THE BONE STAPLE:
Tried and True Superhero of Bone Fixation

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INTRODUCTION

Faster than a self-drilling and self-tapping screw!
Able to leap fractures and osteotomies at a single throw!
Is it a 2-Hole Locking Plate?
Is it 2 Joined K-Wires?
No…
It's Bone Staple!

A bone staple is conceptually a single fixation device made up of 2 or more points of entry into bone that are joined to each other. By design, it is fabricated as a fixed metal device of single construction and variable thickness made up of 2 or more legs of varying length with sharp tips joined by a bridge of varying width that is driven directly into bone typically with a hammering motion. The actual shape of the legs and bridge components need not be similar. A bone staple can be prefabricated by a manufacturer or it can be fabricated on site in the operating room by double bending a pin or wire that is biased cut to create the sharp ends or tips. The legs need not be joined to the bridge at the time of their insertion into the bone. The legs could be inserted into the bone individually then joined together through a separate bridge component. An example of such a fixation device would be a 2-hole locking plate. This device provides versatility over bone staples in terms of leg position options as well as added purchase into bone through the threaded screws that make up the legs. The leg-to-bridge angles are fixed and not adjustable in a locking plate unless the plate itself is bent. The bridge joining the legs could be located outside the skin with the legs percutaneus as in an external fixator, a staple-like device.

Another possible construct is where the legs are driven into bone first as separate pins or wires then bent, cut and joined to each other. The junction joining the pins may be either buried beneath the skin or percutaneously located creating a staple-like configuration. This construct is versatile in application as the varying bridge-to-leg angles and bridge or leg lengths possible could not be achieved with single device construction. In single device construction, the bridge joining the legs could be manufactured so as to be adjustable after the staple is inserted. Following insertion, the bridge joining the legs could be shortened by some

Figure 1. Examples of bone staple design and construction demonstrating various cross sectional shapes, leg lengths, bridge shape, tip contours and the presence or absence of leg barbs.

mechanism permitting a degree of compression as the legs are drawn closer together. In terms of function regardless of construction, the staple system itself can be considered to neutralize, buttress or compress an osteotomy or fracture based on the application such as a bone plate (Figure 1). What may or may not be considered a staple by definition is limited only by imagination, but the principles of application are more constant and must be appreciated to understand the possibilities of utilizing this versatile bone fixation device.

CONCEPTS

The distinctions among various forms of bone fixation devices in terms of design and concept are evolving and becoming more and more clouded and complex. Multiple new and interesting screws, plates, pins and their accompanying instrumentation sets seem to appear constantly. It can be difficult not only for the surgeon, but the hospital and operating room staff to learn and manage these new devices effectively. The choices are varied and options are multiple, limited only by the freedom of imagination and the reality of insurance coverage. The tried and true older fixation systems can take a back seat, lost on the operating room shelf, forgotten by residents and surgeons as newer more exciting devices take precedent. These older systems are typically readily available; cheaper not requiring special budgetary requests; and more cost effective. The classic simple bone staple is a prime example.

The bone staple essentially represents simplicity in design and use. In the classic application, the bone staple is simply pounded into the bone to help stabilize a fracture or osteotomy to promote bone healing. Bone staples can be used as adjuncts to other forms of fixation or as single or multiple bone staples at one site. The evolution of application of the bone staple coupled with newer engineered designs in the hands of a skilled and knowledgeable surgeon can expand use and possibilities. Application implies the purpose of the bone staple in a particular fracture or osteotomy. The actual application or use of a bone staple can be expanded beyond simply holding 2 bone ends together. A bone staple in terms of application can be considered as a type of bone plate. A bone staple or a bone plate is not constructed differently for different applications, but is defined by the application. Bone staples can be used for neutralization, buttress, or compression much like any bone plate. The basic use of a bone staple is neutralization (Figure 2). Bone staples may be utilized in terms of application to help buttress loose fragments to help prevent their movement or migration (Figure 3). By placing a pre-insertion compression force at the fracture or osteotomy surfaces; stabilizing opposite a side of compression as a tension band; or inserting the staple with divergent legs, compression forces can be achieved across the fracture or osteotomy surfaces even in the absence of mechanical or metallurgical mechanisms (Figure 4).

