The use of titanium osseointegrated dental implants to replace missing teeth has been shown to be predictable; they were first used in completely edentulous patients. Today, partially edentulous patients benefit from implant therapy. Either one- or two-stage implant systems have been documented as providing satisfactory longevity and survival and success rates.

Osseointegrated implants remain stable when loaded with orthodontic forces, giving the orthodontist a strong anchorage defined as “ankylosed anchorage.” The control of anchorage is essential in orthodontic treatment planning and often greatly influences the objective of therapies. Moreover, tooth movements become very difficult in circumstances such as periodontally compromised or partially edentulous patients, where the remaining teeth do not give sufficient anchorage. Similar problems occur when mandibular molars or a group of teeth have to be moved distally or vertically and when patients are unwilling to use extraoral orthodontic devices.

The aim of the present work was the evaluation of implant stability and periimplant bone reaction by histologic and clinical evaluation after therapeutic orthodontic loads. Forty-one adult patients received titanium implants as an orthodontic anchorage device; 12 patients received a retromolar or palatal implant to obtain tooth movement. Seven implants were removed at the end of the orthodontic therapy, after 2, 4, 6, and 12 months of orthodontic load, and processed for histologic examination. It was possible to distalize maxillary and mandibular molars and a group of teeth (molars and premolars), and to obtain tipping, uprighting, intrusion, extrusion, and transfer of anchorage in other parts of the mouth. The results showed that orthodontic therapy is facilitated and quickened by the use of implants. All implants remained stable in the bone up to 12 months of loading, and all were osseointegrated. Microfractures, microcracks, and microcalsi were observed around implants that had been placed in both low- and high-density bone. The remodeling rate was still elevated after 18 months. (Int J Periodontics Restorative Dent 2002;22:31–43.)

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To overcome such problems, the use of orthodontic implants has been studied in animals\textsuperscript{13–16} and humans, particularly in adult orthodontic treatments.\textsuperscript{17–21} There are no standardized methods for orthodontic treatments in adult patients\textsuperscript{22–24} or for orthodontic applications of implants, because few applications have been tested.\textsuperscript{17–20} The experimental\textsuperscript{13–16} and clinical studies\textsuperscript{17–24} showed that implants used as orthodontic anchorage remain stable during the traction period, allowing orthodontic intraoral direct bone anchorage. Finally, it is important to evaluate the clinical improvements that can be obtained by the use of orthodontic implants in treatment plans.

The aim of the present article is the evaluation, by clinical follow-up and histologic analysis of the bone-implant interface, of implant stability and periimplant bone reaction during different therapeutic orthodontic conditions.

**Method and materials**

Orthodontic implants were manufactured by Exacta (Biaggini Ormco) as a conical screw-shaped implant, 3.3 mm wide and 5 or 7 mm long (Fig 1), made of commercially pure titanium grade 3 (Uni 9763/2) with a blasted surface (mean $R_a = 1.329; R_t = 21.557; R_{\text{max}} = 20.847$). Different specifically designed abutments (Biaggini Ormco) that allow several positions of the arch were often used to apply the orthodontic load to the implant.

**Patient selection and orthodontic treatment**

Forty-one adult patients needing orthodontic treatment for various malocclusions received titanium implants as an orthodontic anchorage device. The patients received detailed information about the aim and scope of the therapy and accepted the therapy.

Twenty-nine patients needed implants as an orthodontic anchorage because the reduced number of remaining teeth provided inadequate anchorage for orthodontic treatment. In these patients, standard Exacta titanium-blasted implants, 11 or 13 mm long and 4 mm in diameter, were also used as artificial roots for the final prosthetic rehabilitation at the end of the orthodontic therapy. Ten patients received a molar or retromolar mandibular implant, and two patients received one palatal implant each to obtain tooth movement without compliance-dependent anchorage aids (headgear, class II or III elastics).\textsuperscript{21–23}

Orthodontic traction was performed by connecting an elastic (Figs 2 and 3) or by placing springs from the implants to the tooth to be moved. One of the implants was placed according to Roberts et al\textsuperscript{22} in the mandibular ramus to distalize the molars and was immediately loaded after placement using an orthodontic arch. All other implants were loaded 2 months following placement, with a force ranging in almost all cases between 80 and 120 g as measured by an orthodontic dynamometer.

