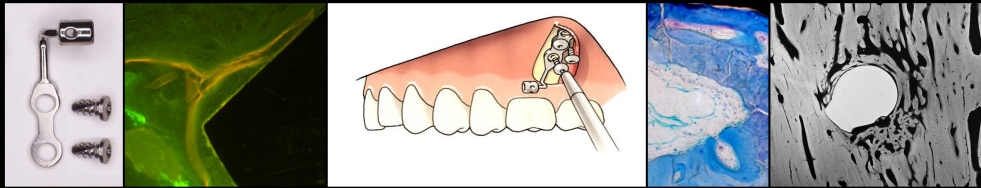


Université catholique de Louvain
Faculty of Medicine

Experimental Morphology Unit
Orthodontics Unit



Miniplates as temporary anchorage in orthodontics : experimental and clinical studies



Marie CORNELIS

Doctoral thesis

Supervisor: Prof. C. BEHETS - Cosupervisor: Prof. H. DE CLERCK

2008

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submitted to obtain the degree of
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Promoteur : Prof. C. BEHETS - Copromoteur : Prof. H. DE CLERCK

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“Find what you love and do it”

Frank McCourt

Acknowledgements

Le parcours de ce doctorat a commencé il y a près de 4 ans, en 2004. Mon mémoire de spécialisation en orthodontie, entre 1999 et 2003, m'avait fait découvrir le passionnant domaine de l'ancrage orthodontique et revoir mes bases d'histologie osseuse par le biais d'une étude pilote ouvrant la porte à la partie expérimentale de cette thèse. Conjointement, une étude clinique en collaboration avec le département d'orthodontie de la *University of North Carolina at Chapel Hill* se dessinait sur le même sujet. Les Professeurs Catherine Behets et Hugo De Clerck m'ont alors proposé de démarrer le présent passionnant projet, combinant recherche expérimentale et clinique, dans un domaine florissant de l'orthodontie. Durant le long périple de cette thèse, j'ai bénéficié de l'aide, du savoir et des conseils de nombreuses personnes, que je tiens à remercier ici.

Je souhaite tout d'abord exprimer toute ma gratitude envers le Professeur Catherine Behets, promoteur de ce travail. Je la remercie pour sa gentillesse et sa patience à mon égard, mais aussi pour sa disponibilité à toute épreuve, son optimisme et sa redoutable efficacité. Elle m'a appris énormément, non seulement sur le plan scientifique mais aussi sur le plan humain, et a veillé sans relâche à ce que ma thèse de doctorat se déroule dans des conditions optimales. Je ne l'en remercierai jamais assez.

Je remercie ensuite mon copromoteur, le Professeur Hugo De Clerck, de m'avoir donné la possibilité de monter dans le train en marche du développement naissant des miniplaques orthodontiques. Son enthousiasme débordant, l'originalité de ses idées et ses talents de clinicien ont été la clé de voûte des miniplaques étudiées dans ce travail, et de la collaboration avec Chapel Hill. Je lui en suis infiniment reconnaissante.

During my thesis, I was very fortunate to work with Professor Kittie Tulloch. I sincerely thank her, not only for sharing her precious knowledge about clinical research, for giving me invaluable advice for writing, or for coaching me along my investigations, but above all for her endless kindness. I am extremely grateful to her for giving me the opportunity to spend 6 months as a visiting research scholar in her excellent department, and I thank her and her husband for graciously being my hosts and caring for me during my stay in Chapel Hill.

I acknowledge Professor Anne-Marie Kuijpers-Jagtman for her critical reading of the present manuscript and for her presence at my defence as a jury member.

Je remercie le Professeur Benoît Lengelé de m'avoir accueillie au sein du laboratoire de Morphologie Expérimentale où j'ai bénéficié d'excellentes conditions de travail, et d'avoir présidé avec efficacité et justesse le comité d'encadrement et le jury de ma thèse de doctorat. Je lui exprime également toute ma gratitude pour son soutien bienveillant face à certaines difficultés rencontrées.

J'adresse mes plus vifs remerciements au Professeur Hervé Reyckler et au Professeur Christian Vanzeveren pour leur lecture critique et rigoureuse de ce manuscrit, ainsi que pour leurs encouragements et leur soutien pendant ces quatre années.

During this project, I had the chance to collaborate with Dr. Nicole Scheffler, who has carried out the clinical perception survey in Chapel Hill while I was doing the same in Brussels. I thank her for her huge motivation and for her massive work throughout the study, but also for her kindness during my multiple stays in North Carolina and for her friendship.

Je remercie le Docteur Pierre Mahy pour le précieux temps passé à placer les miniplaques pour la partie expérimentale de cette thèse, ainsi que pour sa généreuse participation au projet clinique par le remplissage de très nombreux questionnaires. Mille mercis également aux Docteurs Sergio Siciliano, Marc Laloux et Calix De Clercq pour les informations relatives au travers de ces mêmes questionnaires, ainsi que pour la mise au point de la technique de

placement des miniplaques. Je remercie enfin le Docteur Francis Nsimba pour son assistance chirurgicale lors de la partie expérimentale de ce projet.

Merci au Professeur William D'Hoore pour son expertise statistique, au Professeur Jean-Paul Dehoux pour le suivi et la gestion des animaux ainsi qu'au Professeur Jean-Pierre Devogelaer pour l'accès au pQCT. Je les remercie tous trois pour leur gentillesse à mon égard.

In Chapel Hill, I had the chance to have interesting discussions with Dr. Ching-Chang Ko and with Dr. Paolo Cattaneo about both the pQCT and histological aspects of my experimental research. I would like to thank them for their critical opinions, which allowed me to improve the related papers. Also, I express my gratitude to Dr. Gavin Heymann for helping me in the data extraction for the literature review, as well as for sharing with me his enthusiastic points of view about skeletal anchorage. The great help of Debbie Price for the questionnaires and for the data management of the clinical survey, is gratefully acknowledged. Beside this, a special and indelible thought to whoever wanted to go to a party (a birthday party) during my stay in the US!

La participation dynamique, efficace et surtout très sympathique des étudiants chercheurs associés au projet expérimental de cette thèse, Jérôme Duisit et Simon Vandergugten, m'a considérablement aidée. Qu'ils en soient ici très sincèrement remerciés.

Je remercie chaleureusement Claudette Benoît pour la préparation des coupes histologiques et des microradiographies, ainsi que Dominique Dienst pour son assistance technique au pQCT. Pour sa gentillesse, sa disponibilité, sa patience et son sens du travail bien fait lors de la mise en page de cette thèse, je remercie de tout coeur Michelle Parisi. Merci également à Walter Hudders pour son aide dans l'iconographie des publications, à Guillermo Araujo pour le soin quotidien à l'animalerie, ainsi qu'à Bernard Caelen et Dominique Lognoul pour le coup de main pour couper les prélèvements enrobés.

Mes remerciements vont de manière plus générale à tous les membres de l'unité de Morphologie Expérimentale, que j'ai côtoyés et appris à connaître avec beaucoup de plaisir. Les rires et les cris adoptés comme moyen de communication d'un bout à l'autre du labo font partie des très bons souvenirs que je garderai de mon séjour en Morphologie Expérimentale.

Un immense merci à toute l'unité d'Orthodontie de l'Ecole de Médecine Dentaire et de Stomatologie. En particulier, je remercie les assistants qui étaient mes pairs lorsque j'étais en formation, pour leur amitié et leurs encouragements tout au long de ce projet de thèse, et pour toutes ces fois où nous avons refait le monde. Un grand merci également aux assistants en cours de formation et fraîchement diplômés, compagnons de clinique, de lunchs ou de congrès selon l'heure, pour toutes les conversations autour de l'un ou l'autre patient, et pour leur soutien en général. Je remercie sincèrement tous les orthodontistes du service pour le temps passé à compléter les nombreux questionnaires de mon étude clinique. Mes remerciements vont aussi à mes collègues côtoyées en pratique privée, pour leur enthousiasme face aux miniplaques et pour les discussions cliniques motivantes que cela a généré.

Toute ma gratitude revient à mes amies et mes amis pour leurs précieux encouragements et leur soutien tellement appréciés durant ces derniers mois difficiles. J'adresse un clin d'œil amical aux doctorants parmi ceux-ci, et en particulier à Magali Dewaele pour nos interminables discussions d'étudiantes, de thésardes, de dentistes et surtout d'amies. Pour terminer, je voudrais remercier infiniment mes parents pour leur confiance et leur soutien inconditionnel, qui m'ont permis d'être aujourd'hui là où je suis. Merci aussi mes frère et soeur pour l'affection fraternelle que je leur porte et que je reçois en retour. Enfin, je remercie Jean-Benoît pour son aide, son soutien, sa patience et sa compréhension.

This research was supported by the Special Research Fund from the Université catholique de Louvain.

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Chapter 1

General introduction

General introduction

Skeletal anchorage was introduced in orthodontics 25 years ago, to widen the scope of orthodontics by reducing the need for compliance and by simplifying complex treatments, especially in adults. Initially, conventional endosseous implants have been used temporarily for orthodontic anchorage in edentulous (Willems et al. 1999), palatal (Wehrbein et al. 1996) or retromolar (Roberts et al. 1994) areas. More recently, miniscrews and miniplates, which are smaller devices that can be inserted in multiple locations close to the dental arch, have been developed specifically for orthodontic purposes. Miniplates require a more invasive surgical procedure than miniscrews, however, they seem to present better success rates (Chen et al. 2007, Miyawaki et al. 2003) and provide an orthodontic attachment close to the teeth while the screws stabilizing the miniplates are placed at a safe distance from the roots. Miniplates allow free movement of roots past the anchor, for example during *en masse* distalization, while miniscrews, inserted in between the roots, often need to be replaced during orthodontic treatment. Moreover, miniplates open the doors to challenging possibilities of orthopedic treatments (Kircelli et al. 2006, Singer et al. 2000), and alternatives to orthognathic surgery (Sugawara et al. 2002).

Whereas miniplates offer important therapeutic advantages, there are only few prospective clinical series investigating their success rate (Cheng et al. 2004, Choi et al. 2005, Mommaerts et al. 2005), and none of them dealt with their acceptance by patients and practitioners. To the best of our knowledge, no densitometric or histomorphometric evaluation of the bone healing around screws supporting miniplates is reported in the actual fundamental literature. The lack of knowledge in this field was the starting point of the investigations reported in the present dissertation.

GENERAL AIM

The experimental purposes of this thesis were to evaluate the bone healing reactions around screws supporting miniplates by densitometric, microradiographic and histological analysis.

The aims of the clinical investigations were to evaluate the success rate of orthodontic miniplates, to identify adverse effects and outcomes and to document orthodontist's, surgeon's and patient's perceptions of their use.

The data provided by these complementary approaches aimed to contribute to an evidence-based clinical protocol for the use of miniplates.

OVERVIEW OF THE THESIS

Chapter 1 provides a short general introduction to this thesis.

Chapter 2 gives an overview of the biological concepts underlying osseointegration, focusing particularly on the expected bone healing reactions after implantation and after functional loading of implants.

Chapter 3 reviews the experimental literature on implants, miniscrews and miniplates used under orthodontic load. This chapter refers to the publication appended in appendix 1.

In chapter 4, the different types of temporary skeletal anchorage devices are reviewed, in terms of advantages, limitations, indications and complications.

Chapter 5 reports the effect of orthodontic loading on the bone mineral density of the bone surrounding screws supporting miniplates in beagle dogs. The bone mineral density, measured with peripheral Quantitative Computed Tomography (pQCT), was also compared in the maxilla and in

the mandible, as well as after a short (5 weeks) and a long (27 weeks) period of loading. The effect of the direction of load was also analyzed.

Chapter 6 describes the histological components of the bone-metal interface of screws supporting miniplate systems in dogs. The impact of a short (5 weeks) and a long (27 weeks) period of orthodontic loading on osseointegration is reported after observation under fluorescence and ordinary light microscopy. The effects of load, direction of load and implantation site on bone-implant contact and bone volume measured on microradiographs are shown.

