FIXATION METHODS IN MANDIBULAR RECONSTRUCTION USING FIBULA GRAFTS: A COMPARATIVE STUDY INTO THE RELATIVE STRENGTH OF THREE DIFFERENT TYPES OF OSTEOSYNTHESIS

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Accepted 10 April 2000

Abstract: *Background.* Bone staples made of a nickel titanium alloy exert dynamic compression, require little dissection, and may provide an alternative to conventional fixation in mandibular reconstruction with a free vascularized fibula graft.

Methods. To evaluate its stability relative to conventional methods of fixation with interosseous wires or miniplates, an in vitro model using beech dowels was developed. Torsional stiffness and strength and compression stiffness and strength were examined.

Results. The compression test results showed that maximum strength of interosseous wires is significantly less than memory staples, which in turn are significantly weaker than titanium miniplates. Miniplates are significantly the most rigid form of fixation. Torsional testing showed no significant difference in strength between staples and miniplates and only a marginal difference in elasticity. Interosseous wires show a rapid decrease of strength and rigidity during torsional stress.

Conclusion. When considering interosseous wires the least and miniplates the most stable form of fixation by which bone healing can occur, memory staples can provide enough stability to ensure consolidation. *Head Neck* **23:** 1–7, 2001.

Keywords: mandibular reconstruction; surgical flaps; interosseous; miniplates; memory staples

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After oncologic resection of the mandible, reconstruction using a free vascularized bone graft has become the predominant treatment of choice. The free fibula graft is most commonly used.[1] To restore the contour of the mandible it is necessary to make one or more osteotomies in the bone graft, depending on the size of the defect. The use of a reconstruction plate as a template alleviates the problem of positioning and fixation between the residual bone segments. These segments are fixed to the reconstruction plate with two screws.[2] The trend in free bone graft surgery is, however, to avoid large plates in favor of an optimal minimum of fixation material of a much smaller dimension like miniplates.

In recent years nickel-titanium (NiTi)–alloy staples suitable for use in mandibular fracture

osteosynthesis have become available. The advantage these staples have over plates lies in the fact that they have only minimal effect on the periosteal blood supply. Little dissection is necessary to place drill holes, and the area of contact between fixation material and periosteum is minimal. A particular characteristic of the NiTi-alloy is the shape-memory effect. Their shape is temperature dependent. The staples can be modeled in a cooled state and on warming up, regain their original form, exerting compression.

To assess the usefulness of this mode of fixation, the Memory staple was compared with two other fixation techniques currently in use—stainless steel interosseous wires and 2.0 titanium miniplates. Their relative strength on compression and under torsional stress was measured with a fibula model.

METHOD

Mechanical testing osteosynthesis techniques in mandibular reconstruction is possible using in vivo models or cadaveric specimens. To avoid the inherent interspecimen variation of these studies, a model with the approximate geometry of a fibula was carved from a piece of beech dowel to imitate a mandibular reconstruction. This removes questions regarding the osteosynthesis material-model interface. Beech dowel was chosen because it is particularly homogenous, and its elasticity module is comparable to that of bone.[3] Two saw cuts of an angle of 50 degrees were made, and a wedge-shaped piece of material was removed. The cut surfaces of the two halves were placed against each other. Fixation occurred in the anterolateral (= future frontal) and the dorsal (= future occlusal) aspects at an angle of just less than 90 degrees in relation to each other. All the fixation materials were sited in an identical location. Interosseous stainless steel wire and Memory staples were introduced through identically situated drill holes.

