REVERSE TORQUE TESTING AND EARLY LOADING FAILURES: HELP OR HINDRANCE?

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KEY WORDS

Reverse torque testing
Early loading
Bone density
Implant failure

Reverse torque testing has been suggested to reduce the incidence of early loading failures during the first year of loading. However, the variables of bone density at stage II uncovery, the assessment of a small degree of implant rotation, and the effect of implant size and design have not been adequately evaluated. In addition, bone is weakest to shear forces, yet this is the primary force applied with reverse torque testing. This article reviews the benefits and disadvantages of reverse torque testing and suggests early crestal bone loss and failure of implants may be the result of this test, especially in less dense bone types. In addition, a nomenclature of implant failures is introduced to improve the correlation of information in the literature to the failure of implants in clinical practice.

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INTRODUCTION

Reverse torque testing (RTT) is a common mechanical test that has been used for many years to investigate the nature and strength of the bone-implant interface of endosteal implants. Many research studies have been performed with reverse torque testing techniques.[1–8] More recently, RTT has been said to be beneficial at stage 2 surgery as a definitive clinical verification of initial integration[9] or ''adequacy'' of the implant-bone interface.[8] Although it is generally agreed that most occlusal forces on the implant-bone interface should be axial or compressive in origin, interest in the resistance of the bone-implant interface to torsional forces has been heightened since higher than previously believed necessary torquing preload forces are needed to help reduce the incidence of abutment screw loosening.[10,11] In addition, the language of implant failure with regard to cause or time of occurrence is often confusing. This paper reviews the advantages and disadvantages of reverse torque testing as a definitive determinant of initial osseointegration and proposes a terminology system for implant failure.

MATERIALS AND METHODS

Reverse torque testing as a biomechanical measure of anchorage

As a research methodology, RTT typically involves placing implants in an animal model. Various species have been used, including rabbits, dogs, and baboons. The implants are placed in bone, either in the jaws or long bones. After a predetermined healing period, the animals are sacrificed and the implants are removed by applying a

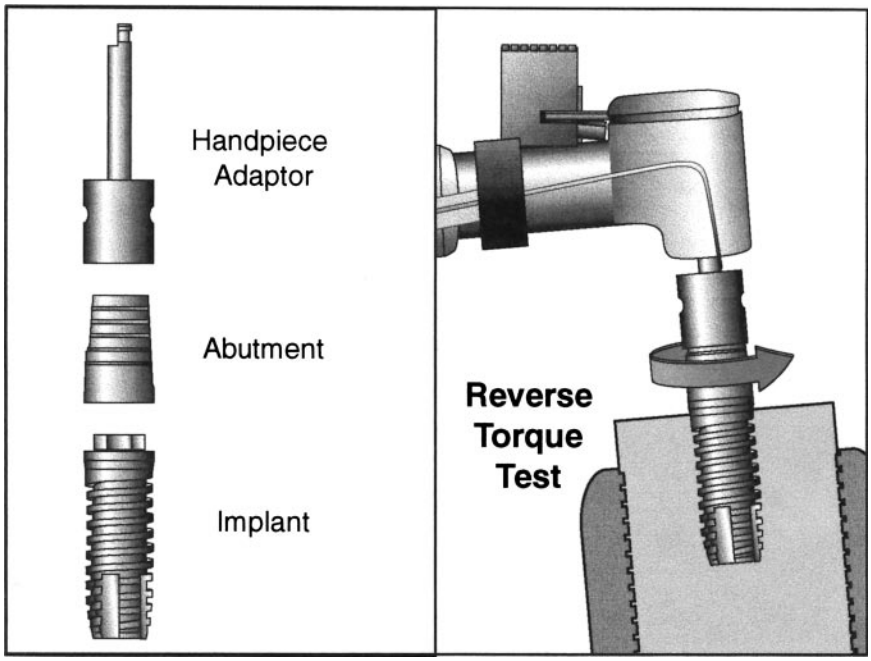

FIGURE 1. Schematic diagram of an *in vitro* reverse torque testing experiment.

counterclockwise (reverse) force with a computerized torque driver (Fig 1). The level of torque required to remove the implant from bone is recorded; this is commonly expressed in Newton-centimeter (Ncm) units.