In chapter 7, the perceptions of patients having miniplates for orthodontic anchorage are reported, after placement surgery and during orthodontic treatment. The success rate of the use of miniplates in this 97 patients clinical series is mentioned. In addition, orthodontist's opinion regarding to this type of skeletal anchorage is detailed, mostly in terms of handling complexity, indications and treatment facilitation. The questionnaires filled in by the patients and orthodontists during this study are shown in appendix 2.

Chapter 8 describes the techniques of placement and removal of miniplates used for temporary orthodontic anchorage. Surgeon's perceptions of their use are reported following questionnaires (see appendix 3) they filled out after both surgeries. Time, type of anesthesia, prescription of medications are evaluated as well.

Finally, chapter 9 is a general conclusion. Connections are established between the different chapters of the thesis and perspectives are discussed.

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Chapter 2

Biological concepts underlying osseointegration

Biological concepts underlying osseointegration

DEFINITION OF OSSEOINTEGRATION

Osseointegration has been defined as a “direct structural and functional connection between ordered, living bone and the surface of an implant” (Listgarten et al. 1991). A common practice definition of osseointegration could be the presence of direct or nearly direct bone apposition over a substantial portion of the available implant surface (Brunski et al. 2005). It has been suggested that osseointegration corresponds to 60 % to 85 % bony contact at the cortical passage (Albrektsson et al. 1993, Garetto et al. 1995, Roberts et al. 1989). A close contact of bone and implants at the cellular level is a prerequisite for success, and it must allow transmission of forces with little relative displacement of bone and implants (Brunski et al. 2005). Significant correlations were observed between mechanical capacity of implants and bone presence around the fixtures (Brånemark et al. 1997, Sennerby et al. 1992). Because of the rigidly integrated interface preventing the movement of an implant relative to its supporting bone by a mechanism similar to ankylosis, implants fail to move orthodontically and even resist to orthodontic movement, despite intense bone remodelling activity (Roberts 2000).

Osseointegration needs peri-implant endosseous healing, comparable with direct fracture healing, in which the fragment ends become united by bone, without intermediate fibrous tissue or fibrocartilage formation (Schenk & Buser 1998). Like primary fracture healing, osseointegration requires precise fitting, primary stability and adequate loading during the healing period. In addition, osseointegration requires a biocompatible material, i.e. material that does not release any harmful substance and therefore does not elicit adverse tissue reactions. Titanium, either commercially pure or in certain alloys, is generally recognized as being

biocompatible and presents good mechanical properties (Schenk & Buser 1998). Therefore, it is today the material of choice for both dental and orthopedic surgery. No alternative implant materials could provide as much evidence for longevity and satisfying success rates as titanium.

PERI-IMPLANT ENDOSSEOUS HEALING

Immediately after implant placement, gaps and direct bone-implant contacts alternate along the interface (Brunski et al. 2005). Regions of direct contact between the implant and the bordering necrotic bone are responsible for the primary stability mentioned previously, whereas gaps represent potential sites of blood clotting, matrix remodelling, angiogenesis, cell recruitment and differentiation and finally ossification (Brunski et al. 2005). The initial healing reaction involves **woven bone** formation, subsequently covered by **lamellar bone** apposition to adapt bone mass to load (Schenk & Buser 1998). The last step of the healing reaction consists in skeletal adaptation to load by **bone remodelling** (Schenk & Buser 1998) in order to replace the non vital osseous interface.

What is the difference between woven bone and lamellar bone ?

Woven bone is a haphazardly and irregularly organized calcified tissue, which contains numerous randomly distributed osteocytes. From membranous origin, it is formed rapidly (30-50 $\mu\text{m}/\text{day}$) in embryonic development or in response to trauma or skeletal overload, without the need of an existing bone or cartilage surface. Its trabecular architecture confers on it a low density, whereas its high mineral content makes it relatively brittle (Goret-Nicaise & Dhem 1985). Lamellar bone is deposited at a slower rate (0.6 μm to 1.0 $\mu\text{m}/\text{day}$) (Roberts et al. 2006a) and its osteocytes, less numerous than in woven bone, are arranged parallel with the lamellae. Its highly organized architecture, either trabecular or compact, is

responsible for its rigidity, allowing it to resist to mechanical strain. Although their biochemical composition is nearly similar, their respective rate of apposition produces the significant differences in histological appearances of woven and lamellar bone (Gorski 1998).

What is bone remodelling ?

Whereas the term “modelling” designates a change in shape or size of an osseous structure by differential bone formation and resorption along the periosteal and endosteal surfaces, “remodelling” refers to physiologic internal turnover of osseous tissue without change in shape (Lacroix 1971). Controlled by both metabolic and biomechanical mechanisms, remodelling is a specific coupled sequence of resorptive and osteogenic events identified in the XIXth century (Tomes & De Morgan 1853). In trabecular bone, it serves mainly as a flexible source of metabolic calcium regulated by the endocrine system, whereas in cortical bone, it is related to mechanical loading and healing of accumulated tissue damage (Roberts et al. 2006b).

Bone remodelling occurs along vascularised surfaces and is carried on by “basic multicellular units”, i.e. osteoclasts, osteoblasts, connective tissue, nerves and blood vessels (Dhem 1965, Frost 1969). The remodelling cycle is a sequence of cell activation, osteoclastic resorption of old bone, reversal phase and replacement by formation of new bone (Frost 1969, Ham 1969, Parfitt 1994). At the end of the resorption phase starts the formation of the cement substance by differentiating osteogenic cells on the previously resorbing surface. In other words, the cement line delimits the point where resorption ends and bone formation starts; it is a collagen-free, mineralized interfacial matrix laid down between old bone and new bone (Davies 1996, Davies 2003). Once the cement line is formed, osteoblasts

deposit new bone to fill the resorption cavity and are finally buried as osteocytes (Roberts et al. 2006a). In cortical bone, Haversian remodelling comprises a cutting cone of osteoclasts in front, followed by a closing cone lined by osteoblasts (Dhem 1965), resulting in tissular units called “secondary osteon”, which maintain their size, shape and internal organization for many months while travelling through bone in a controlled direction (Parfitt 1994). In general, the duration of the remodelling cycle is proportional to the size of the animal (Roberts et al. 2006a) : 1.5 months in the rabbit, 3 months in the dog, 4.25 months in humans (Roberts 1988).

Around endosseous implants, osteoblasts may lay down bone on the implant surface itself or on the pre-existing bone surface : those phenomena are called contact and distance osteogenesis. Both of them are involved in trabecular bone healing (Davies 2003), whereas cortical bone healing relies mostly on lamellar remodelling, explaining a relatively slow regeneration.

1. Contact osteogenesis

Contact osteogenesis is based on the principle of osteoconduction (Davies 2003). Osteoconduction is defined as bone growth on a surface, including an implant (Albrektsson & Johansson 2001). After implant surgery, blood vessels are damaged, generating hemorrhage and formation of a blood clot. Platelets degranulation releases cytokines and growth factors resulting in directed osteogenic cell recruitment and migration through a transient fibrin-based structural matrix of the blood clot to the implant surface. The implant surface design can influence osteoconduction by modulating the levels of platelet activation, and by anchoring the fibrin scaffold through which these cells travel to the implant surface (Davies 2003).

Once the bone cells get to the implant surface, they synthesize *de novo* bone by laying down a 100- to 400-nm-thick mineralized interfacial matrix equivalent to that of the cement line in lamellar bone remodelling (Davies 2003, Linder et al. 1983, Sennerby et al. 1991). The sequence starts with secretion and adsorption to the substratum of organic components, among which are bone matrix proteins, such as osteopontin and bone sialoprotein (Ayukawa et al. 1998, Davies 1996), which are believed to play roles in cell adhesion and binding of mineral (Butler & Ritchie 1995, Klinger et al. 1998). This interfacial zone might be the source of whatever mechanism of “bonding” between natural hard tissue and biomaterial (Brunski et al. 2000). Mineralization of this matrix occurs by the seeding of nanocrystalline calcium phosphate, preceding collagen fibres, which are not adsorbed to the underlying solid surface. Collagen fibre assembly occurs after the elaboration of the cement line, and is then mineralized to produce bone matrix (Davies 1996).

2. Distance osteogenesis

Distance osteogenesis is the term used when new bone is formed on the surfaces of old bone in the peri-implant site. Very similar to the previously described remodelling process, it can be expected in cortical bone healing since vascular disruption during implant surgery is known to lead to necrosis of the peri-implant cortical bone and its subsequent remodelling by osteoclast invasion from the underlying medullary compartment (Davies et al. 1990). The bone surfaces provide osteogenic cells that lay down a new matrix on bone, finally surrounding the implant.

3. Peri-implant bone remodelling

Implant surgery, even optimal, causes mechanical trauma to the pre-existing bone. About 1 mm of bone surrounding the implant undergoes

necrosis postoperatively. Repair of this damaged area occurs by remodelling (Roberts 1988). The mechanism of osseointegration implies thus a high rate of bone remodelling (300-500 %/year) (Huja et al. 1998). Beside the remodelling of that zone that is frankly altered by the surgery, there is an increased remodelling of cortical bone even some millimetres beyond this damaged region (Brunski et al. 2000). It corresponds to the concept of regional acceleratory phenomenon defined by Frost to describe distant increased remodelling events associated to healing situations and improving local resistance to infection and other challenges. In the maxillo-facial area, these events can be fractures, surgical procedures, tooth extractions, orthodontic treatment, implantation, or periodontal disease (Frost 1994, Roberts et al. 2006b).

How long does this healing phase take ? Damaged bone around an implant cannot be remodelled faster than one remodelling cycle. It is even unlikely that one remodelling cycle would be sufficient for complete repair since all areas of damaged bone probably do not start remodelling simultaneously (Brunski et al. 2005). However, the activation frequency can increase, amplifying the remodelling extent (Parfitt 1984).

Huja et al. suggested that the zone of remodelled bone adjacent to implants is more compliant, and therefore relatively resistant to fatigue loads and able to limit microdamage initiation (Huja et al. 1998, Huja et al. 1999). The high success rates of implants may be due to the presence of this less mineralized region, physiologically compensating for maintaining a stiff, inert, metallic device in living bone (Garetto et al. 1995, Huja & Roberts 2004).

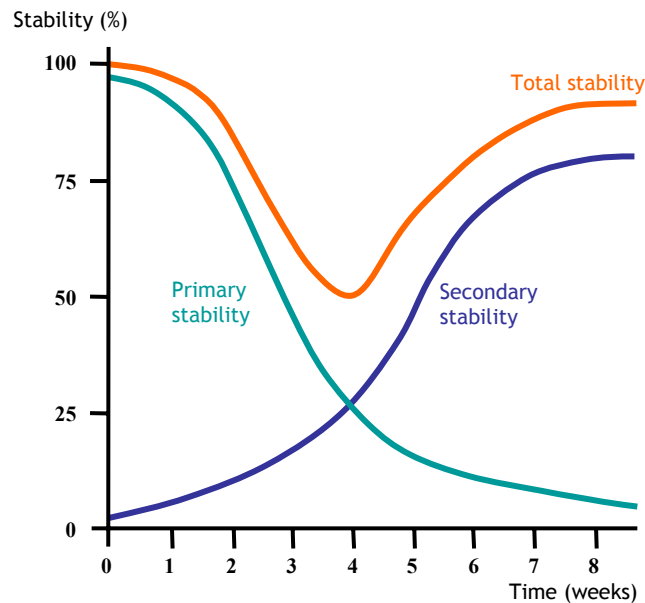


Figure 1.- The decrease in primary stability and the increase in secondary stability result in a general decline in global stability between weeks 2 and 4 after implantation (adapted from Raghavendra S, Wood MC, Taylor TD. Early wound healing around endosseous implants : a review of the literature. *Int J Oral Maxillofac Implants* 2005; 20 : 425-31).

Whereas *primary stability* is obtained by tight-fitting of the implant in cortical bone areas, later on, remodelling substantially contributes to the increase of bone at the interface and generates *secondary stability* (Schenk & Buser 1998) (Fig. 1). Trabecular bone contributes much less to the primary stability. However, trabecular bone remodels far more quickly than cortical bone because of its higher surface/volume ratio, putting it in extended contact with mesenchymal osteoprogenitor cells, circulating mononuclear precursors of osteoclasts and endothelial line needed for angiogenesis. Therefore, trabecular bone represents a tissue ideally featured for rapid bone healing, and should definitely not be considered as “poor quality” bone, even though it does not contribute much to primary stability.