The following materials were used in the fixation methods:

- Amp Memory Staples 12-mm wide with a leg length of 13 and 16 mm, respectively. (Amp, Villeurbanne, France) The 16-mm long staple was positioned on the anterolateral aspect and the 13-mm staple on the dorsal aspect. These lengths ensured that the points of the staples were buried just underneath the surface of the wood. With a drill gauge, two holes of 2.2 mm for each staple were drilled at a distance of 12 mm from each other. The staple was positioned after having been modeled in the cooled state (−15°C).
- Interosseous wires of stainless steel 0.5 mm in diameter were used. They were tightened to a point where there was no discernible movement between the two parts.
- Synthes Craniofacial 4-hole titanium plates 0.9-mm thick and 25-mm long, fixed with four 2.0 self-tapping cortical screws of a minimum length of 8 mm (Fig. 1)

Measurements were carried out at a temperature of 35°C.

Two different types of measurement per fixation method were performed, each of which was repeated five times. During the compression tests, forces were exerted on the experimental model with a compression/distraction bench micrometer (Tensometer type "W," Monsanto, UK) with a constant displacement speed of 3.18 mm/min. Compression on the model resulted in distraction at the site of the fixation material (Fig. 2). The measurements were registered by a line amplifier (Philips PR 9340) on an XY recorder (Philips PM 8134). All compression measurements were continued until the fixation material broke or extruded through the wood.

For torsion tests the model was so positioned in a jig that the axis of rotation ran through the center of the contact area between the two halves of the dowel (Fig. 3). The test was carried out with continuous rotation of 0.3 degrees per second in a torsion bench developed by the Department of

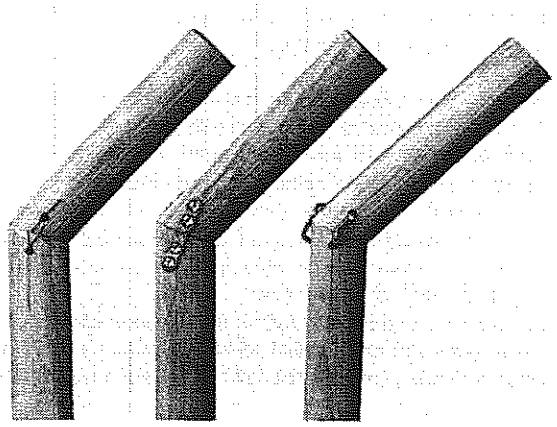

FIGURE 1. Three forms of fixation (interosseous wire, Synthes miniplates, and Amp Memory staples, applied to the fibula model. Note that all the fixation materials were sited in an identical location.

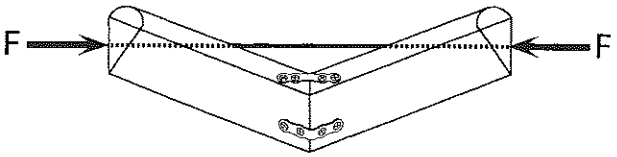

FIGURE 2. Schematic representation of the compression test setup. A force is exerted (arrows) along the line connecting both ends of the model. This results in bending in the contact area and thus distraction on the fixation material.

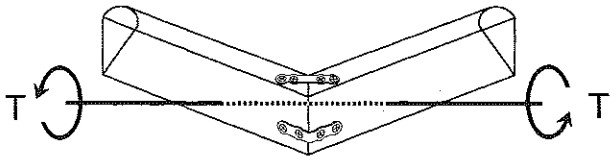

FIGURE 3. Schematic representation of the torsion-test setup. The model was so positioned in a jig that the axis of rotation ran through the center of the contact area between the two halves of the dowel. The two halves are rotated in opposing directions (arrows).

Medical Technical Development at the Academic Medical Center. Torsion measurement was carried out to an arbitrarily chosen value of 85 degrees.

The measurements were registered by a line amplifier (Philips PR 9340) on an XY recorder (Philips PM 8134).

The top of the curves were taken as the maximum reading and expressed in units of Newton/meter.

As relative measures of elasticity, the displacement in millimeters or the rotation in degrees and their associated power in units of Newton or Newton/meter were registered on the linear part of the curves produced. The manner of the failure of the fixation material in relation to the forces exerted was recorded. The data were analyzed using the statistical program InStat (Graphpad Software, San Diego CA) on a Macintosh PowerPC 8500/120.