This type of mechanical testing is beneficial when comparing implant design, materials, and surface treatments in terms of shear strength measurement, quality of implant-bone contact, and speed of formation of contact. For example, RTT and similar tests have helped verify the high bone-implant interface strength values that can be established with hydroxyapetite coatings and the time in which this interface can be formed.[12–15]

Reverse torque testing as a definitive determinant of initial osseointegration

The rigidly fixated endosteal dental implant has increased in use during the last decade.[16] Ochi *et al*[17] have found that the loss of implants from initial surgery has gradually decreased over this time, the rate of loss is often less than 5%. These failures may be explained to the patient as due to local conditions or individual patient healing response, explanations that are relatively well accepted by the patient. A number of reports have reported on the phenomenon of later failures. This term has not been specifically defined, although it is generally understood that the term *late failures* refers to implants that have failed in the time between an apparently successful second-stage surgery and before or shortly after the prosthesis is fabricated. The incidence of late failures ranges from 2.4% to 3.9% in good quality of bone. When the bone is of very poor quality, the late failures may be over 50%. In the Jaffin and Berman retrospective report, the surgical failure in soft bone was 8%, whereas the late failure ranged from 35% in the anterior mandible to 65% in the maxilla[9,17–23] (Table 1). Although the late failure rate in good-quality bone may appear relatively low and inconsequential, these late failures do pose a problem, since the restoring dentist usually has already initiated the restoration process, with associated laboratory and chair time costs. In addition, the patient may often blame the restoring dentist for this complication, perhaps relating it to some clinical event, such as the final impression or removal of the transitional prosthesis.[24] Many implant prostheses have more than one implant to support the restoration, and if each prosthesis averaged three implants, a 5% increase in failure rate may affect 15% of the final restorations.[20]

RTT, used as clinical verification of initial osseointegration (rigid fixation),

TABLE 1

Implant failure rate comparison

Number of Implants	Early Failures, %	Late Failures (Early Loading Failure), %	All Failures, %	Reference
274	7.7	2.9	10.6	Zarb and Schmitt[18]
509	3.3	2.4	5.7	Naert and Quirynen[19]
404	4.7	2.5	7.2	Sullivan *et al*[9,*]
22,177 implants 7403 prostheses	Not reported	5.9 (1107 Prostheses affected, or 15%)		Root Laboratory[20]
204	2.0	3.9	6.9	Salonen *et al*[21]
364	1.1	0	1.1	Misch *et al*[22]
1168	8	35 to 65 (by location)	55	Jaffin and Berman[23] (soft bone)

*Implants in this study were subjected to reverse torque testing at stage II surgery.

involves applying a defined reverse torque (counterclockwise) to the implant (via mount) at stage 2 uncovery surgery.[9] The level of applied torque ranges from 10 to 20 Ncm. Implants failing such testing are presumed to be fibrous encapsulated, are likely to become late failures, and are therefore not recommended for use as support for prosthesis abutments. Proponents of this type of clinical testing acknowledge, however, that the test does not guarantee long-term implant survival or provide prognostic information as to whether enough bony interface exists to support occlusal forces in an individual patient, since it does not simulate *in vivo* loading of an implant in prosthetic function.[9]

The rationale for RTT as a clinical test appears to be based on the premise that most, if not all, late failures are not the result of stress-related causes but instead are the result of an inconspicuous nonintegration. This is a condition whereby an implant passes current assessments for the evaluation of osseointegration (such as manual mobility or radiographs), yet is insufficiently integrated to provide support for a prosthesis.

Implant failure relative to time

With the development of many different techniques, such as single or two-stage surgery, immediate loading, or all of these, implant terminology relative to failure can be confusing. A review of the literature shows that authors are inconsistent in the terminology they use to describe implant failures relative to time. For example, the event classified in early studies as *abutment connection* is more commonly referred to now as second-stage or stage 2 surgery. The terms *late failure* or *later failure,* which have been used in discussions of implant failure, have not been precisely defined. This term is open to interpretation and could refer to early loading failures after stage 2 uncovery or to complications occurring several years to decades after implant loading. Hence, there is a need for a more descriptive system for the classification of implant failures based on time of failure. A classification of implant failures based on time has been suggested by Misch.[25] Many implant failures are not ideally described by the time of the complication and are not addressed in this nomenclature.