LOADING OF IMPLANTS

As implant loading takes place in healing bone environment, each detail of its application will interfere in peri-implant remodelling.

1. Mechanical control of remodelling

Biomechanical control of remodelling, related to the magnitude and frequency of dynamic loading, can be resumed by the principle of mechanotransduction, which is the conversion of a biophysical force into a cellular response (Turner & Pavalko 1998). In bone, it includes 4 distinct phases : **mechanocoupling** (transduction of a mechanical force applied to the bone into a local mechanical signal perceived by a sensor cell, the osteocyte, which is stretched to the same amount as the bone tissue during mechanical usage), **biochemical coupling** (transduction of a local mechanical signal into a biochemical signal and, ultimately, gene expression and protein activation), **transmission of signal** from the sensor cell to the effector cell (that will actually form or remove bone) and finally **effector cell response**. Although mechanical strain itself was long thought to be the direct stimulus controlling remodelling, strain may simply be the force driving fluid shifts within the bone (You et al. 2000); the fluid flow around osteocytes probably provides the signal directing the remodelling process (Pavalko et al. 2003).

Frost described 4 windows of mechanical usage of bone (Frost 1994). The **acute disuse window** (strain $<50 \mu\text{E}$) corresponds to loads under the level of the optimal range for the balanced steady state : mechanically controlled remodelling stays off and the formation fraction decreases. Within the **adapted window** (strain between 50 and $1500 \mu\text{E}$) formation tends to equalize resorption. The **mild overload window** (between 1500 and $3000 \mu\text{E}$) may apply to the strains caused by some dental implants. Resorption and formation tend to stay equalized, but lamellar remodelling

is now switched on, to strengthen the bone and reduce future strains under the same mechanical loads towards that strain region. Loads exceeding the optimal range result in subperiosteal hypertrophy. By contrast, in the **pathologic overload window** (strains > 3000 μE) anarchic bone resorption, not coupled to formation, can result from woven bone remodelling intending to strengthen bone faster than lamellar remodelling does. Overloading can generate rapid increase of microdamage due to overwhelming of remodelling events that should repair it. This can happen in fatigue fractures and in bone overloaded by endosseous implants (Frost 1994). To summarize, normal bone can adapt to mild overloads, given enough time, but may not endure pathologic overloads neither underloads. Mori and Burr demonstrated the presence of a cause to effect relationship between microdamage and remodelling (Mori & Burr 1993). In presence of mechanical fatigue damage, remodelling events repair and keep it from accumulating by replacement of damaged bone by new bone.

The great strength of bone could come from adjusting its architecture to keep typical strains below its microdamage threshold. The design and use of all load-bearing implants should keep the strains of the supporting bone below its microdamage threshold(s).

2. Effect of magnitude of loading

In normal natural human dentition, maximal vertical biting forces can be about 800 N (Brunski et al. 2005).

Duyck and coworkers, comparing static (3 kg), dynamic (1.5 kg) and non-loaded implants, showed no significant difference in bone contact between the different implant groups, nor between the pressure and non-pressure sides. However, marginal bone resorption was found around the dynamic loaded implants, supporting the hypothesis that excessive load can trigger bone resorption through the induction of microdamage (Duyck et al. 2001).

Isidor showed in an animal model that implants with excessive occlusal load lost osseointegration, and attributed this to fatigue microfractures in the bone exceeding the repair potential (Isidor 1996).

Following Roberts et al., a static orthodontic load between implants that is superimposed on a dynamic functional load may generate an osseous hypertrophic response in the supporting bone (Roberts et al. 1989, Roberts et al. 1984). Other investigations about orthodontic range of loading did not lead to univocal conclusions (see chapter 3).

3. Effect of timing of loading

Previously, a load-free healing period of at least 3 months was recommended after implant placement (Brånemark et al. 1977), mainly because it was thought that the necrotic bone adjacent to the implant surface (Albrektsson et al. 1981) had to be replaced with new bone before applying load (Sagara et al. 1993). However, early loading was later found not to be responsible for failure of osseointegration : as bone remodelling does not occur all at once around the entire implant, the mobility that was feared during the osseous remodelling process was not consistent.

Specifically, only excessive micromotion was directly related to fibro-integration, and not the immediate loading *per se* (Szmukler-Moncler et al. 1998). Moreover, a certain amount of micromotion may favour an increased mineralization of the peri-implant bone, as it is known from osteoporosis and fracture healing research (Frost 1994).

Several animal studies showed that implant loading can be performed immediately without disturbing the biological osseointegration process (Ko et al. 2003, Meyer et al. 2004, Nkenke et al. 2003, Piattelli et al. 1997, Piattelli et al. 1998, Romanos et al. 2002). Peri-implant bone density was even found to be significantly higher around early than around delayed loaded implants (Ko et al. 2003, Piattelli et al. 1997, Romanos et al. 2002).

Some authors found an increase in bone implant contact when comparing immediately loaded implants with delayed loaded ones (Piattelli et al. 1998). By contrast, the bone mineral apposition rate was not found to be affected by immediate loading (Nkenke et al. 2003). These experimental observations were confirmed by clinical studies showing that immediate loading is possible (Degidi & Piattelli 2005, Ottoni et al. 2005, Randow et al. 1999).

MATERIAL RESPONSE : BIOCOMPATIBILITY AND BIOREACTIVITY

Oxidation of metallic implants is responsible for the changes observed in the implant's surface. Commercially pure implants have an oxide thickness of 2 to 6 nm before implantation. However, films on implants retrieved from human tissues are 2 to 3 times thicker (Sundgren et al. 1985). There is thus some release of metallic species into tissues. *In vitro*, metal ions interfere with differentiation of osteoblasts and osteoclasts. It remains to be determined whether these effects on bone cells also occur *in vivo*, specially with oral and maxillofacial implants, which are much smaller than orthopedic implants (Brunski et al. 2000).

There are 2 potential factors affecting the bone-implant interfacial bond : the intrinsic strength of the interface and the roughness of the surface.

The intrinsic bond of the interface is the chemical bonding, corresponding to the strength of the attachment of bone on an implant surface when there is no roughness. This intrinsic strength relies on the strength of the cement line, which should be weak given its non-mineralized make-up (Brunski et al. 2005). For smooth implants, interfacial shear and tensile strengths are lower than the full shear strength of bone (Brunski et al. 2005). It can be concluded that bone-implant interfaces have negligible

chemical bonding : most of their interfacial strength comes from mechanical retention (Wong et al. 1995).

Mechanical retention is given by the surface roughness. The extent of the bone-implant contact increases with the roughness of the implant surface (Buser et al. 1991, Trisi et al. 1999). Davies hypothesized that rough surfaces can capture the fibrin clot more readily than smooth surfaces and thereby positively affect the initial stages of osseointegration (Davies 2003). Distance osteogenesis was shown to predominate in smooth implants, while around rough surfaces both distance osteogenesis and contact osteogenesis are present (Franchi et al. 2004).

The titanium plasma-sprayed (TPS) surface, gives rise to roughened and increased surface area of the implant, in order to provide a greater bone-implant contact (BIC). Hydroxyapatite (HA) coated surfaces, in addition to being rough and highly porous relative to the titanium surfaces, share some characteristics with the mineral content of bone tissue (Cochran 1999). Titanium implants with a roughened surface created by sandblasting, sandblasted and acid-etching (SLA) were also used. Buser et al. showed that SLA, TPS and HA coating demonstrated greater BIC than did titanium implants with smoother surface. The highest BIC was obtained with SLA and HA coating (Buser et al. 1991).

IMPLANT FAILURE

Failure of osseointegration can be divided in early failure and delayed failure, related to occlusal load.

Early failure of dental implants is generally caused by an inability to establish the necessary intimate bone-implant contact. Lack of initial stability, excessive surgical trauma, infection, impaired healing, lack of implant material biocompatibility are possible factors of failure during this direct interfacial bone healing (Esposito et al. 1999). Implants displaying

excessive micromotion stimulate formation of a vascularised, non-mineralized interfacial fibrous tissue with varying degrees of collagen fibre orientation and inflammatory cell infiltrate (Brunski et al. 2005), possibly due to the non-adherence of the fibrin clot to the implant surface during early healing (Davies 2003). Factors that will most likely affect stability include the implant shape, surface and loading, as well as the quality of bone (Brunski et al. 2005).

During functional loading, delayed failure or disruption of established osteointegration can be caused by a range of inflammatory, infectious or biomechanical factors (Adell et al. 1981, Brunski et al. 2005). These latter initiate a vicious circle where damage of bone stimulates remodelling, likely worsening local conditions at interfaces.

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Temporary skeletal anchorage : the experimental literature

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Temporary skeletal anchorage : the experimental literature

INTRODUCTION

One important challenge in orthodontics is to find sufficient anchorage to achieve planned tooth movements. Conventional approaches take advantage of the biological potential of the dentition, frequently in combination with compliance dependent devices such as intermaxillary elastics or headgear. Anchorage possibilities are reduced in adult patients with partial edentulism and/or periodontally compromised dentitions. The development of skeletal anchorage systems has increased the orthodontic treatment possibilities and reduced dependence on patient compliance (Creekmore and Eklund, 1983). Conventional dental implants, when used to provide absolute anchorage (Higuchi and Slack, 1991; Willems *et al.*, 1999) were quickly seen to have the disadvantage of high cost and significant space requirements, and this argued in favor of developing implants located outside the dental arch, specifically oriented to orthodontic needs. Retromolar (Roberts *et al.*, 1990) and palatal implants (Wehrbein *et al.*, 1996; 1999a) were later introduced, but their use is restricted to specific locations; they are expensive, require 3 months healing for osseointegration before orthodontic loading, and provide only indirect anchorage. Smaller, cheaper devices that can be placed in various locations within or adjacent to the dental arch and require much shorter healing periods, such as miniscrews (Costa *et al.*, 1998; Melsen and Costa, 2000) and miniplates (Jenner and Fitzpatrick, 1985; Sherwood *et al.*, 2002), allow wider orthodontic applications and are associated with less surgical trauma and healing time. These devices, grouped under the term of *temporary skeletal anchorage devices* (TSADs), are documented in the clinical literature mostly by case-reports or case series (Ari-Demirkaya *et al.*, 2005; Cheng *et al.*, 2004; Choi *et al.*, 2005; Cornelis *et al.*, 2008;

Kuroda *et al.*, 2007a; 2007b; Liou *et al.*, 2004; Luzi *et al.*, 2007; Miyawaki *et al.*, 2003; Park *et al.*, 2006; Sugawara *et al.*, 2002; 2004; Tseng *et al.*, 2006).

Miniscrews, which are of small size and frequently placed by the orthodontists themselves (Freudenthaler *et al.*, 2001; Giancotti *et al.*, 2004; Hong *et al.*, 2005; Park and Kwon, 2004; Park *et al.*, 2003; 2005; Poggio *et al.*, 2006; Schnelle *et al.*, 2004), are associated with a high failure risk when placed in unattached gingiva (Cheng *et al.*, 2004; Liou *et al.*, 2004; Miyawaki *et al.*, 2003), and root injury when placed in keratinized mucosa (Park *et al.*, 2003). While root impingement is less probable with smaller screws, the risk of failure (Miyawaki *et al.*, 2003) and screw fracture during placement (Buchter *et al.*, 2005) increases as the diameter decreases. Unscrewing moments must be avoided during force application (Costa *et al.*, 1998), and miniscrews may need to be repositioned during treatment to allow complete tooth movements.

Orthodontic miniplates are surgical osteosynthesis plates modified to allow a connection to the orthodontic appliance (Choi *et al.*, 2005; Chung *et al.*, 2002; Cornelis and De Clerck, 2006; De Clerck *et al.*, 2002; Erverdi *et al.*, 2006; Jenner and Fitzpatrick, 1985; Sherwood *et al.*, 2002; Sugawara *et al.*, 2002; 2006; Umemori *et al.*, 1999). Miniplates present some advantage in that the fixation screws are placed at a safe distance from the roots, while the connection to the orthodontic appliance is still located in attached gingiva close to the dental arch. The roots can therefore slide past the device and *en masse* distalization of an entire dental arch can occur (De Clerck and Cornelis, 2006). Clinical reports suggest lower failure rates for miniplates (Miyawaki *et al.*, 2003). Miniplates may also provide more secure anchorage when higher forces, such as orthopedic forces are needed (Kircelli *et al.*, 2006). However, miniplate placement does require flap elevation, and thus is usually carried out by an oral surgeon or periodontist. Clinical studies can provide some evidence concerning the

relative success rate, orthodontic indications and efficiency of these devices, but the factors influencing TSAD's stability or the bone response to orthodontic loading remain largely unanswered by reference to the clinical orthodontic literature alone.