Figure 2. Application of bone staples as neutralization devices as adjuncts to compression screw fixation in an ankle arthrodesis.

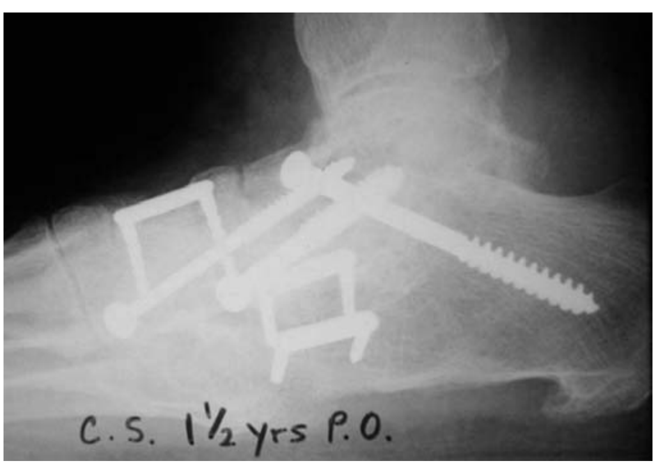

Figure 3. Application of bone staples as buttress devices to hold fragments of bone in a Charcot reconstruction.

Newer engineered fixation systems expand not only bone staple versatility, but the ease of technical implantation and their ability to add a degree of compression across an osteotomy or fracture. Metallurgical and mechanical bridge design options of bone staples provide the ability to shorten the bridge of the staple. The application of heat or the spreading apart of a split bridge shortens the bridge of the staple after insertion, bringing the legs closer together (Figure 5). The purpose of these mechanical or metallurgical maneuvers at the level of the staple bridge is to impart a degree of compression across the fracture or osteotomy surfaces. At a minimum, bridge shortening will tend to enhance the seating of the legs of the bone staple and help prevent distraction across the fracture or osteotomy surfaces. This compression effect can only occur if the staple does not extrude from the bone and the leg-to-bridge angle is stable and fixed. If the bone staple deforms or extrudes with bridge shortening, the compression effect may be diminished or lost completely.

Figure 4. Application of bone staples at the calcaneocuboid joint as compression devices opposite compression screws at the talonavicular joint to act as a tension band at the midtarsal joint component of a triple arthrodesis.

Figure 5A. Heat activated staples to shorten bridge width applied in a first MTPJ arthrodesis.

If a through-and-through fracture or osteotomy exists, then far cortex gapping can occur, negating the compression effect of bone staple bridge shortening. Far cortex gapping opposite a side of compression can likewise result in the potential for bone malalignment as can occur with a compression plate or compression screw. Stabilizing the far cortex opposite the compression force is what a tension-band accomplishes converting the far cortex gapping to compression of the fracture or osteotomy, whether a screw, plate or staple is being utilized to create the compression. Two bone staples on opposite sides of a fracture or osteotomy may represent one bone staple stabilizing as a tension-band and the other bone staple compressing the construct, not just a simple 2-bone staple multi-plane stabilization type of fixation. Any bone fixation construct is defined not just by device, but more importantly by application.

A bone staple can be considered conceptually in terms of device construction like a simpler version of a 2-hole plate (Figure 6A). The plate or bridge component can have varying lengths just like the bridges of the bone staples themselves. The legs of the bone staple are the screws. The screws may be able to purchase the bone more effectively than the smooth wire or pin-like construction of staple legs. Barbs present on the legs of the bone staple may help enhance bone staple leg-to-bone contact. Barbs on bone staple legs can adversely damage the bone channels where they are seated if the staple must be removed intra-operatively due to positioning or technical errors on insertion. The actual cross sectional shape of the legs of the bone staple can impact strength to prevent pull out from the bone. The strongest bone staple leg cross sectional shape design is a square with rounded corners. This design is followed by square, round, and triangular in progressive degrees of weakening bone purchase for pull-out. Minimizing the pre-drilling of bone substrate for the channels of the bone staple legs prior to insertion enhances bone staple leg-to-bone contact. The staple legs barbed or not, purchase bone more effectively if driven directly like nails into wood rather than through pre-drilled channels.