A *surgical failure* describes the failure or failed attempt to place the implant at the time of surgery. This usually is the result of a bone fracture during the osteotomy formed by compression or expansion, failure to obtain initial rigid fixation, or fenestration of a lateral wall during the preparation of an osteotomy. An *osseous healing failure* describes failure in the time from implant placement to the early development of the bone-implant interface, and results with a mobile implant before the prosthesis reconstruction. This may apply to both one- and two-stage surgical protocols. The successful connection of the prosthetic abutment most often is the end for this failure period. An *early loading failure* describes the failure of an implant during the first year the implant serves as a prosthetic abutment. When immediate loading is performed, the osseous healing and early loading time overlap, and failures during the first year using immediate loading come under this heading. The objective of RTT is to reduce the incidence of this type of failure.[9] An *intermediate implant failure* occurs in the time period after the first year of loading and includes a period of 5 years of prosthesis function. *Late implant failure* describes failures in the time after the implant and prosthesis have been loaded for more than 5 and fewer than 10 years. *Long-term failure* occurs after 10 years in function.

DISCUSSION

The rationale for reverse torque testing

A primary objective of RTT is to identify nonintegrated implants at the earliest possible stage with a clinical verification method that is ''objective, easy to administer, use available armamentaria, be as definitive as possible within the available knowledge base, and possess an adequate level of safety so that damage to the implant-bone interface does not occur.''[9] Although represented as objective, RTT depends upon a number of subjective factors that individually and collectively may damage a healthy implant-bone interface.

Among the subjective variables of RTT are the determination of bone density, the assessment of a small degree of implant rotation, and the effect of implant size and design. The strength of trabecular bone in the jaws before fracture is directly related to its density.[26] The term *type* was first used by Linkow and Chercheve[27] in describing three types of bone in the jaws. Lekholm and Zarb[28] have used the term *quality* to describe four types of bone found in anterior and posterior regions of the jaws in the anterior regions of the jaws. Jaffin and Berman[23] used the term *type* for their retrospective report of implants in soft bone. Misch[29,30] chose the word *density* to describe four types of bone found in anterior and posterior regions of the jaws and compared their tactile sense during the implant osteotomy to different materials (*ie,* oak, spruce, balsa, and Styrofoam). Although each author's classification may be slightly different and dependent upon his clinical experience, these terms will be used as if they were synonymous in this article. The most dense bone (D1 or 2) is 5 to 10 times stronger than the least dense (D4).[26] The RTT is suggested to be most beneficial in less dense bone, since this is the type of bone with the highest incidence of early loading failure.[9] However, this density of bone, even when fully healed, is most at risk of fracture with RTT. After a 4-month healing period, bone is only 60% mineralized and is often still woven bone rather than lamellar bone as a result of the surgical trauma from the initial surgery.[31] Woven bone is unorganized and weaker

than lamellar bone, whose load-bearing properties are more desirable around the implant. According to computer densitometric studies, the bone interface may be more dense and stronger at the time of initial implant placement when compared with that at stage II uncovery.[32] The bone interface at the end of the osseous healing period is less dense than after the interface has been loaded for 1 year,[24] and the early testing of an implant-bone interface may place the complex at more risk of overload failure, regardless of bone density.

The surgeon can use tactile sensation during the osteotomy preparation process to initially classify bone density using either of two common classification systems.[28,30] However, fewer clinical diagnostic criteria are available to evaluate the bone density at stage 2 uncovery. Determination of bone density after healing is critical for the use of RTT, since testing implants too early in the healing process (relative to bone density) is more likely to risk overtorque of implants that would otherwise remain integrated after loading.

The bone-implant interface can be improved by progressive bone loading. Studies have demonstrated a decrease in Periotest (Seamens AG, Bernsheim, Germany) values (compared with controls), an increase in bone density, and reduced crestal bone loss with computerized digital images after loading.[24,34,35] Clinical RTT does not permit this improved interface to form prior to testing. Therefore, using RTT at stage 2 uncovery evaluates the interface when it is more at risk to fracture from overload, especially in less dense bone. A RTT after progressive loading would be less likely to fracture a potentially mature interface but would require several prosthetic steps, negating the supposed value of the RTT at stage 2 uncovery. Misch *et al.*[22] used progressive loading in their report of 360 implants supporting 105 prostheses and found no early loading failures during the first 12 to 26 months of loading.

The issue of which bone densities warrant RTT is unclear. As previously mentioned, clinical RTT is recommended for bone types 3 and 4 but was not considered necessary in D1 or D2 bone. Concern for stripping of the antirotation hex, the higher bone density and strength, and presumed lower incidence of early loading failures are said to lessen or obviate the need for RTT for these bones types.[9] However, since RTT is limited to 10–20 Ncm of torque in all bone densities, the risk of damage to the hex is the same for all bone densities and is therefore not greater in denser bone types. The observation of a greater increase of early loading and RTT failures in soft bone is more likely related to the strength of the interface, not a lack of initial integration.

