CHAPTER **33**

TENSION BAND PRINCIPLE IN FOOT AND ANKLE SURGERY

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INTRODUCTION

Tension Band Principle: It is a device that will exert a force equal in magnitude, but opposite in direction, to an applied bending force.
Orthopedics Traumatology – A Resident's Guide, 2006.

The concept of tension bands and the tension band effect in foot ankle surgery impacts not only the forces within a particular fixation construct, but how external forces such as weightbearing and movement will impact the fixation construct. A tension band is not in actuality a specific device, but more a principle that produces an effect of compression from distraction. The tension band concept was introduced in surgery in the 1930s by Pauwels, but has been understood by engineers for much longer.

The tension band can be a useful tool within internal and external fixation constructs themselves by converting harmful distraction forces created by eccentric compression fixation into more useful stabilizing compression forces. It can likewise be employed to create compression out of external weightbearing or joint movement forces of distraction into more stabilizing compression forces. A lack of understanding of either of these two types of tension band effects can result in the loss of an opportunity to enhance or create the desired fixation effect. A review will be presented here of what best may be termed the tension band effect or principle in foot and ankle surgery fixation applications. Understanding this principle and its practical application can help enhance bone fixation stability as well as help avoid the potential for instability.

DEFINITION

A tension band is a simple machine that converts a distraction force into a compression force. The classical example is the boom construction crane with an eccentric load or a load picked up or applied off center from the vertical support superstructure. If one pictures a crane at a construction site with a long boom with a hoist at the end, the load to be lifted pulls down on the boom at a distance away from the support structure that is fixed to the ground. Since the load is being lifted away from the vertical support structure, it is termed an eccentric load. That would be in distinction to an elevator lifting a load within the support structure itself as a centric load (Figure 1). As the load is lifted at the end of the boom, a compression force occurs at the underside of the boom and a distraction force at the top side of the boom to the point of breaking the boom by pulling it apart at the top surface (Figure 2).

In order to add strength to the boom, a reinforcing wire is run from the upper tip of the boom at the crane end over a post to elevate it from the boom to the opposite end of the boom near the supporting structure. As the load is lifted, this reinforcing wire converts the distracting force at the top of the boom surface into a compressing force through the entire boom, allowing more load to be lifted than would otherwise be physically possible. That reinforcing wire is a tension band (Figure 3). The plantar fascia can be considered to function as a tension band in weightbearing through what has been termed the windlass mechanism. As the foot bears weight, the plantar fascia prevents plantar joint gapping by converting this distracting joint force to a compression force through the arch bone structures and joints aiding overall foot stability in gait.

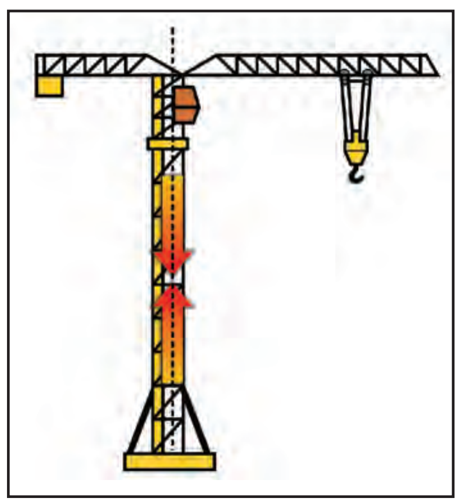

Figure 1. A centric load is like an elevator within an elevator shaft where the load lifted is in direct line with the support structure. The arrows of force and counter force are collinear in opposite directions.

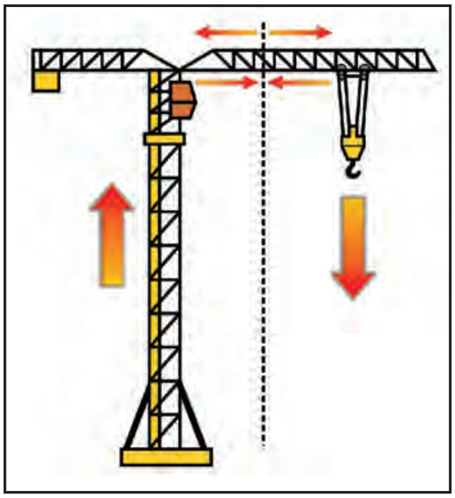

Figure 2. An eccentric force is one where a given distance exists between the two opposing forces such as on a crane. A boom of given thickness joins these two forces and is acted on by them. The forces can break the boom by pulling it apart on the top surface and crushing the under surface.