Seven mandibular posterior implants not useful for prosthetic rehabilitation were removed with a thin layer of surrounding bone and processed for histologic examination at the end of the orthodontic therapy. One implant was retrieved after 2 months of load, two implants were retrieved after 4 months of load, one implant was retrieved after 6 months of load, and one implant was retrieved after 12 months of load. Two more implants had a 2-month healing period, 8 and 6 months of loading, respectively, and a resting period of 10 and 12 months, respectively, before retrieval. The overall orthodontic treatment period varied from 2 to 15 months.

**Surgical procedure**

Exhaustive medical histories were collected. All patients were healthy and did not have any contraindication to oral surgical procedures.

Each patient received one or more implants that healed nonsubmerged. The orthoimplants were placed 2 mm over the crestal level, since the polished neck of the implant measured 2 mm. Depending on the soft tissue height, a transmucosal healing screw was selected to ensure nonsubmerged healing. The bone density was classified using drilling resistance according to Trisi and Rao.\textsuperscript{24}

Two weeks and 1 week before implant retrieval, the patients were
given a single 1-g dose of tetracycline (Ambramicina, Sharp) to label the remodeling dynamics. After the loading period necessary to achieve the desired tooth movements, the orthoimplants were removed. Under local anesthesia, the orthoimplants were carefully retrieved, together with a small portion of periimplant bone, using a cooled trephine bur. The area of surgery was thoroughly rinsed with sterile saline solution, and a regenerative procedure using a collagen barrier membrane (Paroguide, Vebas) was performed to obtain healing of the residual defect.

**Histologic procedure**

All bone biopsies were immediately rinsed in saline, fixed in 10% neutral buffered formalin, and processed to obtain thin ground sections. The specimens were dehydrated in an ascending series of alcohol rinses and then embedded in Remacryl resin (an experimental resin, Istituto di Microscopia Elettronica Clinica, Ospedale Sant’Orsola). After polymerization, the specimens were sectioned at 200 to 250 µm by a Micromet high-speed rotating-blade microtome (Remet) and ground down to about 40 to 50 µm by an LS2 (Remet) grinding machine. The histologic slides were stained routinely with toluidine blue and basic fuchsine. For the tetracycline label analysis, a special UV filter applied to a Zeiss Axioscope light microscope was used.

**Results**

The obtained tooth movements were distalization of maxillary and mandibular molars, contemporaneous distalization of a group of teeth (molars and premolars), and tipping, uprighting, intrusion, extrusion, and transfer of anchorage in other parts of the mouth.

No apparent problems occurred in the implants loaded with orthodontic force, except for one standard 13-mm implant that showed 4 mm of bone loss, which healed after appropriate treatment. No loss of bone was detectable around the moved teeth. A common finding in standard periapical radiographic examination of the orthodontic implants was the apparent presence of a corticalization of the periimplant bone with formation of a radiopaque basket around implants initially placed in low-density bone.

The movements obtained were always very rapid compared to movements obtained using an extraoral device, even when the applied force was inferior. Some of the implants seemed to move during the first days of traction in the direction of the traction and to find a fixed position after a few weeks of traction, especially when they had been placed in very low-quality bone. All implants healed uneventfully and were stable until retrieval, without signs of inflammation.
Histologic results

Two-month healing, two-month traction. This implant was oriented during the retrieval, and it was possible to distinguish between the different sides during sectioning and histologic analysis. A 100-g continuous elastic traction was applied for 2 months. The implant was placed in type II–III bone.

The analysis of the mesiodistal sections showed an impressive amount of woven bone formation at the crestal tension side and on the apex that was positive to the tetracycline labels. At the crest of the compression side (Fig 4) and the apex of the tension side, few areas of bone-implant contact (BIC) were visible, as the rest of the implant was surrounded by soft tissue. The thick cortical crest of the compression side was undergoing strong remodeling, with the formation of many new cutting-filling cones that were positive to the double tetracycline labels running perpendicular to the section plane and implant surface (Fig 4). On this side, the bone at the interface was undergoing huge resorption.