Figure 5B. Expandable split bridge staples to mechanically shorten bridge width applied in a tarsometatarsal joint arthrodesis.

Figure 6A. Two hole locking plate fixation of a closing base wedge osteotomy in hallux valgus surgery.

A 2-hole plate can be considered as conceptually similar to a bone staple. A 2-hole plate has limited and potentially weaker bone-to-fixation contact over a multi-holed plate with multiple screws as well as weaker

Figure 6B. External fixator stabilizing a distal leg fracture.

Figure 6C. Two joined pin fixation of a first MTPJ arthrodesis.

screw to plate contact. The fixation construct strength of a 2 screw plate can be enhanced with a locking plate system where the screws literally fix themselves to the plate creating more of a staple-like construct. In a locking plate the screws are unable to move in an angular fashion relative to the plate as occurs in a classic non-locking plate. A staple with a good and strong leg-to-arm angular construction is similar in concept to a locking plate.

The strength of the attachment of the 2 screws to the locking plate or likewise the legs to the bridge of a bone staple substantially enhances pull-out strength. As the staple deforms it acts more like a non-locking plate loosening and losing fixation effectiveness. The stronger the angular relationship, whether screw-to-plate or leg-to-bridge, the stronger the device and the more stable the fixation construct. This concept is similar for external fixator systems with a single bridge (Figure 6B).

A locking plate is functionally similar to an external fixator. The locking plate itself does not require intimate contact to the bone itself just as is the case of the external fixator arm outside the skin. The locking plate requires a strong screw-to-plate relationship just as is the case for the external fixator-to-pin relationship. A bone staple conceptually can act as an external fixator. There needs to be a strong bridge-to-leg relationship of the staple itself. There does not need to be a strong bone staple bridge-to-bone contact. It is acceptable for the bridge of the bone staple to be angled to the contiguous bone surface or not be perfectly flush in contact with it. The strength of the construct is intrinsic to the device itself and not to its contact to the bone through the bridge, only its contact to the bone through the legs. Attempts to "adjust" the position or angle of the bone staple after completing insertion to enhance the bridge-to-bone contact or reduce staple bridge prominence, can result in bone staple loosening. Such ill-advised adjustments affect the quality of the bone staple leg-to-bone interface through the channels of bone surrounding the bone staple legs. The more intimate the contact of fixation-to-bone through the legs, the stronger the fixation construct.

The importance of the bone-to-fixation contact of the bone staple legs exclusive of the bridge-to-bone contact is demonstrated in the 2 joined pins fixation construct (Figure 6C). This construct is not unlike a bone staple where the legs or in this case pins are driven into the bone separately then bent, cut and joined as a bridge following insertion. By joining the 2 pins together, the strength of purchase of each pin is enhanced as the factor of pin rotation is illuminated. A bone staple then can be considered as a pin with an anti-rotation outrigger. If one leg of the staple or one arm of the 2 pin system is well seated, the less well seated leg or arm at a minimum will help prevent loosening of the stronger purchased arm as a point of counter rotation. The segment where the 2 pins are joined may be placed outside the skin surface just as the cross member in an external fixator. This fact demonstrates the lack of need for an intimate bone staple bridge-to-bone contact for effective fixation. The only need for encouraging bone staple bridge-to-bone contact or avoiding undue angulations of the bridge of the bone staple is to prevent a proud prominence of the staple that could be symptomatic to shoe irritation and pressure postoperatively.

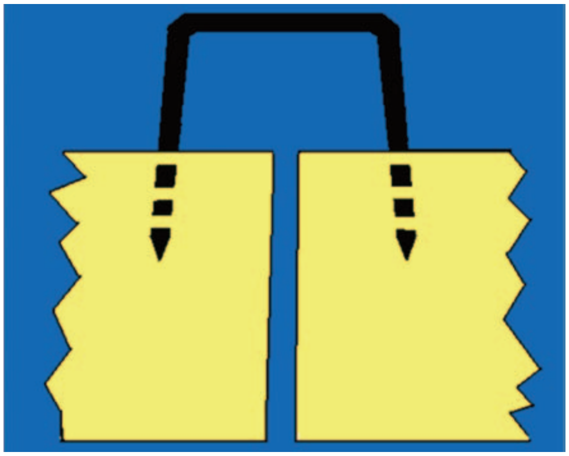

Figure 7A. Divergent bone staple legs prior to insertion with gapping of the osteotomy or fracture line.