Dental implants have been well-described in the prosthodontic literature; but there are substantial differences between prosthetic and orthodontic anchors : conventional prosthodontic implants are generally only loaded after osseointegration has occurred and are intended to be in place permanently, while miniscrews and miniplates are usually loaded long before osseointegration could be achieved, and are intended to be removed relatively soon. Conventional implants are subject to the high intermittent forces of mastication, while forces to miniscrews and miniplates are light and continuous. The direction of loading and dimensions of the devices also vary between the systems. These fundamental differences raise several important questions about the use of implants for orthodontic anchorage, which may be clarified by reference to the experimental literature.

Studies to determine the functional and morphologic tissue reactions around orthodontically loaded TSADs have been conducted in a variety of animal models. These studies are important because they are generally controlled, and frequently allow histologic evaluation of the bone implant interface and the response of the tissues to force. However, there are some important considerations when translating experimental studies in animals to the clinic. These relate to factors such as differences between humans and animals in the rate of turnover that results in the transformation of immature bone into mature load-resistant bone, the body mass of the experimental animal relative to the magnitude of the load delivered, and the location of the implant in the different experimental models.

Currently three types of orthodontic anchors have been studied in animals : conventional, palatal or retromolar implants (Table 1), miniscrews with a 2.2 mm diameter or less (Table 2) and bone plates (Table 3). The experimental literature concerning the use of miniscrews and miniplates has been reviewed recently (Cornelis *et al.*, 2007), but data from orthodontically loaded conventional, palatal or retromolar implants was not included. Interesting insights can be gained by including information concerning these particular precursor implants, and new information on plates and screws is now available. The PubMed electronic database was the primary source of the relevant literature included in this systematic review. Only those articles that reported on animal studies using orthodontically loaded, intraosseous metal TSADs have been included for a total of 34 studies. Articles on extraosseous implants, wires or onplants, as well as articles involving distraction were excluded. The articles were divided into 3 groups : animal studies testing dental, palatal or retromolar implants under orthodontic load (Table 1); animal studies using miniscrews (Table 2); and animal studies with orthodontic miniplates (Table 3).

The information is summarized to address the specific issues of **stability**, and **tissue response to loading**.

1. STABILITY

Failure rates varied widely from 0 to 43 % in studies with conventional implants (Table 1), 0 to 15 % for miniscrews (Table 2) and 0 to 42 % for miniplates (Table 3). In general, one might expect a higher success rate in humans than animals, since hygiene and compliance should be easier to control. From this systematic review some hypotheses of factors determining stability can be advanced, including healing time, magnitude of load, soft tissue inflammation and screw-to-root contact.

Healing time

One important issue facing clinicians is the optimal time before loading a TSAD. The healing times reported vary between 0 and 48 weeks for implants (Table 1), 0 and 12 weeks for miniscrews (Table 2) and 2 and 12 weeks for miniplates (Table 3).

- Implants

In the rabbit model, clinically acceptable stability is apparently achieved after a short healing time (2 weeks), with a high percentage of direct bone-to-implant contact (Majzoub *et al.*, 1999). An initial healing of 6 weeks without loading was thought necessary by Roberts and coworkers (1984) since direct bone-implant contact depends not only on rigidity at the point of insertion into vital bone, but also on the mechanical stability obtained during the first weeks of healing. They observed spontaneous fractures and 100 % implant failure after immediate loading in rabbit femurs, and concluded that immediate loading is not indicated in any animal species. However, it should be recognized that the applied load was quite high (100 g) and the implant large with reference to the size of animal.

- Miniscrews

In dogs, 3, 6 and 12 weeks of healing periods were compared. The authors concluded that a 3-week healing period is sufficient for orthodontic loading (Deguchi *et al.*, 2003). When this is transposed to the human bone remodelling cycle, it corresponds to a 4 to 5 week healing period being sufficient to allow resistance to the light forces generally used in orthodontic tooth movement.

	Authors and year published	Animal model	Number of animals	Number of loaded TSADs	Number of nonloaded TSADs	Manufacturer	Material
1	Akin-Nergiz <i>et al.</i> , 1998	dog	3	6	12	Bonefit, Straumann, Waldenburg, Switzerland	titanium
2	Aldikacti <i>et al.</i> , 2004	dog	5	6	2	Straumann, Waldenburg, Switzerland	titanium, SLA surface
3	Asikainen <i>et al.</i> , 1997	sheep	5	20	0	Straumann, Waldenburg, Switzerland	titanium, TPS surface
4	Cattaneo <i>et al.</i> , 2007	monkey	4	14	2	Exacta, Biagini Medical Devices, La Spezia, Italy	titanium, sandblasted surface
5	Fritz <i>et al.</i> , 2003	dog	4	15	1	Orthosystem, Straumann, Waldenburg, Switzerland	titanium, SLA surface
6	Gotfredsen <i>et al.</i> , 2001a	dog	3	18	6	ITI Dental Implant System, Straumann, Waldenburg, Switzerland	titanium, TPS surface
7	Gotfredsen <i>et al.</i> , 2001b	dog	3	12	0	Straumann, Waldenburg, Switzerland	titanium, TPS surface or uncoated
8	Gotfredsen <i>et al.</i> , 2001c	dog	3	36	0	ITI Dental Implant System, Straumann, Waldenburg, Switzerland	titanium, TPS surface
9	Hürzeler <i>et al.</i> , 1998	monkey	5	20	20	Nobel Biocare, Cologne, Germany	titanium
10	Liang <i>et al.</i> , 1998	dog	2	12	0	BAM, Huashen, Sichuan, China	titanium, HA surface
11	Liang <i>et al.</i> , 1999	dog	2	24	0	BAM, Huashen, Sichuan, China	titanium, HA surface or TPS surface or uncoated
12	Linder-Aronson <i>et al.</i> , 1990	monkey	2	2	0	Biotes, Nobelpharma, Sweden	titanium
13	Majzoub <i>et al.</i> , 1999	rabbit	10	16	4	not reported	titanium
14	Oyonarte <i>et al.</i> , 2005a; 2005b	dog	5	20	10	Innova Corporation, Toronto, Canada	Ti-6Al-4V alloy, porous-surfaced or uncoated
15	Roberts <i>et al.</i> , 1984	rabbit	14	28	28	not reported	titanium, acid-etched
16	Roberts <i>et al.</i> , 1989	rabbit* - dog**	6* - 4**	12* - 8**	12* - 8**	not reported	titanium, acid-etched
						Biotes, Nobelpharma, Sweden	titanium
17	Saito <i>et al.</i> , 2000	dog	4	8	8	not reported	titanium
18	Southard <i>et al.</i> , 1995	dog	8	8	0	Nobelpharma, Chicago, Illinois, USA	titanium
19	Turley <i>et al.</i> , 1988	dog	6	8	34	not reported	titanium, acid-etched
20	Wehrbein and Diedrich, 1993	dog	2	8	4	Branemark	titanium
21	Wehrbein <i>et al.</i> , 1997	dog	2	6	4	Bonefit, Straumann, Waldenburg, Switzerland	titanium
22	Whebein <i>et al.</i> , 1999b	dog	2	6	4	Bonefit, Straumann, Waldenburg, Switzerland	titanium

Table 1.- Studies testing implants : sample and implant characteristics, loading protocols and outcomes.

Temporary skeletal anchorage : the experimental literature

Length x diameter (mm)	TSAD location	Time before loading (weeks)	Amount of force (g)	Length of loading (weeks)	Failures before loading	Failures after loading	Osseointegration index of loaded and stable TSADs (%)
12 x 4.1	mandible	12	500	36	0	0	40-56
10 x 4.1	maxilla/mandible	6	200	52	0	0	40-49
4.5 x 3.5	forehead	15	250-350	12	0	3/20	N/A
7 x 3.3	maxilla/mandible	17	50	16	0	0	52-86
4 x 3.3	maxilla/mandible	24	50-200	12	4/16	0	N/A
8 x 3.3	mandible	12	N/A*	24	0	0	66
8 x 3.3	mandible	12	N/A*	24	0	0	53-60
8 x 3.3	mandible	12 - 48	N/A*	10 - 46	0	0	81-83
7 x 3.75	mandible	16	300	26 - 32	N/A	N/A	57
10 x 3.5	mandible	12	150	13	0	0	N/A
13 x 3.5	femur	12	200	8	0	0	N/A
7 x unknown	mandible	8	60	8	0	0	N/A
3.25 x 4	calvaria	2	150	8	0	1/16	75
5 x 4.1	mandible	7	300	22	0	1/20	50-72
8 x 3.2	femur	0 - 6 - 12	100	4 - 8	0	9/28	N/A
7 x 3.2 - 13 x 3.75	femur*/mandible**	6* - 8**	100*-300**	4* - 13**	0* - 1/16**	0	>50*-24**
7 x 3.75	mandible	18	200	24 - 32	0	0	70
10 x 3.75	mandible	12	50-100	16	0	0	N/A
6 x 2.4 - 6 x 4.75	mandible/maxilla/temporal/zygoma	10 - 24	300-1000	7 - 18	18/42	0	N/A
10 x 3.75	maxilla/mandible	25	200	26	0	0	N/A
6 x 4	maxilla	8	100-200	26	0	0	N/A
6 x 4	maxilla	8	200	26	0	0	N/A

* the orthodontic force was described as being generated by an expansion device and was not quantified, only the distance and frequency of activation were reported.

	Authors and year published	Animal model	Number of animals	Number of loaded TSADs	Number of nonloaded TSADs	Manufacturer	Material
1	Buchter <i>et al.</i> , 2005	minipig	8	160	32	Absoanchor ¹ , Dentos, Taegu, Korea - Dual-Top ² , Jeil, Seoul, Korea	titanium ¹ - Ti-6Al-4V alloy ²
2	Buchter <i>et al.</i> , 2006	minipig	8	160	32	Absoanchor ¹ , Dentos, Taegu, Korea - Dual-Top ² , Jeil, Seoul, Korea	titanium ¹ - Ti-6Al-4V alloy ²
3	Deguchi <i>et al.</i> , 2003	dog	8	48	48	Stryker Leibinger, Kalamazoo, Michigan, USA	titanium
4	Kim <i>et al.</i> , 2005	dog	2	32	0	Osas, Epoch Medical, Seoul, Korea	titanium
5	Melsen and Costa, 2000	monkey	4	16	0	Aarhus screw, Medident Hellerup, Denmark	titanium vanadium
6	Melsen and Lang, 2001	monkey	6	10	2	Straumann, Waldenburg, Switzerland	titanium, TPS surface
7	Morais <i>et al.</i> , 2007	rabbit	18	36	36	Conexao Sistemas de Proteses, Sao Paulo, Brazil	TI-6Al-4V alloy
8	Ohmae <i>et al.</i> , 2001	dog	3	12	24	Sankin, Tokyo, Japan	titanium
9	Yano <i>et al.</i> , 2006	rat	20	20	20	ISA Orthodontic implants, Biodent, Tokyo, Japan	titanium

Table 2.- Studies testing miniscrews : sample and implant characteristics, loading protocols and outcomes.

	Authors and year published	Animal model	Number of animals	Number of loaded TSADs	Number of nonloaded TSADs	Manufacturer	Material
1	Cornelis <i>et al.</i> , submitted for publication; in press	dog	10	40	40	Bollard, Surgi-Tec, Bruges, Belgium	plates: titanium - screws: TI-6Al-4V alloy
2	Daimaruya <i>et al.</i> , 2001	dog	6	6	6	Sankin, Tokyo, Japan - Leibinger, Freiburg, Germany	titanium
3	Daimaruya <i>et al.</i> , 2003	dog	6	6	6	Sankin, Tokyo, Japan - Leibinger, Freiburg, Germany	titanium

Table 3.- Studies testing miniplates : sample and implant characteristics, loading protocols and outcomes.