RESULTS

Compression Tests. In all cases the fixation in the frontal aspect was the first to fail. The stainless steel wires underwent a short period of elastic deformation followed by gradual untwisting. This occurred in the virtually horizontal part of the curve (Fig. 4). The Memory staples deform first in the bridge area followed by the legs bending and sliding out of the drill holes. In two cases the staples fractured in the eye-shaped bridge area. The plates showed deformation of the first hole adjacent to the contact area, after which in three cases, the screws broke out of the wood, and in the remaining cases the plate fractured. The maximum force (F) that can be exerted on the fixation material together with standard deviations are reproduced in Table 1.

The reliability of the measurements of the interosseous wire, staples, and plates is shown by Student's t test ($p < .0001$). The Tukey-Kramer multicomparison test shows a significant difference between the F of all three osteosynthesis methods. The biggest differences are between the interosseous wires and the plates ($p < .0001$) and between the staples and the plates.

The difference between the elasticity (Ec) of

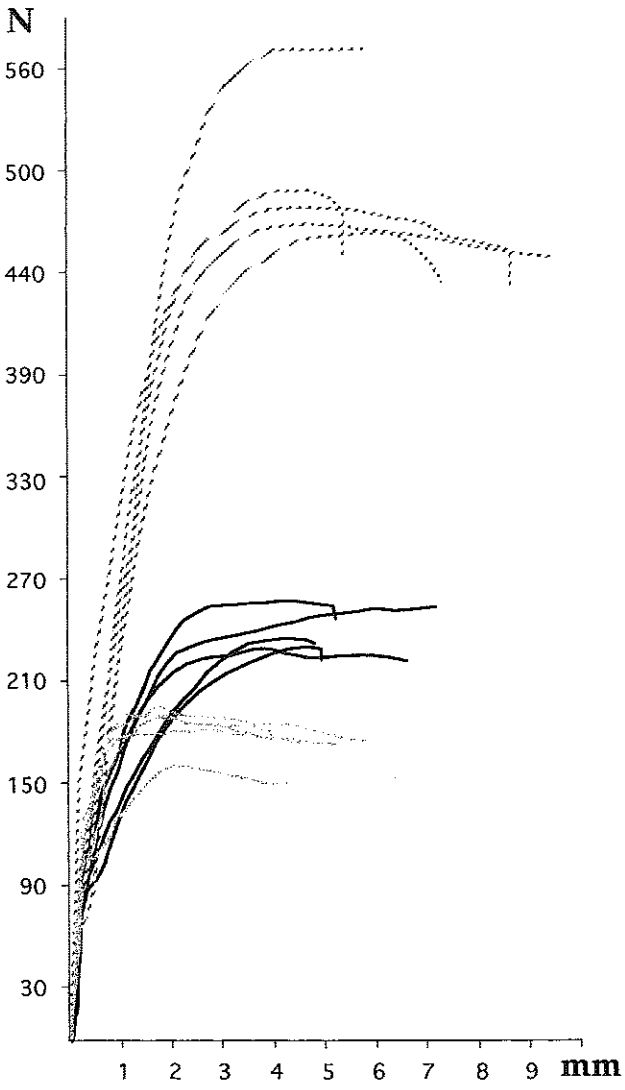

FIGURE 4. Force-displacement curves. The elastic stiffness was measured as the slope of the linear portion of the load deflection curve. Legend: ▨ mini plates, ■ memory staples, ■ interosseous wires. Displacement in mm, exerted force in Newton (N).

Table 1. Results of compression testing.*

Fixation material	F (SD)	Ec (SD)
Interosseous wires	184.60 (12.58)	8.33 (2.37)
Memory staples	243.80 (12.80)	6.90 (0.82)
Miniplates	507.00 (44.39)	21.40 (3.29)

**Mean maximum value of force (F) in Newton (N) and elasticity (Ec) in N/meter. Standard deviation in parentheses.*

the interosseous wires and the staples is not significant. However, the difference is significant when comparing interosseous wires and staples with the plates ($p < .001$).