On the buccal aspect (Fig 5), the bone crest showed signs of microfractures with repairing phenomena. The old, thick trabeculae of the crest showed signs of fracture and separation. The space between the displaced trabeculae was filled by newly formed lamellar or woven bone that was labeled with double tetracycline lines. On the middle buccal aspect of the implant interface, only newly formed composite bone was present, directly attached to the implant surface with small remnants of fractured bone embedded in the newly formed matrix. Also,
microcracks were visible at the tip of the thread at this level (Fig 6). In some instances, the space between the fractured ends of the trabeculae was quite small and was nicely filled by new lamellar bone, with lamellae arranged parallel to the surface of the fractured trabeculae. In some regions, the space between the ends of the broken trabeculae was wider and filled with woven bone.

Two-month healing, four-month traction. This implant was not oriented during the retrieval, and it was not possible to distinguish between the different sides. An almost continuous trabeculum layer of bone, 100 to 200 µm thick, surrounded the implant surface (Fig 7). These trabeculae were thickened at three levels—the crest, the threads, and the apex—and were connected to few thick trabeculae arranged perpendicular to the implant surface. Most of the bone matrix was made of composite bone, with some primary osteons at the interfacial level. A high rate of remodeling was evident all around the periimplant bone. Resorption was evident at the crestal surface, reducing the bone height without the formation of an infrabony pocket. The BIC seemed very high.

Two-month healing, four-month traction. In this case, the implant and the section were oriented. This implant sustained a stronger force application of 200 g 2 months before retrieval, starting when the patient received the double tetracycline labeling and lasting 2 weeks. After this strong orthodontic stress, the force was brought back to 100 g for the following 8 weeks before retrieval. The pressure side showed a huge amount of woven bone, some still undergoing active formation and some undergoing remodeling (Fig 8). This bone was not in contact with the implant surface, but more buccally it had the aspect of a large microcallus attached to the implant surface on one side and connected to the thin trabeculae on the other side (Fig 9). Signs of fracture into the trabeculae of the woven bone in the microcallus were also seen (Figs 10 and 11). On the tension side, the crestal bone was fully corticalized.

The shadow of the old bone was visible inside the crest, with a profile that well matched that of the implant (Fig 9) at a distance of about 1 mm from the actual implant interface, allowing the hypothesis of a displacement of the implant in the direction of the orthodontic traction. This space was filled with newly formed composite bone that was heavily labeled with tetracycline. At the level of the apical thread, it seemed that the thread had migrated from its original position, since the imprint of the thread was still present in the old bone even though a remodeling process had slightly modified this profile.

Bone remodeling units (BRU) were visible at this level. The surface of the crest did not show signs of bone resorption, but areas of woven bone formation were present near the implant surface. In the central part of the implant, the bony structures became more cancellous. On one side, the bone was more dense and compact and few thick trabeculae started from the implant surface toward the surrounding region. The percentage of BIC at this level was very high. On the opposite side, the bony structure was more cancellous, with thin trabeculae and large marrow spaces, and the percentage of BIC was low in the apical part. The bone matrix was mainly composed of lamellar bone.

Zero-month healing, twelve-month traction. This implant was placed in the very dense bone of the mandibular ramus. On one side, the implant was surrounded only by cortical bone. At this side, the most coronal bone showed crestal growth along the implant surface. This crest did not show signs of resorption. Cutting-filling cones (BRUs) were evident inside the cortical bone. Almost all the bone matrix was composed of lamellar bone with new osteons and old osteons. On the opposite side, the bone showed a reduced density because of an intense resorption activity that produced large marrow spaces. Moreover, at the tip of the screw thread, an intense remodeling and woven bone formation was evident, as were microcracks (Fig 13). At this side, the crest showed resorption up to the first thread.
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Fig 7 Four-month traction implant is surrounded by cancellous bone characterized by few thick trabeculae (T) that are fully adherent to the implant surface, arranged perpendicular and parallel to the implant surface. The interfacial structure presents a thickening of the trabeculae at three levels—the crest, spire, and apex. An almost continuous shell of bone surrounds the implant (I), and the BIC rate is near 100% (toluidine blue–basic fuchsin stain; original magnification × 5). S = soft connective gingival tissues; M = marrow spaces.