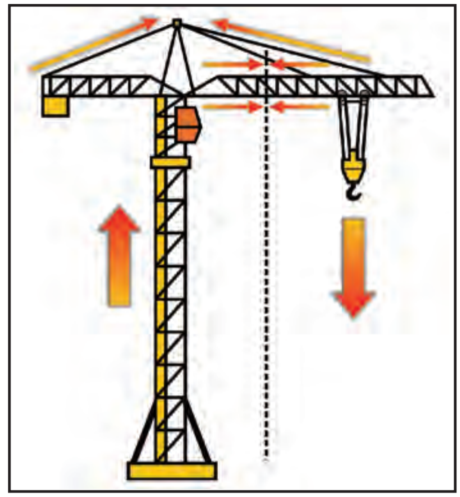

Figure 3. By adding a wire system over a pole on top of the boom or a tension band, the forces of distraction on the top of the boom are assumed by the wire, converting the forces on the top and bottom of the boom itself into compression.

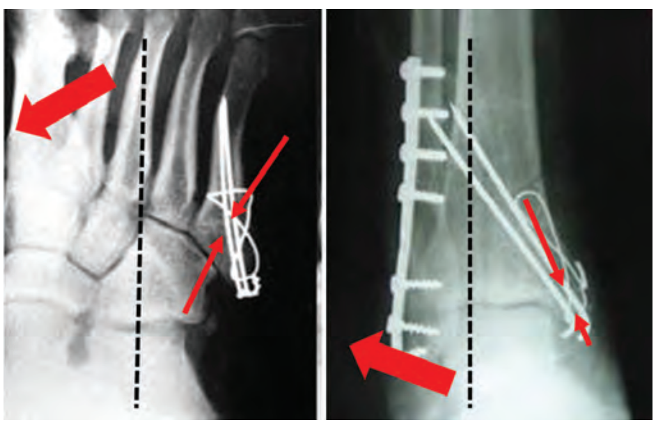

Figure 4. Examples of classic tension band principle application in foot and ankle surgery with figure-of-8 wire and parallel pins. The construct only truly functions as a tension band when external forces are applied as through gait with weightbearing or active physical therapy.

The classic tension band in foot and ankle surgery is the two-parallel pins and figure-of-8 wire construct applied to smaller distal tibial malleolar fractures or small fifth metatarsal styloid fractures (Figure 4). This fixation construct is actually a dynamic not a static system, converting the unwanted force of distraction of the fragments with foot and ankle inversion into the desired force of compression. The 2 pins of the construct have multiple purposes. They first provide stability for the fracture fragments countering side-to-side or rotary displacement that a single pin would not.

Secondly, they are purposefully directed parallel to permit the possibility of movement or force of compression from the tension band. If they were not parallel and placed crossed, then the effect of compression would be negated. They finally act as an anchoring point for the figure-of-8 wire component that actually creates the tension band effect. The wire is placed over the outer surface of the bone to place it as far from the point or axis of inversion bending force and movement as possible, much like the pole of the crane boom reinforcing wire. The figure-of-8 wire is anchored proximally through a transverse drill hole in the bone or suspended on a hanging screw.

It is more desirable to have the transverse line of the wire passing through the osseous tunnel proximally on the same plane and parallel with the transverse plane of the entrance points of the pins distally on the fracture fragment. If the line of the proximal bone tunnel exit points is not contiguous and on the same plane with the line of the pin entrance points, then an undesired twisting or torque effect with the compression effect can occur. Once the construct is completed at the distal tibial malleolus and a force of inversion is applied to the ankle, the distraction that would occur at the outside margin of the fracture site without this fixation in place is converted to a compression force along the pins by the figure-of-8 wire. The same could be said of the fifth metatarsal styloid tension band construct with inversion or adduction force through the mid-foot. Weight-bearing or natural foot movements are the forces acting on the bone segments to separate them converted to compression by the tension band. The fixation within itself does not produce compression on its own. There would be no tension band effect in these two examples with the foot and ankle immobilized in a cast, it would occur during physical therapy movements or gait.