Torsion Tests. The torsion tests show a virtually identical pattern of fixation material deformation. Staple fracture and screw extrusion did not occur. The test results are shown in Table 2. Initially, the staples showed torsion between the legs followed by deformation of the eye-shaped bridge area. Here the curve runs parallel to the curve formed by the titanium plates (Fig. 5). The interosseous wires untwisted gradually. The interosseous wire did not break or cut through the surface of the wood. A high degree of reproducibility was seen in the torsion tests on all three modes of fixation. This is true for both maximum values of torsional strength (T) and degree of elasticity (Et) ($p < .001$).

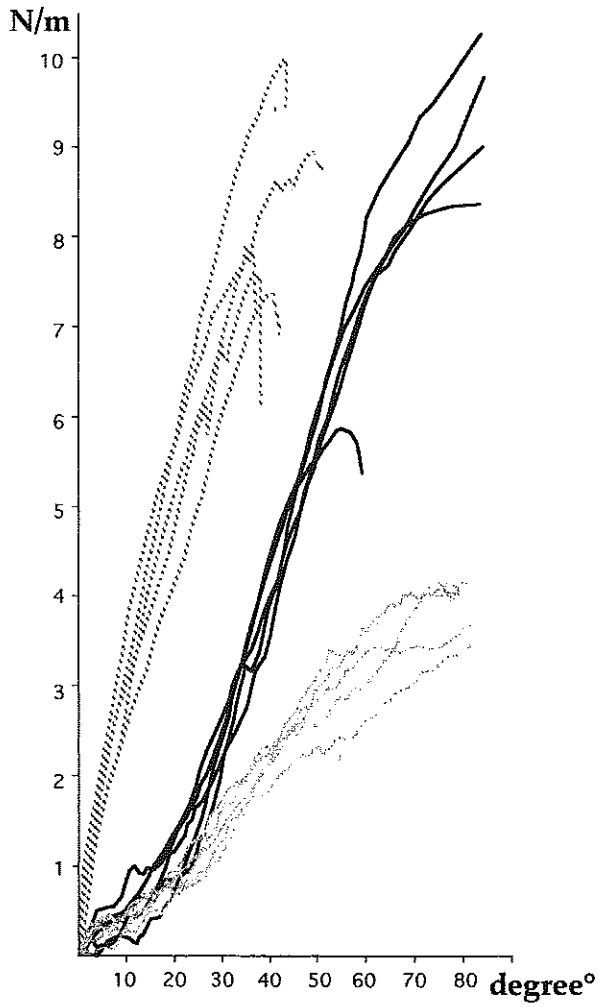

FIGURE 5. Torque-rotation curves. The elastic stiffness was measured as the slope of the linear portion of the load deflection curve. Legend: ▨ mini plates, ■ memory staples, ■ interosseous wires. Rotation in degrees, exerted force in Newton/meter (N/m).

Table 2. Results of torsion testing.*

Fixation material	T (SD)	Et (SD)
Interosseous wires	3.84 (0.33)	0.07 (0.10)
Memory staples	8.74 (1.84)	0.18 (0.02)
Miniplates	8.34 (1.16)	0.23 (.45)

Mean maximum value of torque (T) in Newton (N/m) and elasticity (Et) in (N/m)/degree. Standard deviation in parentheses.

The torsional strength and elasticity of the interosseous wires differ significantly in the Tukey-Kramer multicomparisons test in relation to both staples and plates ($p < .0001$). The torsional strength of staples and plates is not significantly different. The difference in the elasticity of staples and plates is marginal ($p < .05$ with a q value of 3.9487, in which $q = 3.7730$ is significant). It is noteworthy that when exertion of forces on the staple fixation was discontinued, the staples returned to almost exactly their original position. It would appear that up to 85 degrees of rotation, the extent of plastic deformation incurred by Memory staples is limited, unlike that of the titanium plates.