Fig 8 Four-month traction implant. The compression side (C) shows low-density trabecular woven bone (W) and a low BIC rate and almost no bone contact in the apical part. On the tension side (T), the bone density is high, with a thick cortical crest (*) adherent to the implant (I); in this part, the BIC is high (toluidine blue stain; original magnification × 5). Arrows = direction of the orthodontic force applied.

Fig 9 Overview of the implant in Fig 8 in a more lingual section. On the tension side (T), dense bone is found. This cortical area shows two distinct regions. At the interface, composite bone (N) fills the space between old mature bone (OB) and titanium surface. A net line, matching the implant profile (small arrowheads), delimits this front. The profile of the implant is at a distance from the actual interface, suggesting displacement from its original position. The space between the old bone and the actual implant interface is filled by new woven bone fully corticalized with new primary osteons. Many cutting-filling cones are forming inside the old bone, testifying to the enhanced remodeling rate at this level. On the compression side (C), woven bone structures (W) testify to the presence of a micro-callus (large arrowheads) (toluidine blue stain; original magnification × 5). M = marrow space; arrows = direction of the traction.
Fig 10  Higher magnification of the implant in Fig 9 at the compression side, at the level of the microcallus. A continuous layer of woven bone is attached to the implant. Many small bone trabeculae reflect the formation of a large microcallus. A small microcrack is visible in one of these trabeculae (arrow) (toluidine blue stain; original magnification × 50). I = implant; T = woven bone trabeculae; M = marrow spaces.

Fig 11  Higher magnification of Fig 10 at the level of the microcallus. The arrows point to a small microcrack in the thickness of the woven bone trabeculae (T), probably because of the compressive forces (toluidine blue stain; original magnification × 100). M = marrow spaces.

Fig 12  Six-month traction implant. The most coronal third is surrounded by a very dense cortex (C). In the central part of the implant, the bony structures become more cancellous (S) (toluidine blue–basic fuchsin stain; original magnification × 5).

Fig 13  (left)  High-power magnification of the bone-implant interface at the apex of a thread of an implant loaded for 12 months in very dense mandibular bone. Epifluorescent light demonstrates the presence of a small microcrack (arrows) of the bone matrix aligned along the canaliculi of the osteocytes (O), starting from the interface (original magnification × 1,000). I = implant; B = bone.

Fig 14  (right)  Twelve-month traction, six-month rest implant. This implant was placed in very dense bone from the crest to the apex. On the non-remodeled side (N) the bone is dense, and almost 100% BIC is evident. On the remodeled side (R) high remodeling activity caused high porosity and a low BIC (toluidine blue–basic fuchsin stain; original magnification × 5). M = marrow spaces; S = soft supracrestal gingival connective tissues.
Two-month healing, twelve-month traction, six-month rest. Very dense bone from the crest to the apex surrounded this implant. At the interface, the bone matrix was composed of woven bone, but many small new BRUs were active on one side of the implant. Because of the remodeling spaces that induced a high porosity of the cortical bone, the BIC was low at this level (Fig 14) despite the corticality of the surrounding bone, while on the opposite side the BIC was very high and the BRU number was lower. More bone remodeling units were present near the interface than at a distance. The crest did not show any signs of resorption.

Two-month healing, eight-month traction, ten-month rest. Very dense cortical bone surrounded this implant, which remained unloaded for 10 months. The bone matrix was mostly mature lamellar bone, with primary and secondary osteons. The crest showed huge resorption activity and coronal growth of the crestal bone. Some remodeling activity was evident, with cutting-filling cones (BRUs) at the interface. Much higher remodeling activity was detected near the interface than at a distance. The BIC was very high.

Discussion

According to previous reports,8–12,16,21,23 implants loaded with orthodontic appliances maintain osseointegration from a histologic perspective; this represents an absolute anchorage in orthodontics. All implants in the present report remained stable for the treatment period. The use of rigid intraoral anchorage units is an efficacious alternative to orthopedic and orthodontic extraoral force application and modifies the approach to complex orthodontic movements, allowing simultaneous application of different forces in different regions of the mouth. The force applied through an osseointegrated implant is continuous and allows movements with absolute anchorage without compliance-dependent anchorage aids.23 It allows, for instance, the rigid stabilization of a tooth, contemporaneous traction of more than one tooth, and different three-dimensional vector applications, by applying all forces to a single implant. The treatment of the presented cases was always faster than standard treatment.