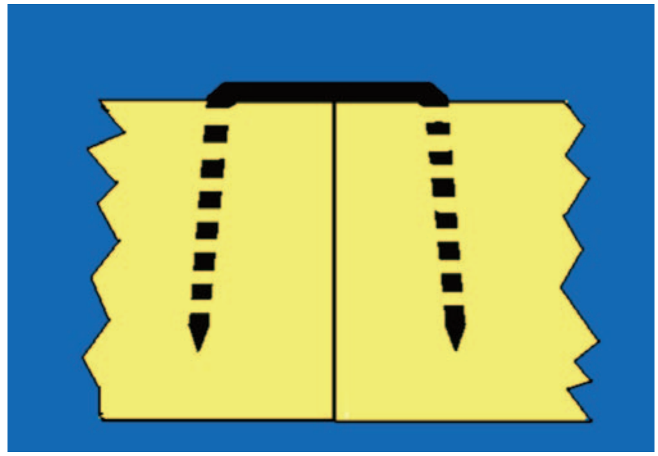

Figure 7B. Divergent bone staple legs after insertion with closer proximity and compression of the osteotomy or fracture line.

TECHNIQUE

The essence of fixation effectiveness, besides the intrinsic strength of the device itself, is the intimacy of the fixation-to-bone contact. The frictional relationship of fixation-to-bone varies based both on the construction of the device itself and the quality of the bone substrate. The threads of screws enhance bone contact over smoother fixation devices such as pins.

Compression of the osteotomy or fracture through the screw enhances screw-to-bone contact. Movement of the fixation device within the bone either over time before adequate bone healing occurs or during the technical act of fixation insertion can result in a looser fixation-to-bone relationship. Osteoporotic bone will not necessarily hold fixation as well as bone of more normal density. Cortical bone will typically hold fixation stronger than cancellous bone. Removal of bone substrate prior to insertion of the fixation can result in a looser fixation-to-bone construct than if no bone substrate is removed. These principles are especially important in bone staple use as the legs are typically smooth much more like pins only enhanced to a degree with barbs. The actual act of inserting the bone staple itself can impact significantly the fixation-to-bone contact of the bone staple.

If the bone staple legs are slightly divergent prior to insertion, as the staple is driven into the bone a degree of compression is imparted to the fracture or osteotomy site. As the legs are driven and advance into the bone, more bone of a greater width at the open end of the staple near the tips of the legs is forced toward and under the bridge area of the bone staple, which is of lesser width. This action draws the fracture or osteotomy line closer together in greater proximity (Figure 7). The bone staple leg-to-bridge relationship is fixed and does not change with insertion. If the leg-to-bridge angular relationship changes and diverges during insertion, no compression is created at the fracture or osteotomy site. The staple merely deforms. Once the staple is seated, radiographic evidence of divergent legs does not imply compression was achieved at bone staple insertion.

The act of inserting a bone staple should be exact and strong. As bone staples enter the bone, the legs create channels in the bone substrate impacting the surrounding bone about them resulting in enhanced friction between the bone and the staple legs. This act creates more resultant final friction after insertion between the bone staple leg and the bone like driving a nail as opposed to drilling a pin. The act of pre-drilling for the bone staple legs may help avoid cracking out and compromise of the staple leg channel in very dense bone, but can tend to weaken the bone staple leg-to-bone contact.

The bone staple must be driven straight and true in line with the legs. Any angular change in the direction the bone staple is being driven once the insertion process is begun can distort the bone channels surrounding the legs impacting the intimacy of the leg-to-bone contact. Prior to insertion, the bone staple needs to be aligned so that the final bridge-to-bone relationship desired is achieved (Figure 8). Generally this requires one of the legs started into bone first on the higher side of the fracture or osteotomy. Rarely are both legs in contact with the bone surfaces initially at insertion.