DISCUSSION

Currently the fibula is the most commonly used free flap bone graft in mandibular reconstruction. It is long enough for an extensive jaw reconstruction and can be divided into relatively small segments of up to 2 cm without compromising vascularization.[4]

The number of osteotomies and the length of the bone segments have a definite effect on the degree of difficulty of the fixation method. The larger the defect in the jaw, the more osteotomies are necessary and the more complex the procedure becomes. Small changes in the length or angle of the bone segments have a direct effect on the position and projection of the chin.

Fixation techniques can be divided into rigid and nonrigid forms of fixation. Rigid fixation

methods use screws, THORP 4.0 and diverse reconstruction plates, and screws, as well as miniplates.

A reconstruction plate can be used as a final fixation and as a template fixed to the remaining mandibular abutments, within which the bone graft is given a contour and to which the graft can be fixed by one or more screws. The use of a reconstruction plate greatly simplifies the procedure. The disadvantage of this procedure, however, is the relatively large size of plate and screws. A high profile plate can distort the contour of the jaw. This is particularly true of central reconstructions. The fibula segments are sited within the plate, which has already been shaped to the original contour of the jaw. This always results in an osseous reconstruction that is smaller than the original jaw. "Stress shielding" by the rigid reconstruction plate can sometimes delay consolidation.[5] The fixation material may hamper the placement of osseointegrating implants for a dental prosthesis. Secondary positioning of implants often necessitates the removal of plate and screws.[6–8] Miniplates may also have this disadvantage.

Since its introduction by Hidalgo in 1989, the use of the miniplate for mandibular reconstruction has proved to be a reliable method.[9] These small plates are easily modeled and enable an accurate reconstruction of the contour of the jaw using small segments of bone. Two four-hole plates per osteotomy position are usually necessary also for fixation of the neomandible to the remaining mandible. The use of small bone segments always carries the risk of devascularization and necrosis because of compression of the segmental periosteal vessels.[10,11]

Nonrigid fixation uses interosseous wires, sometimes augmented by Kirschner wire fixation. If more than one osteotomy is necessary, modeling and fixation by wires can be a laborious and difficult procedure. The success of the wiring technique depends more on optimal contact between the bone segments than do the other procedures. However, studies have not been able to demonstrate any difference in the rate of bone healing between the rigid and nonrigid fixation methods in mandibular reconstruction,[12,13] in contrast with interosseous wire repair of fractures of the edentulous mandible. The reason for this difference is probably that a vascularized bone graft has a much richer blood supply than the fractured atrophic edentulous mandible.[14]

In recent years an alternative fixation method has become available. This is the nickel-titanium Memory Staple (BRI, BIO Research Innovations, La Seyne, France en Amp, Amp, France). When an object made of this nickel-titanium alloy is cooled below a critical temperature, the metal matrix goes into the so-called martenistic phase. In this condition the metal matrix can be manipulated by bending without being damaged. When the object is warmed up, the metal matrix regains its former configuration, and the original shape is restored. For medical use the nickel-titanium proportion is such that the critical temperature is less than 0°C, and the original crystal formation returns at body temperature.

BRI and Amp Memory Staples are supplied with the points bent toward each other and an S-shaped or oval bridge. After cooling to less than the critical temperature, the legs are straightened until they are parallel and the S-shape or oval straightened out. If proper leg length is chosen to penetrate both cortices, bicortical pressure will be created on rewarming. Comparison of nickel-titanium alloys with other titanium or stainless steel alloys in medical use shows them to have a low elasticity modulus, high tensile strength, and high fatigue strength.[15] This results in continuous dynamic compression at the site of the osteotomy. The biocompatibility of these nickel-containing alloys is comparable with that of titanium.[16]

To date in the field of maxillofacial surgery, Memory staples have been used only in the treatment of fractures.[17,18]