The force applied to the implant seems to induce physiologic bone adaptation, activating bone modeling and remodeling in the periimplant site.8 Orthodontic load is a continuous and constant load, not comparable to occlusal or muscular forces. Artificial animal loading experiments showed that static loading has no effect on the bone remodeling process, while dynamic loads induce remodeling,26,27 but other studies contradict this thesis.28–30 When a static load is applied in a living subject to bone that is also functionally loaded, this static load is superimposed on the dynamic strain produced by functional activity. On the other hand, experiments where long bones were functionally isolated showed that pure static load does not affect remodeling, unlike dynamic load.31,32 In the present report, orthodontic load was continuous, but it was superimposed on the dynamic strain of the basal bone produced by physiologic functional movements; the effect was a dynamic periimplant bone strain. This could explain the extensive remodeling phenomena observed in the periimplant bone even after load interruption.

The histologic analysis of the retrieved implants gave us the unique opportunity to observe bone adaptation patterns around implants undergoing orthodontic load after different loading periods, but the number of specimens was insufficient to extrapolate statistically significant results. Moreover, because of the different healing times, implant dimensions, bone densities, and amounts and directions of applied force, the analyzed cases were not in comparable clinical conditions.

A study in rabbits8 showed that when the load is eccentric to the load axis of the shaft, rapid osteogenesis of immature woven bone produces a buttress-like lattice that rapidly increases the diameter of the shaft in the direction of concave...
The formation of microdamage or microscopic cracks in the bone matrix has been associated with elevated or altered strain environments and with fatigue loading. Bone microdamage is manifested by the presence of well-defined microcracks in lamellar bone tissue. Microcracks refers to discrete and microscopically visible flaws that may progress and eventually lead to a complete failure of the trabeculum. In the present study, we found microcracks either around implants placed in cortical bone or in periimplant cancellous bone. The contemporary presence of woven bone formation similar to microcalli substantiates the occurrence of trabecular microfractures and successive repairing through microcallus formation. In our specimens, fractures of the trabeculae and possible relative movement of the implant could have appeared during implant placement, tightening of the abutment, or following orthodontic load application.

The tetracycline labeling demonstrated that repair of the trabecular microfractures occurred after orthodontic load application, since the repairing bone was labeled by tetracycline.

It is possible that implant failure in soft bone at the time of abutment connection is due to microfracturing of the thin, brittle trabeculae of the spongious bone. In all of our cases, no implants failed or unscrewed during abutment connection. Nevertheless, it cannot be excluded that microcracks without

Histologically, microcallus formations consist of immature woven bone at locally stressed sites in the bone tissue. The formation of microcalli is a physiologic repair mechanism of the bone tissue to stabilize and renew old and brittle bone. Even entire new trabeculae can emerge in this way. The newly formed woven bone trabeculae of the microcallus are the basic prerequisite for reconstruction of rarefied bone structure. Although microcalli indicate instability of the bone structure, microcallus formation stabilizes and regenerates the bone tissue. Microcallus formations are demonstrable in nearly all spongy bone by means of suitable preparation techniques. The genesis, frequency, and importance of microcalli are largely unknown in the orthopedic literature. It was postulated that trabecular damage might play a role in hip fracture, bone remodeling, and prosthesis loosening.

The process reinforces osseous support in a matter of days, as revealed by tetracycline labeling. Thus, the applied load induces rapid osteogenesis along bone surfaces loaded in compression as a short-term measure to strengthen the shaft. In the present study, the woven bone formation was, conversely, found inside the trabecular architecture of cancellous bone. The simultaneous finding of microcracks and microfractures into the thin and brittle trabeculae, and the morphologic arrangement of this woven bone, may represent the physiologic repair process of microfractures, “microcallus.”

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implant unscrewing occurred at this phase, since some implants were placed in very low-density bone, whose trabeculae are thin and brittle. If this was the case, the trabecular repair should have been started at the time of orthodontic force application. Unfortunately, tetracycline was given 2 weeks before retrieval, so it could not label the initial phase of loading and cannot confirm this hypothesis.