Temporary skeletal anchorage : the experimental literature

Length x diameter (mm)	TSAD location	Time before loading (weeks)	Amount of force (g)	Length of loading (weeks)	Failures before loading	Failures after loading	Osseointegration index of loaded and stable TSADs (%)
10 x 1.1 - 10 x 1.6	mandible	0	100-300-500	3 - 10	0	5/160	N/A
10 x 1.1 - 10 x 1.6	mandible	0	100-300-500	3 - 10	0	5/160	49-86
5 x 1	maxilla/mandible	3 - 6 - 12	200-300	12	3/96	0	31-40
N/A x 1.6	maxilla/mandible	1	200-300	11	N/A	3/32	23-44
8 x 2.2	maxilla/mandible	0	25-50	4 - 8 - 16 - 24	0	2/16	10-58
6 x 2.2	mandible	12	100-200-300	11	0	0	40-45
6 x 2	tibia	0	100	1 - 4 - 12	0	3/30	N/A
4 x 1	mandible	6	150	12 - 18	0	0	25
4 x 1.2 - 4 x 1.4	tibia	0 - 6	200	2	N/A	3/20	33-88

Length x diameter (mm)	TSAD location	Time before loading (weeks)	Amount of force (g)	Length of loading (weeks)	Failures before loading	Failures after loading	Osseointegration index of loaded and stable TSADs (%)
5 x 2.3 (2/plate)	maxilla/mandible	2	125	5 - 27	2/80	17/40	1-77
5/7 x 2 (3/plate)	mandible	12	100-150	16 - 28	0	0	N/A
5/7 x 2 (3/plate)	maxilla	12	80-100	16 - 28	0	0	N/A

This raises the question as to whether immediate loading could or should be recommended. Five animal experiments (Table 2 : 1, 2, 5, 7 and 9) reported immediate loading. In general, the success rates were very high, varying from 89 % to 97 % (Table 2). Supporting this conclusion, Yano *et al.* (2006) found no difference in bone-implant contact between immediately loaded tapered miniscrews and the same screws loaded after a 6-weeks healing period. In addition, Morais *et al.* (2007) did not find any increase in removal torque values between 1 and 4 weeks of healing, although they did note that after 12 weeks, the removal torque values increased significantly, perhaps suggesting favorable bone changes with increased time. Finally, Huja *et al.* (2006), not cited in Table 2 because in their experiment the implants remained unloaded, showed that pullout strength stresses of miniscrews did not differ between immediate placement and 6 weeks post-insertion, supporting the concept of immediate loading.

Implant stability depends on the initial degree of mechanical stability achieved at placement. Mechanical stability depends on the thickness of the cortical bone (Huja *et al.*, 2005; 2006), the implant site preparation - the larger the pre-drilling diameter, the lower the primary stability - and the screw design (Wilmes *et al.*, 2006). Tapered screws seemed to provide better primary stability than straight screws (Yano *et al.*, 2006). Implant stability can be optimized by using a non-drilling procedure, since a higher bone-to-implant ratio was found to be correlated with the absence of preliminary drilling when compared to a procedure that required drilling before placement (Kim *et al.*, 2005). This finding was confirmed by two *in vitro* studies, that suggested pre-drilling should be required in all regions of high bone density (thick cortical bone) (Lohr *et al.*, 2000; Wilmes *et al.*, 2006), whereas non-drilling procedures perform better in cancellous bone (Lohr *et al.*, 2000).

- Miniplates

None of the miniplates experiments used immediate loading; one team loaded the miniplates after 12 weeks (Daimaruya *et al.*, 2001; 2003), and the other after two weeks (Cornelis *et al.*, submitted for publication; in press), corresponding to the healing time of 3 weeks recommended by the same authors in patients (De Clerck and Cornelis, 2006). In this study, mobility occurred on average 5 weeks after implantation, which might represent the critical stage of transition between primary and secondary stability (Schenk and Buser, 1998). If correct, this observation would suggest that loading should be planned either earlier or later than 5 weeks, but not close to that specific time point. It is apparent that surgical technique is important to enhance primary stability. Woven bone was observed as a repair process when the initial hole had to be redrilled on a slightly different axis (Cornelis *et al.*, in press). Since this re-drilling procedure is likely to produce some instability, a drill-free technique might be preferred. Heidemann *et al.* (2001) showed that screw-bone contact with drill free screws was superior to that of self-tapping screws used for osteosynthesis after orthognathic surgery or fracture.

Magnitude of load

With regard to the selection of appropriate forces, this literature reports such a wide variation in forces, particularly when considering the size of the experimental animals, that interpretation of the findings is difficult. It remains impossible to determine from the evidence so far available, what the lower and upper thresholds might be that would switch a positive balance to a negative one. This is an important area for future research, since the application of TSA in orthodontics has already broadened to include such indications as single tooth or whole arch intrusion, and orthopedic correction of skeletal problems. These applications may all call for very different force systems, but the threshold for bone resorption or negative remodelling is still not clearly known.

- Implants

The majority of studies tested forces ranging from 50 to 350 g and very few failures were noted (Table 1). The one study showing a higher failure rate did use 300 to 1000 g, however it was not clearly shown that increased load was associated with failure (Turley *et al.*, 1988).

- Miniscrews

The forces that were tested ranged from 25 g to 500 g (Table 2). Using finite element analysis correlated to histological results (Melsen and Lang, 2001) suggests that both very low and very high strain values resulted in a high incidence of resorption and a negative remodelling balance. Between these extremes, an increase in strain is followed by an increase in bone remodelling, generating a positive balance. In minipigs, mobility was observed with a 300 g loading whereas no mobility was reported with a 100 g force (Buchter *et al.*, 2005; 2006).

- Miniplates

The forces tested varied between 80 and 150 g (Table 3), and loading appeared to have no definite effect on stability since the success rate was not significantly different in loaded vs nonloaded plates (Cornelis *et al.*, submitted for publication).

Soft tissue inflammation

It is known from the clinical literature that prevention of inflammation of the peri-implant tissue is a critical factor regarding miniplate success rate (Choi *et al.*, 2005; Miyawaki *et al.*, 2003). Recently, crevices around titanium orthodontic plates in patients were shown to be supportive of anaerobic growth of bacteria, likely to stimulate peri-implant inflammation leading to implant loosening (Sato *et al.*, 2007).

- Implants

Mild clinical inflammation was noted in most of the included studies, but there were no reports of severe inflammatory reactions. At the microscopic level, most authors reported no inflammatory reaction in the interface zone, except for the marginal area where inflammation due to gingivitis was frequently observed. An early study in dogs suggested that implant placement in non-keratinized tissue constitutes a risk factor because it might generate soft tissue inflammation (Turley *et al.*, 1988).

- Miniscrews

The highest rate of mobile screws was reported in the only study that placed screws in non-keratinized mucosa (Melsen and Costa, 2000), suggesting that placement in non-keratinized mucosa might be a risk factor. In contrast, immediate loading of completely submerged TSADs (screws and coil-springs covered by soft tissues) had a low failure rate (5 of 160)(Buchter *et al.*, 2005), suggesting once again the key role played by the soft tissues.

- Miniplates

Miniplates mobility was reported to be systematically associated with gingival inflammation (Cornelis *et al.*, submitted for publication), although one other study showed slight inflammatory changes at the transmucosal area but reported no failures (Daimaruya *et al.*, 2001; 2003).

Screw-to-root contact

From the clinical literature root proximity has been proposed as major risk factor for miniscrew failure (Kuroda *et al.*, 2007b). An experiment in dogs, not included in the review since no loading was applied on the orthodontic miniscrews, showed almost complete repair of the periodontal structure within 12 weeks after root damage caused by the screws (Asscherickx *et*

al., 2005). For all three types of TSADs, implant-root contact was so infrequently reported that conclusions drawn were tenuous at best.

2. TISSUE RESPONSE TO LOADING

The effect of loading on bone healing around implants is of critical importance; a negative effect might decrease TSAD stability, whereas a positive could compromise the ease of removal of the device once the anchor is no longer needed. The effect of loading on bone-implant contact and bone remodelling has been discussed in the literature. It has been hypothesized that remodelling around implants generates a compliant layer of bone preventing microdamage accumulation and allowing long-term success of endosseous implants (Huja *et al.*, 1999). Microcalli have been observed in clinical conditions, and attributed to microrepair after orthodontic load (Trisi and Rebaudi, 2002). With regard to the effect of load on osseointegration, it has been shown that the strain levels generated by orthodontic are considerably lower than occlusal forces, and lower than the adapted window magnitudes (Frost, 1990), suggesting an absence of effect of load on bone-implant contact (Cattaneo *et al.*, 2007).

▪ Implants

The reported bone-implant contact in different studies varied from 24 to 86 % (Table 1). Minimal integration index related to stability of orthodontically loaded implants was reported to be 10 % (Roberts *et al.*, 1989). High bone remodelling was observed by most of the authors (Table 1 : 2, 4, 5, 6-8, 16, 19) around loaded as well as nonloaded implants. Loading was shown to increase bone remodelling (Table 1 : 1, 4, 15, 20-22). By contrast, the 6 studies reporting quantitative data could not determine a statistically significant effect of orthodontic load on bone-implant contact (Table 1 : 2, 9, 13, 14, 16, 17). The type of stress applied, whether compression or tension, was not associated with difference in

bone response in 9 of the included papers (Table 1 : 2, 6, 8, 13, 14, 17, 20-22). Thus, the hypothesis of an effect of load on degree of osseointegration is not supported by the quantitative analyses currently available. It may be that the morphometric techniques used to determine integration indices differ so widely among studies, that unequivocal conclusions cannot be drawn about the relationship between load and osseointegration.

The effect of coating around regular implants has been studied. The highest shear bond strength was found for hydroxyapatite- (HA-) coated implants compared to titanium plasma sprayed- (TPS-), and uncoated implants (Liang *et al.*, 1999). Increased bone-implant contact was found for TPS- (Gotfredsen *et al.*, 2001b) and porous-surface (Oyonarte *et al.*, 2005a; 2005b) implants compared to machined-surface implants. From these studies, we can speculate that uncoated implants might be preferred to prevent excessive osseointegration and complicated later surgical removal.

- Miniscrews

Bone-implant contact varied from 25 to 86 % (Table 2). Thus, titanium screws do resist, in general, orthodontic forces, maintaining their initial positions without marginal bone loss. This is in contradiction with some clinical results stating that screws are clinically stable but not absolutely stationary when loaded (Liou *et al.*, 2004). Osseous contact with an implant as low as 5 % (Deguchi *et al.*, 2003) has been shown to resist orthodontic loads. Some authors (Ohmae *et al.*, 2001) suggested an integration index of 25 % to be a reliable anchorage tool. Lower values of osseointegration were generally obtained with miniscrews compared to conventional implants (Table 2 : 3, 5, 6, 8). Obviously complete osseointegration would be undesirable for a temporary anchor device, and it seems clear that screws can serve as anchorage even with a very low integration index. As long as mechanical stability is obtained,

osseointegration is probably not necessary at all, but when titanium is used a certain percentage of bone-implant contact is obtained, even if the achievement of osseointegration is not a goal in itself.

Remodelling was reported to be higher around loaded than unloaded screws (Melsen and Lang, 2001; Ohmae *et al.*, 2001). High bone remodelling with intense formation of woven bone around the screws was observed 3 weeks after placement, whereas predominant lamellar bone was found after 6 or 12 weeks (Deguchi *et al.*, 2003). However, quantitative studies could not determine any significant effect of orthodontic load on bone-screw contact (Table 2 : 2, 3, 6, 8, 9), even though removal torque values were reported to be higher in nonloaded implants compared to loaded ones (Morais *et al.*, 2007). The type of stress applied, whether compression or tension, was not associated with difference in bone response (Melsen and Costa, 2000; Melsen and Lang, 2001).

The degree of osseointegration increased with the time the miniscrews were loaded (Buchter *et al.*, 2006; Melsen and Costa, 2000).