Care must be taken as the bone density at both legs is rarely similar. The leg in the less dense bone could advance quicker or the leg in the more dense bone could advance more slowly resulting in unwanted bone staple angulations. Final angular adjusts of the bridge of the bone staple following insertion is discouraged as they can weaken bone staple leg purchase. The bridge of the staple need not be in intimate contact with the bone surface. Angulations of the bone staple bridge from the bone surface are acceptable

Figure 8. Two bone staple fixation talonavicular arthrodesis with the narrower bridge bone staple legs close to violating the naviculocunioform joints in an ill-advised attempt to avoid clinical bone staple bridge prominence over the medial foot surface.

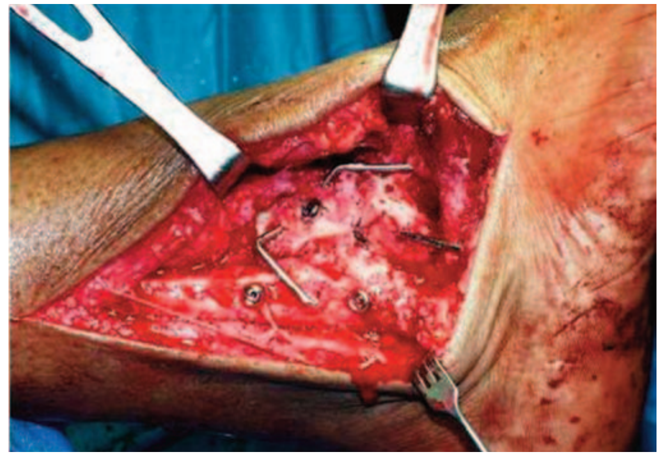

Figure 9. Supplemental bone staple fixation of an ankle arthrodesis. Note the gap of the bone staple bridges from the bone surface. The position of the staple in terms of functional application or the potential impact of the bone staple legs on the surrounding structures is more critical than the contact of the bridge to the bone surface.

Figure 10. Bone staple insertion demonstrating effective counter pressure in an opposite direction to the forces applied to insert the bone staple.

(Figure 9). The more crucial positioning of the bone staple is maintaining the legs of the bone staple as parallel to the osteotomy or fracture surface as possible for maximizing bone mass about the bone staple legs relative to the fracture or osteotomy surfaces and to provide an even force of compression. This must all be accomplished while at the same time avoiding placing the legs of the bone staple inadvertently within the surrounding joints or tissues.

Fewer stronger raps are preferred over multiple lighter taps to reduce the possibility of angulations and enhance the impaction of the bone about the bone staple legs. Counter pressure applied firmly to the extremity opposite the direction the bone staple is to be driven is critical to good bone staple insertion technique helping to better exact the insertion process (Figure 9A). The bridge of the staple should be wide enough to permit adequate bone mass from the bone staple leg channels to the fracture or osteotomy surfaces. The legs should be chosen long over shorter to enhance bone staple leg-to-bone contact. Multiple staples in varying planes are a stronger construct than a single staple. When possible and practical, the bone staple should be placed, like a bone plate, on the tension side of the osteotomy or fracture promoting compression as a tension-band.

The bone staple leg-to-bone contact may be more solid on one leg of the bone staple and less on the other. The fixation can still be effective. This situation is conceptually like a single pin that has been cut and bent then driven or locked into the bone. The second point of bone contact enhances the fixation construct by limiting movement or rotation of the pin or bone staple. A similar scenario conceptually is where 2 pins are driven independently then bent and secured to each other. This construct is commonly performed with crossed percutaneous pin fixation of interphalangeal joint arthrodesis of the hallux. The construct is not unlike forming a bone staple from 2 pins once they are joined and secured to each other. Generally one pin is more secure into the bone and the other pin functions more to prevent pin rotation enhancing the fixation of both pins by preventing movement and loosening.

CONCLUSION

When you hear…
"Here I come to save the day!"
…you'll know that Mighty Bone Staple, is on the way!