The hypothesis of trabecular microfractures during orthodontic load has never been reported in the literature, but our observations support it. In fact, two samples showed evidence of periimplant microcalli highly labeled after abutment connection, suggesting that microcallus formed some time after loading had started.

The question of why some implants present microfractures while others do not arises. Most likely, the difference could be a matter of biomechanical load of the periimplant bone. Among the biomechanical parameters involved in the bone-implant interaction are implant surface and macrogeometry, bone density, amount and direction of the applied force, early loading, and rate of osseointegration after healing.

The rate of osseointegration for this type of implant is high, even in low-density bone. Loading implants after 2 months of healing was shown to be safe and is considered the standard for orthodontic implants. The last factor to be considered is the bone density.

Bone density notably varies in the different regions of the jaws and between different patients, and for this reason it can be assumed that implants placed in weak bony host tissue are less resistant to biomechanical overstrain and are at higher risk of failure. Type D4 bone may reach up to 90% porosity. In this context, it is possible to place an implant that achieves osseointegration after an adequate healing period, but the abrupt implant load after the second-stage surgery may threaten the thin and delicate bony trabeculae attached over the implant surface. Our observations support this hypothesis.

In fact, histologic analysis of implants showing microdisplacement and microcalli revealed that low-density bone surrounded them. The occurrence of microfractures in this context may represent one of the mechanisms responsible for the well-documented early postloading failure of implants placed in low-density bone. Nevertheless, after 4 months of loading, we observed the formation of a bone basket composed of a continuous periimplant trabeculum and few thick trabeculae arranged at the level of the main strain and stress force lines. Primary osteons were appearing, giving rise to a manifest corticalization. Some studies showed that an orthodontic load applied to an ankylosed implant might induce bone apposition around the periimplant bone. At 6 months the bone was in a more quiet state and the amount of BIC was approaching 100%, but at 12 months the remodeling was still high. In the 18-month specimens, which had a prolonged resting period, we expected to find a resting bone and interface, but the pattern was quite similar to the 12-month sample. The presence of composite bone at the interface indicates that the remodeling cycles had not been able to replace all the newly formed interfacial bone. The presence of the woven bone could also be explained by a possible overload of the periimplant bone, since overload may induce the formation of woven bone in critically loaded regions.

After 18 months, 4 to 6 implants (completed remodeling period) were elapsed and the implant interface should have reached the steady state, but the remodeling was still high, particularly on one side of the implant. Previous reports showed that the remodeling of the periimplant bone remains elevated throughout the implant's life when implants are under functional load. Animal studies dealing with remodeling of the periimplant bone surrounding unloaded implants in long bones showed a reduction of labeled osteons at 3 months following surgery. This indicates that in the first 3 months after implantation the high remodeling rate is mainly a consequence of the rapid acceleratory phenomenon. Nevertheless, in our samples, the remodeling was also high after 6 or 10 months without loading. This may be due to the load interruption that induced disuse atrophy, or to the disturbing effect that the implant induces in the biomechanics of the cortical bone.

On the other hand, the presence of microcracks around implants...
placed in dense cortical bone, associated with high remodeling rate and porosity of the bone, could indicate an overload. It has been postulated that microdamage accumulation stimulates remodeling, thus leading to a net loss of bone and void formation adjacent to the implant\(^5\); this is exactly what we found around one implant.

It has also been postulated that bone microdamage caused by loading stimulates increased new modeling and remodeling events to repair bone damage.\(^5\) If bone remodeling targets bone microdamage for repair, and if there is a positive feedback between damage and remodeling, then accumulation of microdamage around prosthetic implants could be responsible for the biologic responses that lead to implant loosening.\(^5\) A recent literature review\(^6\) stated that there is evidence supporting the hypothesis that fatigue microdamage can occur in interfacial bone around a heavily loaded dental implant that eventually predisposes a net loss of bone and implant failure.

Stress and strain energy is not only proportional to the applied force, but also to the length and diameter of the implant, the bone density, and the root:crown ratio. For this reason, it is not easy to generalize the biologic effect observed in the present report, but an accurate analysis of all the biomechanical factors involved in the implant-bone interaction is required to better understand the biomechanical interaction between implant and bone under various loading conditions.

Further studies are necessary to better clarify these factors.

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**References**