Clinically, torque control is another variable that cannot be controlled sufficiently enough to encourage the use of RTT. Most studies have limited RTT to clinical and research situations where either computerized torque drives or Nobelpharma electronic torque controllers have been used. In clinical situations, only results using the Nobelpharma controller have been reported.[9] Although the Nobelpharma controller has been designed to deliver a specific torque to an implant mount with ±10% of the stated torque value, other studies of this unit have found a margin of error of 20–35% when comparing actual torque delivered to the preset torque.[11] In addition, because of the significant expense of the electronic torque controller, practitioners desiring to institute RTT in their second-stage surgical protocol may elect to use manual torque wrenches,[11] which exhibit a percentage error of 23–28%.

An additional subjective factor of RTT is the determination of micromovement. RTT protocol requires a clinician to detect even a small degree of rotation that indicates failure. It is suggested this movement may be subtle enough that the use of magnifying loops are recommended.[9] The amount of implant movement of successful rigid fixated implants is variable[36] and dependent upon bone density, since the modulus of elasticity is dependent upon the density.[26] An implant in D4 bone, subjected to a force of 2000 g, may exhibit lateral mobility much as 60 to 80 μm. As a reference, a lateral incisor tooth in health moves 97 μm, a movement that can easily be visualized.[37] Therefore implant movement could to some degree be attributed to bone density, not necessarily a lack of rigid fixation. It is interesting to note that osseointegrated implants with reverse torque values great enough to cause rotational movement have also been shown to reintegrate. A study by Ivanoff *et al*[38] used a rabbit model in which experimental implants were reverse torqued until failure and allowed to reheal. Histomorphometric evaluation revealed no difference between test and control implants regarding the bone-implant contact and bone area within the threads. Reintegration would not occur if the cause of failure to RTT was a fibrous interface.

The quantity and specificity of reverse torque data that have been reported are insufficient for human clinical application. Torque-to-failure trials in human applications have been limited to only four implants in two studies. Tjellstrom *et al*[1] measured the removal torque of a titanium implant (3.75 × 4 mm) placed in the mastoid bone. The external aspect of the mastoid bone is cortical and coarse trabecular internally, and corresponds to D2 bone. Sullivan *et al*[9] recorded removal torque values for three implants in a human volunteer. The bone density was described to be D4 in the posterior maxilla and mandible regions where the test implants were placed. An unloaded healing time of 6 months was allowed.[26] At retrieval, a cortical lining was described around the implants, which indicated the bone density improved to D2 bone, which is five times stronger than the initial D4 bone. No other reports indicate that soft bone predictably converts to a cortical lining during healing. Hence, these implants may have RTT values greater than

FIGURE 2. Photoelastic study of threaded implant in a bone simulant, which is torqued while in position. The stress contours are at the crestal region around the implant.

those typically found in soft bone. Using a primate model, Carr *et al*[6] found that 5.4% of the metallic implants, otherwise thought to be integrated, could not withstand a reverse torque level of 35 Ncm.

When an implant is subjected to torque, the majority of the stress is transferred to the bone surrounding the crest module of the implant (Fig 2). These stress concentrations have been great enough to result in increases in bone density as well as early crestal bone loss.[39] Although factors such as periosteal reflection, osteotomy preparation, and biologic width formation cannot be completely ruled out as causes of early crestal bone loss, stress factors[40] are the most likely etiology of bone loss beyond 0.5 to 1 mm. Stress factors are also the most likely cause of early loading failures. As a result, it is suggested a countertorque device be used when the abutment screw is preloaded with a 30 Ncm torque (Fig 3). Many variables, including implant design and treatment planning, affect the level of stress transmitted to the bone-implant interface. An in-depth review of these factors is beyond the scope of this paper. However, it is reasonable to suggest that the RTT may even be a potential cause of crestal bone loss for implants that pass the RTT and are otherwise deemed successful.