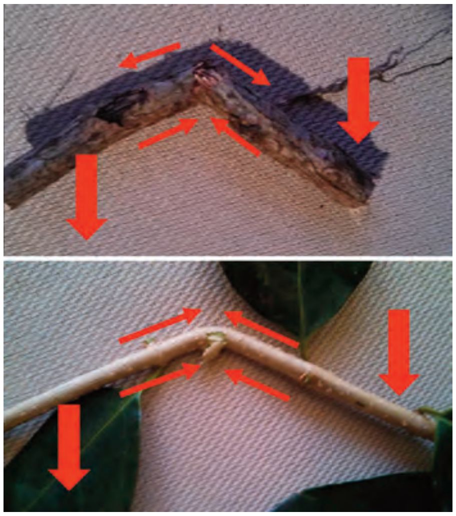

Figure 5. Simple examples demonstrating the tension band principle where the above dry and brittle stick breaks apart at the top when an eccentric force is applied. Below the green stick remains intact on top acting as a tension band crushing the wood beneath with compression throughout.

These construction crane and parallel pins with figure-of-8 wire are classic tension band constructs in industry and surgery for the purpose of creating compression from distraction applied by outside forces. In foot and ankle surgery there are many potential opportunities made or lost where the tension band effect not necessarily a specific tension band construct, can be applied and exploited enhancing fixation within the actual construct of the fixation itself. The compression achieved through the tension band fixation construct itself will occur, even in a cast, as it is intrinsic to the fixation system.

The most practical example of the tension band effect is to consider comparing breaking a live green tree branch over a knee as opposed to a dry dead branch (Figure 5). The dead branch will break splitting apart on the far side of the branch away from the pressure of the knee. The eccentric load is applied by the hands on either side of the knee at the ends of the branch. On the other hand, the green tree branch will not break apart. The wood on the far side from the knee that would typically break apart if the branch were dry and dead, remains intact. This intact wood then causes the wood near the knee to compress and crush in on itself from the eccentric load applied by the hands away from the knee. The outer intact layer of wood is acting as a tension band converting the distracting breaking force on the outer side away from the knee to a compression crushing force on the inner side closer to the knee.

The tension band effect then can be applied to foot and ankle surgery within a fixation construct in side-bending situations to create stability where stability may have been compromised or requires enhancement. Torque, compression-distraction, and translocation forces on bone fragments are generally countered through other fixation techniques only aided by tension band effects.

For a tension band system to function, certain prerequisites in terms of the bone quality and fixation device integrity must exist. First, there must be intact cortical contact on the side opposite the tension band strong enough to accept compression and not collapse. The fixation system employed must be able to withstand the tensile forces that will be applied to convert them to compression forces. Finally, the bone contact surfaces must have enough integrity and be oriented in such a manner to accept the compression the tension band will create.

HINGED-OSTEOTOMIES

The hinge on an osteotomy serves a number of useful functions. It acts as a point for movement of the osteotomy directing that movement in a specific desired direction. The hinge movement is specifically predicted and directed, facilitated by the surgeon accurately following a hinge-axis wire guide as the osteotomy is cut. Any inaccurately directed forces or motions on the bone segments counter to the intact osseous hinge can result in hinge breakage and compromise. The osseous hinge may be compromised through other means such as over-feathering to encourage movement, repeated manipulations, or poor bone quality. Secondly, the hinge of an osteotomy can serve as a supplemental point of fixation. If intact and strong, along with a second point of fixation such as a pin, wire or screw, a stable construct can exist, resisting movement or displacement in multiple planes.

Finally, the hinge of an osteotomy can be considered to act as a tension band. Consider a transverse Akin osteotomy of the proximal phalanx of the hallux with a broken lateral hinge, unknown to the surgeon (Figure 6A). A unicortical wire loop is placed medially to close and fixate the osteotomy, and then twisted for compression. A side-bending force has been applied or an eccentric load to the osteotomy. With the lateral cortical hinge compromised, gapping will occur on the lateral side as a compression force is applied to the medial side of the proximal phalanx. If the lateral phalangeal hinge remains intact, a tension band effect occurs where the gapping or distraction effect is converted to compression (Figure 6B).

