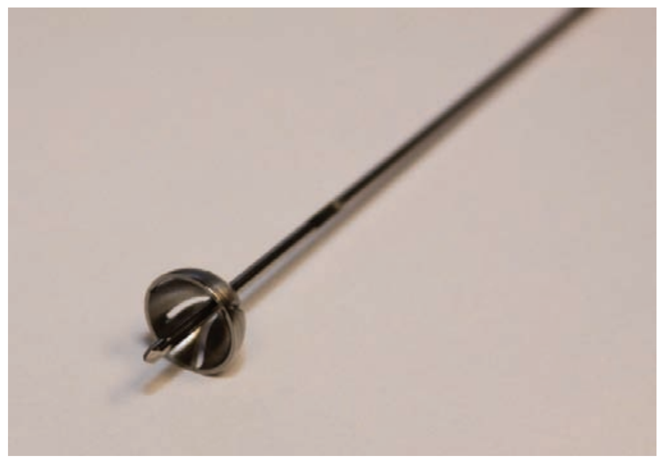

Figure 17.

Figure 18.

Figure 19.