- Miniplates

Direct bone-to-metal contact has been reported around titanium bone screws supporting osteosynthesis miniplates used for mandibular fracture treatment (Cheung *et al.*, 1995; Hirai *et al.*, 2001; Hwang *et al.*, 2000). Only two teams studied bone healing around orthodontically loaded miniplates in experimental conditions. One group described bone-to-metal contact around the screws supporting the miniplate system, and claimed that it increased under loading. This has not been assessed quantitatively however (Daimaruya *et al.*, 2001). The other group found no significant difference in bone-implant contact between the screws of the loaded plates and the screws of the nonloaded ones (Cornelis *et al.*, in press). In this study, bone-implant contact of screws associated with a stable plate

ranged from 1 to 77 %. However, plate stability with a screw having a bone-to-metal contact as low as 1 % could result from a high percentage around the other fixation screw, or to the presence of bone in contact with the miniplate itself.

They also observed bone-implant contact increased with time, not only with the screw but with the plates (Cornelis *et al.*, in press). This might argue in favor of removing the plates as soon as they are no longer necessary, since osseointegration of the screws and plates could seriously impede plate removal.

CONCLUSIONS

Titanium devices for skeletal anchorage have gained rapid acceptance into orthodontic practice. The experimental literature, when summarized, does provide some interesting insights into the application of TSADs and to their management in clinical practice.

While implant failures remain largely unexplained, factors such as healing time, magnitude of load, soft tissue inflammation and possibly screw-to-root contact may influence the success rate. There is as yet little agreement as to what is the optimal loading needed to maintain stability. Immediate loading of miniscrews seems to be acceptable if the range of force is low, although currently there is no evidence to support immediate loading of implants or miniplates. Further research is needed. Immediate loading requires fair primary stability, which depends on the thickness of the cortical bone, placement technique and screw design. All studies agreed on clinical stability of TSADs under orthodontic loading, and some degree of bone-implant contact occurring. TSADs do, in general, resist orthodontic displacement forces absolutely maintaining their initial position, even in the presence of levels of osseointegration as low as 10 % for implants and 5 % for miniscrews. Might there be other materials that

are as biologically acceptable, but do not encourage osseointegration in the way titanium does ? Some stainless steel screws are available on the market, but have been tested only in vitro up to now (Chin *et al.*, 2007).

Loading was shown to increase bone remodelling, but not bone-to-implant contact. Uncoated implants, miniscrews or miniplates should be preferred to avoid excessive osseointegration. Since osseointegration is shown to increase with time, it is recommended to remove the TSADs as soon as they are no longer needed.

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Skeletal anchorage in clinical orthodontics

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Management of anchorage is a key factor for orthodontic treatment success. Newton's third law states that for every action there is an equal and opposite reaction. When orthodontic forces create a desired action to move teeth, the equal and opposite reaction is often unwanted. Orthodontic anchorage can be defined as the resistance to this unwanted tooth movement (Proffit 2007). If adequate anchorage is not available during treatment, not only tooth movement in the active unit may be limited, but unwanted changes may also appear in the resisting or inactive unit.

Classically, inherent anchorage potential of the teeth in their supporting alveolar bone can be enhanced by grouping more teeth against fewer teeth, by creating differential tipping positions or by positioning the roots into cortical bone. Beside this, both intra-oral (Nance button, transpalatal arch, lingual arch, intermaxillary elastics...) and extra-oral (headgear, facemask...) appliances are frequently used to increase dental anchorage, but their efficiency is limited either by biomechanical drawbacks and anchorage loss, or by poor patient's compliance. In adults, the absence of multiple teeth, the reduction of periodontal support or an inadequate occlusion, further restrict the anchorage possibilities.

Skeletal anchorage, introduced in the early eighties (Creekmore & Eklund 1983), is now increasingly used, not only to overcome the limits of conventional anchorage, but also to achieve treatments previously thought beyond the scope of orthodontics. As mentioned before, dental implants react like ankylosed teeth : they are not able to move orthodontically since they are not surrounded by a periodontal ligament. Cope defined as *temporary anchorage device* a device that is "temporarily fixed to bone for the purpose of enhancing orthodontic anchorage either by supporting the

teeth of the reactive unit or by obviating the need for the reactive unit altogether, and which is removed subsequently after use” (Cope 2005). The term temporary *skeletal* anchorage device (TSAD) might even be preferred to underline the intra-bony property of these devices (Cornelis et al. 2007). The aim of these TSADs, allowing a continuous force without need for compliance, is to achieve infinite anchorage, preventing any anchorage loss as a consequence of reaction forces. However, TSADs are not only an alternative to conventional anchorage techniques relying on patient’s compliance; they also widen the range of feasible treatments. Following Melsen, skeletal anchorage is indicated when insufficient teeth are available, when forces on the resisting units would generate adverse side effects, when asymmetrical tooth movements in all planes of space are needed, and finally as an alternative to orthognathic surgery (Melsen 2005). Skeletal anchorage can be used either as direct anchorage, when the forces originating from the implant itself are used to augment anchorage, or as indirect anchorage, when the TSAD stabilizes the teeth, which then serve as an anchor unit (Celenza & Hochman 2000).

Ideally, TSADs should not require invasive placement and removal surgeries. They should be simple to connect to the orthodontic appliance and able to withstand orthodontic forces. They are also expected to be inexpensive, early loadable, and biocompatible, as well as provide equivalent or superior clinical results than traditional anchorage systems (Cope 2005). Although the risks are limited, still an informed consent is recommended.

Prosthetic implants can be used for orthodontic anchorage; however, their use is restricted to the edentulous ridges of patients requiring pre-prosthetic orthodontics. To overcome this limitation, implants were placed in the palate and in the retromolar areas. Onplants were also used in the palate. However, retromolar and palatal implants or Onplants are expensive, require a healing period of at least 2 months before loading to

allow osseointegration, and have limited applications due to their location. Moreover, palatal and retromolar implants removal requires a trephine. These restrictions opened the way to miniscrews and miniplates, which are cheaper, smaller and suitable for multiple locations within the jaws. Their primary stability permits immediate or early loading within 3 weeks of placement. Their surface is generally smooth, by contrast with implants, to avoid important levels of osseointegration that would impede their removal with a screwdriver. Unlike osseointegrated implants, their placement does not require antibiotic coverage. However, they do not tolerate unscrewing moments and as heavy loads as those supported by osseointegrated implants (Costa et al. 2006).

These different types of skeletal anchorage are briefly summarized in the following section.

PROSTHETIC IMPLANTS

Edentulous ridges can be used as implantation sites in patients missing teeth (Higuchi & Slack 1991, Kokich 1996, Odman et al. 1988, Odman et al. 1994). Those implants can be used primarily as orthodontic anchorage and subsequently for prosthodontic replacement of the teeth. However, this double aim requires a careful interdisciplinary treatment planning with diagnostic set-up before placement of the implant, to make sure that the location and orientation of the implants will be compatible with the occlusion and alignment after orthodontic treatment (Kokich 1996, Willems et al. 1999). An experimental study in dogs showed that orthodontic loading of conventional implants does not generate any mobility or attachment loss that might impede an ulterior prosthetic use (Akin-Nergiz et al. 1998).

RETROMOLAR IMPLANTS

Roberts and co-workers placed 3.75 mm diameter and 7 mm length implants in the retromolar areas of the mandible (Roberts et al. 1996, Roberts et al. 1990, Roberts et al. 1994). Those initially submerged implants are uncovered after 4 months to place an anchorage wire between the implant and the fixed appliance. This wire is inserted in a vertical slot of a bracket, in order to stabilise the anterior teeth during protraction of the molars. Those implants are thus used as indirect anchorage. Although this system has been shown to be very efficient for mandibular molar mesialization into extraction or agenesis sites, the indications are however limited. Moreover, some inflammation is often present around the transmucosal wire. In case of loosening of the wire, the site would have to be re-exposed surgically. Histological analysis of a trephined implant showed osseointegration of about 80 % (Roberts et al. 1990), confirming sufficient stability for orthodontic anchorage purposes.

PALATAL IMPLANTS

Palatal implants were first described by Wehrbein and coworkers (Wehrbein et al. 1996). The Orthosystem (Straumann, Switzerland) consists in a 4.1 or 4.8 mm diameter and 4.2 mm length titanium screw-implant with sandblasted and acid-etched surface, and a fixation cap for the transpalatal arch connecting the implant to the teeth. Palatal implants are usually inserted in the anterior midpalate. The length of the implant is reduced to avoid any perforation of the nasal cavity (Wehrbein et al. 1999b). Initially, two lengths were available, 4 mm and 6 mm, and the choice between both was made following a lateral cephalogram (Cousley 2005). Recently, in patients with limited palatal bone height, some authors recommended computerized navigation surgery to increase safety and accuracy during drilling (Wexler et al. 2007).

By contrast with retromolar implants, palatal implants are not submerged during healing, and do not need a second surgery to be uncovered. A transpalatal bar connects the teeth to the implant, which is thus used as indirect anchorage : the forces are transmitted from the implant to those anchoring teeth. This transpalatal bar is usually realized by the laboratory. However, it can be constructed during a more time consuming chair-side procedure to reduce the costs (Crismani et al. 2002, Tinsley et al. 2004). Orthodontic loading was shown to generate some slight anchorage loss, probably related to the deformation of the palatal arch (Wehrbein et al. 1999a). To prevent any loss of anchorage, palatal bars thicker than 1.2 x 1.2 mm should be used (Crismani et al. 2007).

Palatal implants are usually loaded after a 3 months healing period (Wehrbein & Merz 1998). However, a recent study involving 20 patients reported a 90 % success rate when loading was applied after only one week. The authors showed that the stability assessed by resonance frequency analysis over a period of 12 weeks decreased after 2 and 3 weeks post-surgery and then increased from 6 weeks post-surgery (Crismani et al. 2006). They hypothesized that the initial decrease in stability might be related to the formation of woven bone, while the subsequent increase in stability might correspond to the replacement of woven bone by lamellar bone, which is the achievement of secondary stability described before. Palatal implants are usually removed with a trephine as soon as they are no longer needed for anchorage, but a recent study showed that those osseointegrated implants can be simply removed at the end of the treatment by unscrewing them without invasive trephining (Favero et al. 2007). The same team reported complete healing of the mucosa one week after surgery.

Palatal implants are mainly indicated in class II malocclusions treated by extraction of two upper premolars and *en masse* retraction of canines and incisors. A recently conducted randomized clinical trial compared the

effect of palatal implants to headgear in 51 patients treated with extraction of upper premolars to correct a class II malocclusion (Benson et al. 2007). The authors found no statistically significant differences between both groups, though teeth moved more mesially in the headgear group. Palatal implants were also used in non-extraction treatments, to distalize molars. By comparison with distalization with a pendulum appliance, palatal implant-supported pendulum showed significantly less anchorage loss in the incisor and premolar areas (Oncag et al. 2007).

In the previously mentioned study testing a shorter healing period (Crismani et al. 2006), the reasons evoked for failure were interference with the tongue and a too high insertion torque during placement. Another recent study with 14 patients obtained a 79 % success rate, even though the implants were allowed to heal for 13 weeks (Arcuri et al. 2007). The authors reported that the main risk of palatal implants is perforation of the nasal cavity. In 2001, a prospective study with 21 patients reached a success rate of 84.8 % with a healing period of 4 months (Bernhart et al. 2001). Most of the failures happened shortly after the initiation of direct loading, and were attributed to large transverse forces during preparation of impression.

In children and adolescents, placement of implants in the anterior midpalate is not indicated since the sagittal suture is not fused yet, and successful osseointegration can only occur if there is enough bone available. Since complete ossification of the palatal suture is rare before the age of 23, some authors advised implantation in a more posterior area of the palate, which is usually more fused than anteriorly (Schlegel et al. 2002). However, the thickness of the palate decreases laterally and posteriorly (Kang et al. 2007). To overcome these problems, the paramedian region of the anterior palate has been suggested for placement of implants in young patients. Moreover, this area presenting

more bone than the midsagittal region, might be encouraged in adults as well (Bernhart et al. 2000).

A questionnaire study revealed that palatal implants were well accepted : 95 % of the patients were satisfied with the treatment and 86 % would recommend it to other patients (Gunduz et al. 2004). Others asked patients to compare placement of a palatal implant with premolar extractions and found out that implants placement was significantly less painful than premolar extraction (Feldmann et al. 2007).