As compression through unicortical loop twisting occurs on the medial side, the distracting lateral force will be converted to compression across the osteotomy by the tension band effect of the intact lateral hinge. An intact

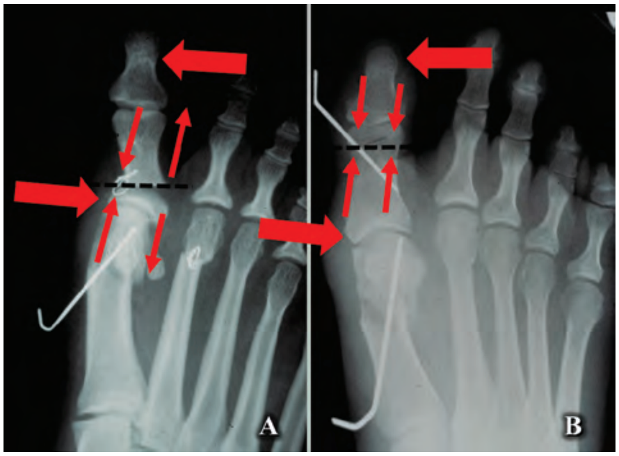

Figure 6A. Medial unicortical loop fixation of a proximal Akin osteotomy with a compromised hinge and distraction of the osteotomy. B. Single pin fixation of a distal Akin osteotomy with an intact hinge acting as a tension band with compression across the osteotomy.

osteotomy hinge then not only adds stability and predictable movement, but based on the orientation of the fixation, can add compression across the osteotomy through a tension band effect within the fixation construct itself. This same response of cortical gapping at a compromised hinge can be observed in oblique Akin osteotomy orientations that permit application of compression screw fixation. As long as the dynamic force of compression is applied in an eccentric fashion, which almost always occurs in surgical applications, the possibility of gapping one side while compressing the other exists. This effect of hinge compromise affecting osteotomy compression through loss of its function as a tension band could be seen in any transverse or oblique osteotomy in foot and ankle surgery. If the potential gapping with hinge loss can be stabilized or neutralized before the compression force is applied, the tension band effect may then encourage compression over distraction. If an osteotomy hinge breaks, not only is stability compromised, but the application of eccentric loading with compression fixation can be counterproductive.

THROUGH-AND-THROUGH OSTEOTOMIES AND ARTHRODESES

A through-and-through osteotomy, just like an arthrodesis can be considered to act in terms of response to eccentrically applied compression fixation much like a hinged osteotomy with a broken hinge. In essence a more unstable situation intrinsically exists in the absence of an intact osseous hinge in through-and through osteotomies or joint arthrodesis as well as the inability to employ the tension band effect with a single fixation device.

Consider an interphalangeal joint of the hallux (HIPJ) arthrodesis with classic linear percutaneous single compression screw fixation. A compression screw, appropriately applied, directed linearly from distal to proximal across the HIPJ arthrodesis site, is both centrally applying compression, not eccentric, as well as is oriented perpendicular to the arthrodesis site. The compressive force is ideally located centrally providing compression evenly throughout the arthrodesis site much like the elevator lifting a load within the tower of the crane example discussed earlier. The force is acting perpendicular to the arthrodesis site not applying any angular compression force effects that could distort or shift the segments as compression is applied.

Such compression applications both centrally applied and perpendicular to the surfaces to be compressed, unfortunately rarely occurs in foot and ankle surgery applications. Typically compression devices from screws to external fixation devices are off center or eccentric in compression load application as well as not perpendicular to the surfaces to be compressed. The opportunity for tension band effect optimization then can be employed respecting the need for two points of fixation and guarding against unwanted migratory movements as compression is applied. Consider the HIPJ arthrodesis and applying an external fixator for compression fixation on the medial side. The compression to be applied is now eccentric not centric as the percutaneous screw. As compression is applied medially, there is the possibility of gapping the lateral aspect of the arthrodesis. This lateral gapping effect could be countered in a number of ways to compression effect by application first of a tension band opposite the external fixation device on the lateral side.

If a staple were driven first on the lateral side, then as eccentric compression was applied on the medial side, the staple would act as a tension band converting the distraction force into compression. A tension band-like effect or more of a central load effect can be aided by directing the pins of the external fixation device through-and-through the bone segments applying force then more evenly at the site to be compressed.