Taking into account the good reports of

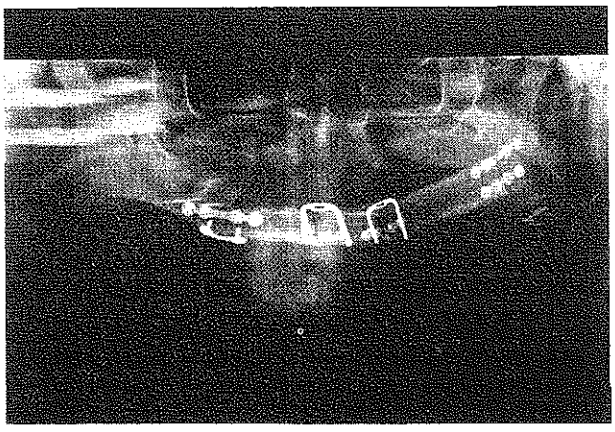

FIGURE 6. Early postoperative panorex view of a patient after segmental mandibular reconstruction with a fibula free flap. The two fibular osteotomies were fixed with Memory staples and Synthes 1.5 titanium miniplates. At that time no custom-made staples were available for use in the frontal plane.

Memory Staples in these and other bone fixation techniques, we considered their use as a potential method of fixation of fibular osteotomies in mandibular reconstruction.

Taking the titanium miniplate method of fixation as one extreme and the cerclage method of fixation as the other, within whose parameters good bone healing is to be expected; the results given by the Memory staples fall somewhere in between. Their ability to withstand torsional stresses is particularly important in central reconstructions and is comparable to that of the titanium miniplate. Memory staples have the additional advantage of exerting dynamic compression at the site of osteosynthesis. Should external forces cause the fixation to become distorted, the use of the staple would cause it to return to its original position. In the same situation, interosseous wire fixation would untwist and loose its stability completely.

Miniplates exhibit more plastic deformation and thus do not regain their original shape. This causes loss of bone contact resulting in reduced stability and slower consolidation.

Staples have a number of advantages over the titanium miniplates. Time is saved because of the reduced number of necessary surgical steps (the drilling of multiple holes, bending of plates, and placing of screws all become redundant). The periosteum is only minimally compromised because the staples are small and have only a limited area of bone contact. Devascularization of the smaller bone segments is unlikely. The bulk of the fixation material is less, thus reducing the need for its removal in case of dental implants.

A disadvantage of the staple is its height in the frontal plane. In fixations of an angle less than 20 degrees, the staple clearly juts out. The degree to which it juts out is, however, limited. At an angle of 50 degrees this translates to approximately 3 mm, which is comparable to the height of a reconstruction plate and screws. This problem can be overcome by making staples with a preformed angle in the bridge area.

In setting up the trials, a model made from material independent of the variations found in cadaver material was deliberately chosen. Cadaver material is not homogenous and differs widely in quality. The dimensions of cadaver material also vary, making identical and comparable positioning of the osteosynthetic material impossible.

It is possible to demonstrate the differences in the strength of the various types of osteosynthetic material effectively on a beech dowel model. Its force displacement curves show that it is strong enough to resist the forces exercised on it. It was only during miniplate compression tests that the screws were occasionally pulled out of the wood. This was accompanied by the extreme plastic deformity of the screw holes. This is never observed in vivo. The moment of failure (miniplate fracture, loosening of screws) is much further on in the process than the point at which plastic deformation begins (Fig. 4).

No attempt to obtain absolute values was made, because in practice they are almost impossible to apply. The forces that act on a reconstructed mandible are highly variable and difficult to quantify. Our experimental model appeared to deliver values high enough to be relevant with a high degree of reproducibility.

Our results and recent clinical experience (Fig. 6) have shown that the Memory Staple has a place as a suitable method of fixation in mandibular reconstruction using a free flap vascularized fibula bone graft.

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