Osseointegration has been defined as an ''interface between an implant and bone at the light microscopy level,''[32] and no definitive percentage of this bone-implant contact has been set as a de facto standard. Albrektsson and Jacobsson[41] suggested that '''most' of the surface must be in contact.'' Other studies have shown that a rigidly fixed implant may initially have 25% or less of its surface in contact with bone and is dependent upon the bone density.[30] For scenarios of partial fibrous encapsulation, no clear criteria have been established by RTT proponents as to what amount of fibrous tissue would define nonintegration. The variability of implant-bone contact, and by default implant-vascular, implant-trabecular space, and implant-fibrous tissue contact, suggests the mere presence of fibrous tissue adjacent to a rigidly fixated implant is not a definitive (objective) sign of future failure. The loss of an implant by fibrous encapsulation implies that the entire implant is surrounded by fibrous tissue. Under these conditions, there is minimal resistance to torquing forces in either a clockwise or counterclockwise direction. Hence, the complete lack of integration can be evaluated by the insertion and tightening of the healing abutment.[42]

Widespread application of RTT in immature bone may lead to significant numbers of ''false positives'' and increasing osseous healing failure rates. Bone, as a material, has a significant variation in strength depending on the forces acting upon it. These forces may take the form of either compression, tension, or shear (torsion). Research has shown that cortical bone is strongest in compression, 70% as strong in tension, and only 35% as strong in

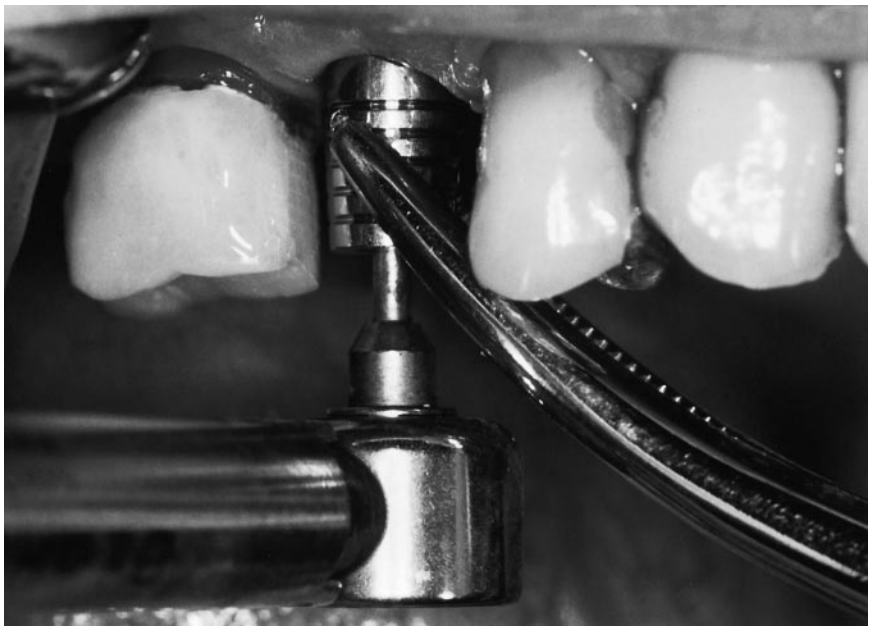

FIGURE 3. A counter torque device (hemostat) is placed upon the abutment while a force of 30 Ncm is applied to the abutment screw.

shear[43,44] (Fig 4). Misch *et al*[26] have also shown the trabecular bone density is related to the strength and modulus of elasticity.[45] It is likely that all clinical loading situations produce elements of all three types of stresses. However, RTT primarily places shear forces on the root form implant with a round cross section. Therefore, the RTT may not directly relate to long-term clinical application. Failure of an implant during RTT does not necessarily mean that it could not have functioned as a successful implant under primarily compressive or tensile loads.

RTT has not been correlated to implant width and length. A wider implant has more bone contact and should have a higher RTT value before failure. Likewise, a narrow implant may have a lower failure value and be stripped by the RTT. A longer implant, which engages cortical bone, will also have a higher RTT before failure. Conversely, a shorter implant should have a lower RTT value. Therefore, using a similar RTT value for all implant diameters and lengths could result in the fracture of the bone-implant interface on narrower or shorter implants even though it was similar in the percentage of bone contact as implants of larger surface area.

RTT may be affected by implant design. Implant bodies with more holes or flat sides to resist shear forces will have greater RTT values to failure. An RTT on a threaded implant uses the mechanical advantage of a screw to break the implant-bone adhesion. In other words, this test attempts to lift the implant from the crypt, using the screw design to assist this aim. It has been observed clinically that to remove unwanted implants as a result of poor angulation or placement, the preferred removal method is the application of reverse torque. Maxillary implants with crestal bone loss can most often be removed in this fashion, even if the apical half of the implant is integrated.[42]

Future research in clinical testing of dental implant interfaces should be directed toward improving noninvasive techniques. Elias *et al*[46] have described a dynamic modal testing technique that shows promise in its ability to noninvasively assess the interface surrounding an endosteal dental implant with a lateral tap from an impedance hammer. This test was able to distinguish interfaces based on the type of bone at the interface and the degree of fixation between the implant and the interface. Sennerby and Meredith[47] are investigating the feasibility of a nondestructive resonance frequency analysis technique to measure implant stability and osseointegration.