A similar situation in foot and ankle surgery can occur in fixation of the calcaneocuboid joint (CCJ) and talonavicular joint (TNJ) of a triple arthrodesis with staples at the CCJ and compression screws at the TNJ. If the CCJ is fixated first and stabilized with staples laterally, as the compression screws are applied to the TNJ medially, the staples will act with a tension band effect laterally encouraging compression across both joints from the eccentric positioning of the medially located TNJ compression screws. Within the fixation construct itself, a tension band effect was created (Figure 7).

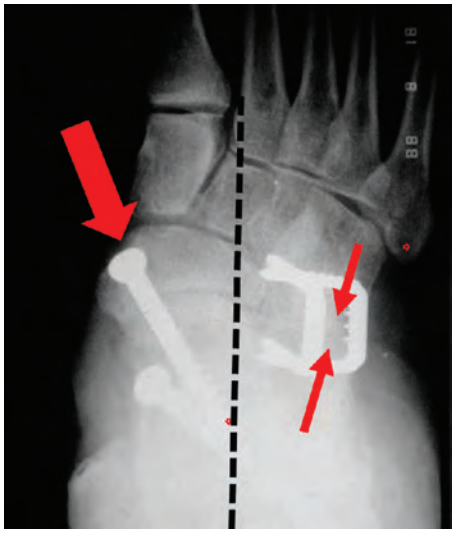

Figure 7. Compression Fixation Force as Eccentric Load. If the staples in this example were placed laterally first at the calcaneocuboid joint, then as compression is achieved with a partially threaded compression screw eccentrically placed medially, the staples will act not only to stabilize the fixation construct, but promote compression acting as a tension band.

Preserving an intact osseous hinge to an osteotomy adds not only stability as a point of fixation to the construct, but encourages more even application of compression with eccentrically applied compression fixation as a tension band. If an osteotomy hinge is lost, the beneficial effects of stability and compression provided to the construct are likewise lost and may be possibly compensated. An additional second point of fixation, such as adding a pin, staple, or wire loop with a compression screw, aids stability against displacement. If the pin, staple, or wire loop could be placed first and in such an orientation to act in place of the lost hinge as the eccentric compression of the screw is applied, then compression over distraction may be achieved as well within the fixation construct itself. If the osseous hinge is lost, a bicortical loop wire fixation perpendicular in either orientation to a transverse osteotomy or in an arthrodesis situation may be a consideration as opposed to two separate fixation devices. The through-and-through effect of the bicortical loop stabilizes the far side of the bone segments as it is twisted and tightened on the near side creating a tension band effect through the fixation itself from the far side. The stability of the loop could be enhanced by a supplemental pin as a second point of fixation.

WEIGHTBEARING

A bicortical loop can act as a tension band providing stability as well as compression as a primary form of fixation against the external forces of weightbearing. An example is a transverse lateral hinge tailor's bunion distal fifth metatarsal osteotomy with bicortical loop fixation (Figure 8). The wire loop is placed transversely proximal and distal to the osteotomy from the lateral side then twisted and tightened on the medial side. The loop is centrally located on the bone from dorsal to plantar. As weightbearing occurs, the loop acts as a tension band converting the plantar distracting forces to compression above the point of the fixation enhancing both construct stability and compression.

Other examples of tension band effects in foot and ankle surgery involve similar situations of attempting to convert plantar distraction or gapping weightbearing forces to compression. One of the two crossing screws of a Lapidus first metatarsocunieform joint arthrodesis are placed to cross more plantar to not only counter the potential for distraction with weightbearing, but convert it to compression. Similarly at least one staple of a staple fixation construct of a first metatarsophalangeal joint or CCJ arthrodesis are kept low to counter distraction and encourage compression with weight-bearing eccentric forces. Here the weight-bearing forces are the eccentric load. As has been discussed, the compression screws themselves can be considered the eccentric load as well. Either or both situations of weightbearing or the fixation itself, can involve a tension band effect that can exist alone or together. This distinction and awareness is important; that the compression devices themselves as well as weight-bearing forces can apply an eccentric load resulting in distraction forces on the fixation construct, which can be enhanced by countering these two distinct types of distraction forces converting them to compression (Figure 9).

The anatomical and practical restrictions of plantarly placed fixation as opposed to dorsally placed fixation as in tarsometatarsal joint or metatarsal plating applications that would more effectively counter weight-bearing forces are well known. Possibly use of a simple stapling type system plantarly could enhance dorsally placed fixation with a tension band effect countering weight-bearing forces.