The effects of orthodontic loading on maxillary palatal and alveolar implants were compared in a dog model (Wehrbein et al. 1997). All implants remained stable and well osseointegrated. However, bone was denser around palatal than alveolar implants. More fibrous tissue was present in the palate than in the alveolar bone, probably related to the presence of the palatal suture.

ONPLANTS

Block and Hoffman described a hydroxy-apatite coated titanium disk, 10-mm-diameter and 2-mm-thick, called Onplant (Nobelbiocare, Sweden), which is placed under the periosteum of the posterior palate (Block & Hoffman 1995). The authors reported good clinical stability during orthodontic movement, without inflammatory reactions around the Onplant.

Placement surgery is performed under local anesthesia. In order to limit the risk of infection, it is recommended to slide the disk towards the midpalate through a subperiosteal tunnel starting in the canine area. The Onplant is subsequently uncovered after 4 months of healing to allow for osseointegration. An impression is then taken for preparation of the transpalatal bar connecting the Onplant to the orthodontic appliance.

Removal requires resection of a mucosal disk covering the Onplant, which is detached with an osteotome.

By contrast with palatal implants, this extra-osseous device is allowed in young children as well as in adults with reduced bone height in the palatal region. However, even though surgery is less invasive than for palatal implants, the placement technique is not considered easy and requires two surgeries. Another disadvantage is that failure of osseointegration will be discovered only 4 months after placement since the Onplant is covered during the healing phase (Celenza & Hochman 2000).

Indications are similar to those of palatal implants. Use of Onplants was also reported for forced eruption of impacted teeth (Janssens et al. 2002) and for maxillary molar distalization (Bondemark et al. 2002).

Finally, an experimental study in dogs confirmed that the disks are well osseointegrated with direct bone apposition on the hydroxyapatite basis of the disk (Hollis et al. 1994).

MINISCREWS

The main characteristic shared by *temporary skeletal anchorage devices* described as miniscrews is their small size. They are often referred as *miniscrews* and *mini-implants*, sometimes as *microscrews*; in the present thesis, the term miniscrew will be preferred.

Miniscrews have a diameter of 2.5 mm or less, and a length generally comprised between 6 and 12 mm (Cope 2005). A diameter under 1.2 mm represents a high risk of breakage (Mah & Bergstrand 2005) : a reduction of 0.2 mm reduces the resistance of the screws of about 50 % (Carano et al. 2005). A decrease in diameter also decreases the insertion torque and thus primary stability (Lim et al. 2008). However, the larger the diameter, the higher the risk of root impingement. Following a study based on CT scans,

a diameter of 1.5 mm and a length of 6-8 mm are the maximal dimensions for safe insertion in alveolar areas (Deguchi et al. 2006).

The shape of miniscrews is either straight or conical, without any agreement in the literature yet about the preference between those 2 options (Carano et al. 2005, Mah & Bergstrand 2005). The head of the miniscrew usually consists in a button, a slot, a hole or a hook to connect an attachment to the fixed appliance. The proportional lengths of intraosseous and transmucosal parts vary to allow placement in different locations (Melsen 2004). The screws are either self-tapping or self-drilling.

Most of the miniscrews are made of commercially pure titanium or titanium vanadium alloy (Ti6Al4V), with the exception of the Orthodontic Mini Implant (Leone, Italy) which is made of stainless steel (Papadopoulos & Tarawneh 2007). Even though stainless steel is more resistant to breakage than titanium, its performance in terms of biocompatibility and flexibility is inferior to titanium. However, the mechanical properties of both titanium and stainless steel screws allow their safe use in orthodontics (Carano et al. 2005).

The surface of orthodontic miniscrews is usually smooth in order to prevent mucosal inflammation on the collar and to limit osseointegration on the intra-osseous part (Melsen 2004). Their cost is low compared to dental implants.

Historically, Creekmore and Eklund were the first ones to suggest the use of vitallium bone screws for orthodontic applications (Creekmore & Eklund 1983). In 1996, a French team used an impacted post made of stainless steel alloy, 0.7 mm diameter and 6 mm length (Bousquet et al. 1996). In 1997, Kanomi introduced the term *mini-implant* (Kanomi 1997). However, in this report, the screws were covered by the soft tissues during a long healing time, before uncovering for orthodontic loading. Costa and co-workers developed the Cizeta screw (Italy) (Costa et al. 1998). The Aarhus Anchorage System (Medident, Germany), made of titanium vanadium, was

described in 1999 (Melsen & Verna 1999). Some authors used transitional prosthetic implants for orthodontic anchorage purposes (Gray & Smith 2000). The term *micro-implant* was later reported, these screws were claimed to sustain 200-300 g without need for osseointegration (Bae et al. 2002). The AbsoAnchor screw was described in 2003, with a button shape head with hole for elastomers, and a diameter as small as 1 mm (Kyung et al. 2003a). The same year, Lin and Liou produced the LOMAS system (Lin & Liou 2003), and Maino and colleagues the Spider screw (Maino et al. 2003, Maino et al. 2005). In 2004, the Miniscrew Anchorage System (M.A.S.) was described (Carano et al. 2004). New systems appeared further in 2005 : the C-Implant (Chung et al. 2004) and the Ortho Implant from IMTEC (USA) (Herman & Cope 2005).

Usual locations are the retromolar area, the anterior nasal spine, the palate, the infrazygomatic crest and the alveolar process in the maxilla; the retromolar area, the alveolar process and the symphysis in the mandible. Several authors studied the thickness of cortical bone in different areas (Costa et al. 2005, Deguchi et al. 2006, Kim et al. 2006), the space available between the roots in the alveolar areas (Kuroda et al. 2007c, Poggio et al. 2006, Schnelle et al. 2004) and the thickness of the infra-zygomatic crest (Liou et al. 2007). The safest locations to place miniscrews in the alveolar bone seem to be mesial and distal to the first molar (Carano et al. 2004, Deguchi et al. 2006). It is recommended to angulate the miniscrews at 30° to the long axis of the teeth to increase the screw surface in contact with cortical bone (Deguchi et al. 2006).

The miniscrews can be easily placed and removed by the orthodontist himself (Mah & Bergstrand 2005, Melsen 2004). Before insertion, it is recommended to use a template as a guide and to take an intraoral radiograph to check the position of the screw relative to the roots (Melsen 2004). Whenever possible, the screw has to be inserted through the attached gingiva. If the miniscrew has to be placed in unattached mucosa,

the mucosa might cover the head of the screw after healing. To avoid a surgical uncovering procedure if this happens, a ligature penetrating the mucosa can be attached to the screw (Melsen 2004).

It is generally not necessary to perform an incision of the mucosa as well as pre-drilling, except if the screw is placed in very dense bone, for example in the mandible. In this case, the pilot hole has to be drilled with a bur about 0.3 mm smaller than the screw (Carano et al. 2005) and without excessive force, since any serious resistance might be due to root contact, imposing redirecting of the bur (Kyung et al. 2003a). The screw is then simply inserted with a manual screwdriver. If the screw is placed without previous drilling, it can be placed with topical anesthetic gel (Kravitz & Kusnoto 2006). If drilling is necessary, local anesthesia is mandatory. Placement under topical anesthesia presents the advantage that the patient will feel if the screw is close to the PDL (Kyung et al. 2003a).

A new screw has to be used if primary stability is not obtained, if the insertion direction is wrong, or if a tooth was hit. The new screw has to be placed at a minimum distance of 5 mm from the original site. If the screw has to be placed at the same site, it is recommended to wait for 6 weeks (Melsen 2004).

Miniscrews are usually immediately loaded after insertion since their primary stability is reliable enough to sustain forces within the range of orthodontic ones (Luzi et al. 2007), and they can be used for direct or indirect anchorage.

Removal is performed by unscrewing with the same screwdriver used for insertion. There is no need for local anesthesia if the screw is in attached mucosa. If the screw is covered by mucosa, a local anesthesia and an incision are necessary. If screw removal is difficult, it is recommended to unscrew again after 3-7 days, since the attempt to unscrew will have

caused microfractures and bone remodelling simplifying ulterior removal (Melsen 2004).

Neither antibiotics nor anti-inflammatory drugs are prescribed after insertion and removal (Mah & Bergstrand 2005). Lee and co-workers observed that the anticipated pain related to miniscrew insertion is often overestimated (Lee et al. 2008). These authors showed that postoperative pain is significantly lower than for initial orthodontic levelling. Seventy-eight percent of the patients were satisfied and would recommend it to others. In another prospective study, the patients complained about no pain, but only mild discomfort after surgery (Chaddad et al. 2008).

Miniscrews were used to intrude incisors (Ohnishi et al. 2005), extruded unopposed single molars (Chang et al. 2004, Lee et al. 2004, Park et al. 2003) or unilateral molars to correct an occlusal cant (Jeon et al. 2006). Bilateral molar intrusion with miniscrews placed in the posterior midpalate and in the buccal alveolar bone between the molars was shown to be efficient for open bite closure (Kuroda et al. 2004, Park et al. 2006b), Xun et al. 2007) or anterior facial height reduction (Paik et al. 2003). Maxillary (Chang et al. 2006, Chung et al. 2005, Gelgor et al. 2004, Gelgor et al. 2007, Karaman et al. 2002, Kinzinger et al. 2006, Kircelli et al. 2006a, Park et al. 2004b) and mandibular (Paik et al. 2006, Park et al. 2004b, Park et al. 2005) molar distalization was achieved with miniscrews without anchorage loss, as well as mandibular molar mesialization (Kuroda et al. 2005, Kyung et al. 2003b). Miniscrews were also used for retraction of incisors and canines after premolar extractions (Lee et al. 2001, Park 1999, Park 2000, Park et al. 2001), for molar uprighting (Park et al. 2002) and for forced eruption of impacted teeth (Giancotti et al. 2004, Park et al. 2004a). Finally, two case reports mentioned maxillary protraction on facemasks (Enacar et al. 2003, Kawakami et al. 2004).

Complications due to miniscrews can be distributed into the 3 successive periods of insertion, loading and removal (Melsen & Verna 2005).

Complications during insertion include lack of initial stability; insertion in a periodontal ligament or a root; slippage of the miniscrew under the mucosa along the periodontium, specially if the angle of insertion is steep; nerve injury; sinus perforation and finally fracture due to increased torsional stress (Kravitz & Kusnoto 2007, Melsen & Verna 2005). Drilling of a pilot hole is recommended in regions with dense cortical bone, to avoid fracture during placement. If dental roots are damaged by miniscrews, it is known that complete repair of tooth and periodontium happens in 12 to 18 weeks after miniscrew removal (Asscherickx et al. 2005). Liou and colleagues reported that miniscrews are stable, but not absolutely stationary under orthodontic load. These authors recommended to place them in a non-tooth bearing area without foramen or major neurovascular pathways; or in a tooth bearing area allowing 2 mm clearance between the roots and the screw (Liou et al. 2004).

During loading, miniscrews might become loose or generate mucosal hypertrophy, specially when the miniscrews are placed in non-attached gingiva (Melsen & Verna 2005).

Finally, it can be impossible to remove them at the end of the treatment. As said before, a second attempt has to be tried a few days later. The miniscrew head can also fracture upon removal : the intraoral part of the screw might have to be trephined if it is not possible to unscrew it (Melsen & Verna 2005).

Clinical studies reported success rates varying from 70 % to 91.6 % (Chaddad et al. 2008, Chen et al. 2006, Chen et al. 2007b, Cheng et al. 2004, Freudenthaler et al. 2001, Fritz et al. 2004, Kuroda et al. 2007b, Luzi et al. 2007, Miyawaki et al. 2003, Moon et al. 2008, Motoyoshi et al. 2006, Park et al. 2006a , Tseng et al. 2006, Wiechmann et al. 2007). Following some authors, miniscrews are as stable as miniplates (Kuroda et al. 2007b), while for others, miniplates are more stable than miniscrews (Chen et al. 2007b).

Inflammation of soft tissues is a major factor for failure (Cheng et al. 2004, Miyawaki et al. 2003, Park et al. 2006a) : optimal hygiene is thus mandatory for success (Deguchi et al. 2003, Kravitz & Kusnoto 2007). It is recommended to place the miniscrews in keratinized tissues to limit the inflammation of the surrounding tissues (Miyawaki et al. 2003).