The Periotest is a nondestructive, objective, and useful test to determine implant micromovement. The Periotest instrument has not been accepted by some RTT proponents on the basis of anecdotal reports and a study by Van Steenberghe and Quirynen,[48] suggesting the prognostic value of the Periotest remains unproven with regard to implants because too few failures have been studied to date and reported in the literature. However, several studies exist[49–52] that describe the usefulness and sensitivity of this instrument. Furthermore, a large-scale study of 1838 implants by Truhlar *et al*[53] found the Periotest to be capable of quantitatively assessing the status of the implant-bone interface, is sensitive to slight differences in the implant dampening effect (mobility), and provides baseline Periotest values (PTVs) that can be helpful in evaluating improvement or degradation of the implant-bone complex. Truhlar *et al*,[53] in describing the rationale for the choice of the Periotest for second-stage implant evaluation study, noted that RTT is of questionable safety in humans and could result in microfractures and subsequent loss of the implant during loading.

CONCLUSION

Reverse torque testing has been and continues to be a beneficial research tool in implant development. As a clinical test, it is represented as a possible solution to a problem of early loading implant failure. However the origin of this complication is most likely excessive stress of the bone-implant interface early in the implant therapy process. Clinical application of RTT involves many subjective variables such as bone density determination, torque control, visualization of movement,

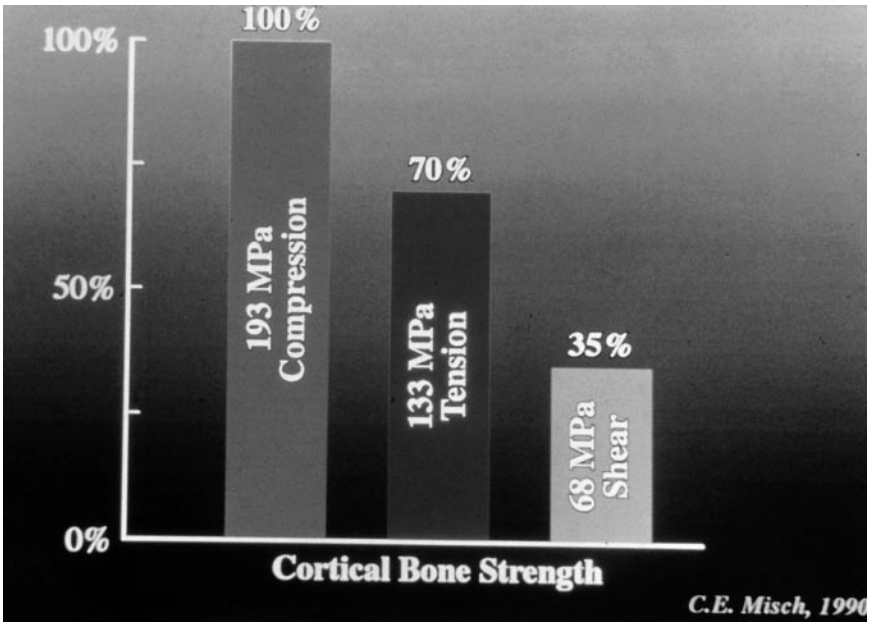

FIGURE 4. Bone is strongest in compression, 30% weaker in tension, and 65% weaker in shear. Torque forces apply shear to the implant-bone interface, especially at the crestal regions.

and lack of sufficient human data from which to select an appropriate test value. Misjudgment can damage the bone-implant interface and prolong treatment as well as increase costs associated with the extra reparative treatment. The most common methods of clinical verification used today, radiographs and manual mobility testing, have an admittedly subjective component. However, they do not place the implant at risk and have been used for a considerable length of time. If complete fibrous encapsulation is present, the clockwise torque of placing an abutment by hand is great enough to rotate the implant and determine lack of integration. The use of the Periotest device, if available, can provide further useful information on the implant-bone interface. In addition, there is no current evidence early loading failures can be eliminated by performing the RTT. It appears the implants that pass the RTT may still fail during the early loading period. In summary, this review finds insufficient data to warrant reverse torque testing as a routine clinical test in humans. In addition, a nomenclature is proposed to help correlate and standardize reports of implant failures.

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