A challenge exists in applying compression fixation forces to oblique osteotomy or fracture orientations without causing displacement of the bone fragments and inadvertent mal-alignment as the compression forces cannot always ideally be applied perpendicular to the osteotomy in all planes. Fractures are reduced with anatomical alignment;

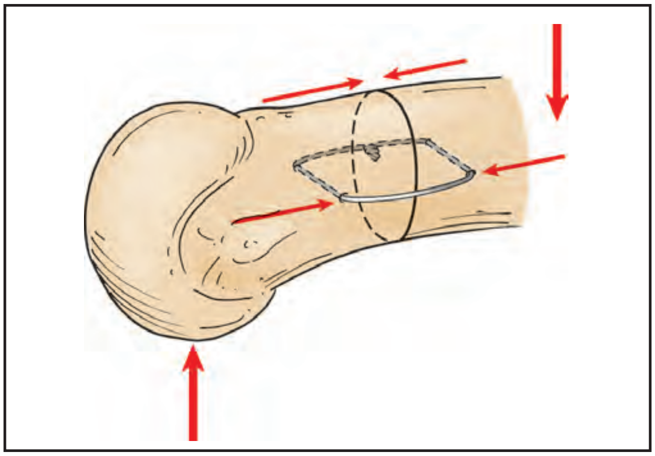

Figure 8. Weightbearing Force as Eccentric Load. A horizontal bicortical loop fixation of a tailor's bunion osteotomy acts not only as a good stabilizing force against transverse plane displacement where a weak hinge may exist, but acts further as a tension band converting sagittal plane plantar distraction forces to compression forces from the plane of fixation to the dorsal cortex.

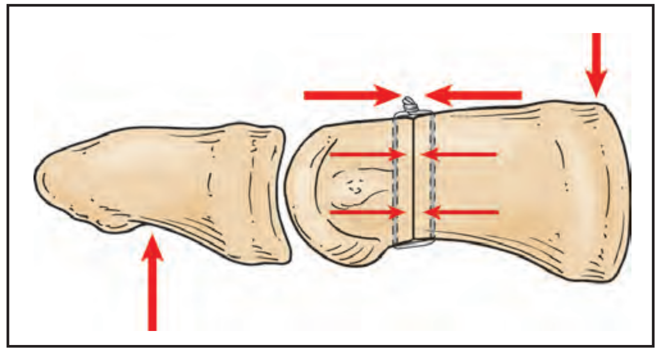

Figure 9. Combination Compression Fixation and Weight-Bearing Forces as Eccentric Load. Example of a vertical bicortical loop fixation of a distal Akin osteotomy. As the wire is twisted and tightened, transverse plane, internal compression against an intact hinge creates compression across the osteotomy within the fixation construct. With weightbearing, sagittal plane, plantar, external distraction forces are converted to compression force throughout the osteotomy.

osteotomies intentionally create mal-alignment of the bony segments. Applying fixation to osteotomies then is generally more challenging than fracture fixation. This mal-alignment effect is countered by placing an anchor screw. An anchor screw is directed perpendicular to the bone crossing the shortest distance across the bone. Applied in this manner, this particular screw counters linear movements of distraction or shortening as the remaining compression fixation is placed or weight-bearing forces are applied. As the remaining screws are applied or in weightbearing, this anchor screw acts with a tension band effect encouraging compression from distraction or other migratory movement forces that can occur at the osteotomy or fracture interface. This effect can be accomplished as well with cerclage wire.

This concept is an important component of the two screw fixation of the oblique base wedge osteotomy in hallux valgus surgery where one screw is first placed as the anchor screw perpendicular to the bone and the second as the compression screw more perpendicular to the osteotomy. Compression without fragment migration is countered both as the force compression fixation is surgically applied as well as when weight-bearing forces are applied.

SUMMARY

The tension band and tension band effect through both compression fixation constructs and weight-bearing forces are important for the foot and ankle surgeon to appreciate. Optimizing their effects can enhance fixation constructs, overlooking and not recognizing their impact can adversely impact bone segment stability. A review of the tension band and the tension band effect has been presented to hopefully enhance the understanding of these principles for the foot and ankle surgeon.