Bone characteristics play a considerable role. As the thickness of cortical bone is crucial for the load transfer from miniscrew to bone, orthodontists should avoid to place screws where the cortex is very thin (Dalstra et al. 2004, Huja 2004), and in areas of increased bone turnover due to resorption of a deciduous tooth or due to orthodontic tooth movement (Luzi et al. 2007). Better success rates observed in adults than in children might be related to the bone characteristics as well (Chen et al. 2007b).

An incorrect surgical procedure can cause failure, for example if wiggling forces are applied on the inserted screw when the screwdriver is removed (Luzi et al. 2007). The insertion torque should be high enough for primary stability (Chaddad et al. 2008), but not too high, to avoid local ischemia and bone necrosis (Motoyoshi et al. 2006).

During loading, torsional forces unscrewing the miniscrews (Melsen & Verna 1999) and occlusal forces must be avoided (Mah & Bergstrand 2005).

Both length (Chen et al. 2006) and diameter (Miyawaki et al. 2003) of the screws affect their success rate.

In terms of location, some authors obtained better success rates in the maxilla compared to the mandible (Chen et al. 2007b, Park et al. 2006a, Wiechmann et al. 2007), while others found less failures in the mandible (Luzi et al. 2007). Several authors pointed out specifically the posterior mandible as an increased failure risk area (Cheng et al. 2004, Kuroda et al. 2007b, Moon et al. 2008). Lingual regions of the mandible showed worse results than buccal ones, probably because they present less keratinized mucosa (Wiechmann et al. 2007). The thickness of the mucosa has also

been pointed out as a factor for failure : when the mucosa is very thick, the point of application of the force is further away from the cortex, creating a moment (Luzi et al. 2007, Tseng et al. 2006). Finally, root proximity has been pointed out as a factor for failure (Kuroda et al. 2007c).

MINIPLATES

Miniplates have been used for a long time in maxillofacial surgery. For this reason, when miniplates started to be used for orthodontic anchorage, there was no doubt about their biocompatibility, and most surgeons had already experienced their placement (Acero et al. 1999).

The objective of using miniplates for orthodontic anchorage is to locate the point of application of force close to the dentition while the screws are located away from the dentition, avoiding any interference with tooth movement. Miniplates work as an onplant screwed on the bone surface, the screws acting as an implant. Both plates and screws are affected by a certain amount of osseointegration as long as they are made of titanium; however, this osseointegration phenomenon is expected to be limited by the usually smooth surface of the devices.

Jenner and Fitzpatrick were the first ones, in 1985, to report the use of osteosynthesis plates for orthodontic anchorage. The plates were placed in the ramus : the last loop was exposed into the oral cavity and used for lower molar distalization (Jenner & Fitzpatrick 1985). In 1999, Umemori and colleagues described as *skeletal anchorage system* a plate screwed in cortical bone (Umemori et al. 1999). In their publication, this system was placed under the mandibular molars in order to intrude them to close an open bite. Other groups used titanium miniplates to intrude molars with the same objective (Erverdi 2002, Erverdi et al. 2004, Sherwood et al. 2002). For the first time, in 2002, a Korean team used a modified miniplate

specifically designed for orthodontic anchorage with a 0.036'' tube. The authors called it *C-tube* (Chung et al. 2002). The same year, De Clerck and colleagues developed another miniplate for orthodontic purposes, with an attachment composed of a slot and a locking screw (Bone Anchor, Surgi-Tec, Belgium) (De Clerck et al. 2002). In the meanwhile, the Japanese team who had described the concept of *skeletal anchorage system* in 1999 developed an orthodontic titanium miniplate (Dentsply-Sankin, Japan) with 3 hooks, existing in different sizes and configurations (Sugawara & Nishimura 2005). The screws associated to the plates are also made of commercially pure titanium, self-tapping, 2 mm in diameter and 5 mm in length. They are monocortical, and require thus at least 2 mm of cortical thickness for stability, following the authors.

The recommended locations are, in the maxilla, the zygomatic buttress and the piriform rim (in between, the bone covering the sinus is very thin), and in the mandible, the alveolar bone apical to the roots, except adjacent to the mental foramen (Sugawara & Nishimura 2005).

The plates are placed under local anesthesia with (Sugawara & Nishimura 2005) or without (De Clerck & Cornelis 2006) intravenous sedation. Placement surgery requires a mucoperiosteal flap, usually pilot drilling, positioning of the screws to fix the plate, and sutures (Sugawara & Nishimura 2005). Orthodontic force is usually applied 3 weeks after placement to allow soft tissue healing (De Clerck et al. 2002, Sugawara & Nishimura 2005). Removal surgery is recommended immediately after orthodontic treatment, and consists in incision, removal of plates and screws and stitches.

As mentioned before, miniplates are indicated for intrusion of maxillary and/or mandibular molars in non-surgical treatment of open bites (Erverdi et al. 2004, Sherwood et al. 2002, Sugawara et al. 2002, Umemori et al. 1999). It has been shown that this type of treatment relapses of about 30 % after treatment : overclosure of the bite is thus essential (Sugawara et al.

2002). No clinically significant root resorptions were observed after intrusion (Ari-Demirkaya et al. 2005, Sugawara et al. 2002). By comparison, molar intrusion with skeletal anchorage was recently shown to be simpler and shorter than 2-jaw surgery, while offering equivalent vertical changes (Kuroda et al. 2007a). Whereas the latter authors used palatal and lingual arches to control molar buccal tipping, others obtained an effective intrusive response with acrylic blocs combined with heavy palatal arches or a hyrax if expansion was needed (Erverdi et al. 2006, Erverdi et al. 2007) (Fig. 1).

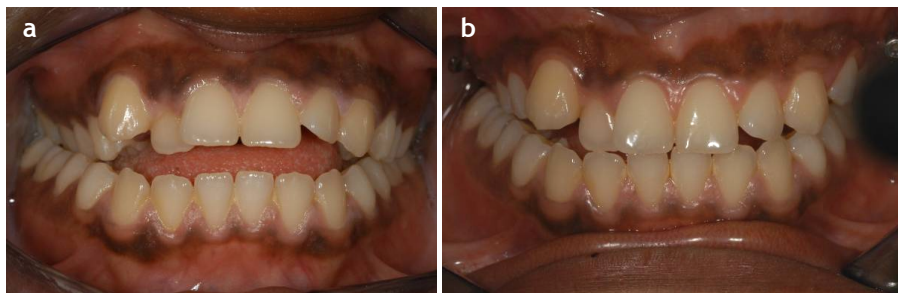


Figure 1.- Intrusion of maxillary molars to close an anterior open bite, without orthognathic surgery. Before (a) and after (b) first phase of treatment consisting in upper molar intrusion with miniplates. A second phase of treatment with upper and lower fixed appliances will follow.

Intrusion of a whole upper arch in long-face patients with gummy smile (DeVincenzo 2006a, DeVincenzo 2006b) and intrusion of extruded unopposed molars (Moon et al. 2007, Sherwood et al. 2003, Yao et al. 2005, Yao et al. 2004) (Fig. 2) have been described as well. An experimental study in dogs showed that histologic changes and pulpal blood flow changes are reversible after intrusion of molars with skeletal anchorage (Konno et al. 2007).

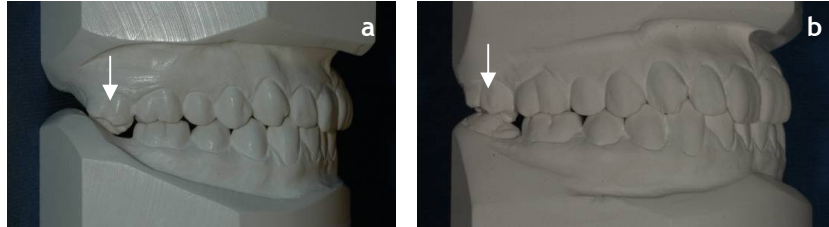


Figure 2.- Intrusion of unopposed extruded upper second molars (arrows) with miniplates. Before (a) and after (b) intrusion of the second molars, without fixed appliance on the rest of the dentition.



Figure 3.- Maxillary molar distalization to correct a class II malocclusion with anterior crowding. Before (a) and after (b) treatment with full fixed appliance and miniplates for anchorage.

Beside intrusion, which is the most documented application, miniplates were also used for distalization of anterior teeth after premolar extractions (Cornelis & De Clerck 2006, Erverdi & Acar 2005, Iino et al. 2006), and for maxillary (De Clerck & Cornelis 2006, Sugawara et al. 2006) and mandibular (Sugawara et al. 2004) molar distalization in non extraction treatment of protrusion or crowding (Fig. 3). Maxillary molar

distalization with miniplates was shown to be an efficient, non-compliance dependent, and predictable treatment modality for patients with class II molar relationship (Cornelis & De Clerck 2007) (see appendix 4).

Other possible indications of miniplates are molar uprighting (De Clerck et al. 2004), and orthopedic protraction of the maxilla (Kircelli et al. 2006b). Use of miniplates in those multiple applications tends to reduce the need for extractions and orthognathic surgery (Fig. 4).



Figure 4.- Use of miniplates as an alternative to orthognathic surgery : distalization of the lower arch and re-opening of the space for the missing upper left lateral incisor (arrow) with miniplate anchorage. Before (a) and after (b) treatment.

Three prospective case series with 48, 35 and 68 miniplates reported success rates of 89 % (Cheng et al. 2004), 91.4 % (Mommaerts et al. 2005) and 93 % (Choi et al. 2005) respectively. In this last study, the failure rate in the maxilla (0 %) was much lower than in the mandible (14 %). Four other studies with 44, 38, 17 and 86 miniplates observed success rates of 95.5 % (Chen et al. 2007a), 86.8 % (Kuroda et al. 2007b), 96.4 % (Miyawaki

et al. 2003) and 98.8 % (Chen et al. 2007) respectively. All studies allowed between 1 and 4 weeks of healing before miniplate loading. Some miniplates could be used orthodontically even though they were slightly mobile (Choi et al. 2005, Mommaerts et al. 2005). Failures were associated with inflammation of soft tissues (Chen et al. 2007, Choi et al. 2005, Miyawaki et al. 2003, Mommaerts et al. 2005); and placement in non-keratinized mucosa (Cheng et al. 2004), in the mandible (Chen et al. 2007, Cheng et al. 2004) in the molar area (Kuroda et al. 2007) or in hyperdivergent patients (Miyawaki et al. 2003), possibly because their cortical bone is usually thinner. Intrusion movement seemed to be critical (Kuroda et al. 2007), as well as the presence of occlusal interferences (Chen et al. 2007). Comparing success rates of miniplates to miniscrews, miniplates were shown to have lower failure rates (Chen et al. 2007).

Complications included plate fractures (Sugawara & Nishimura 2005), gingival dehiscences of the bone plate (Mommaerts et al. 2005) and swelling after placement, likely related to the surgical flap (Miyawaki et al. 2003). Finally, it is important to stress that the environment in crevices around titanium orthodontic miniplates is anaerobic and supportive of anaerobic growth of bacteria, which may trigger inflammation in the tissues around the plates (Sato et al. 2007). Miniplates require thus strict hygiene and regular professional plaque control to prevent infection. Mouth rinses are recommended in presence of inflammation (Chen et al. 2007, Erverdi et al. 2004).

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Orthodontic loading does not influence bone density around titanium miniplates in dogs

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ABSTRACT

Objectives : Orthodontic miniplates are increasingly used as temporary skeletal anchorage devices (TSAD) although no experimental study reports quantitative data about bone-implant reactions, particularly under loading. This animal study aimed to evaluate whether orthodontic loading has an effect on bone mineral density (BMD) of the bone surrounding screws supporting loaded miniplates.

Materials and methods : Two miniplates were inserted in each jaw quadrant of ten dogs. Two weeks later, coil springs were fixed between the miniplates of one upper quadrant of each dog and between those of the contralateral lower quadrant. The other anchors remained unloaded. The dogs were sacrificed 7 or 29 weeks after surgery, and the jaws were scanned with peripheral Quantitative Computed Tomography (pQCT) to assess BMD.

Results : Successful anchorage was achieved in 53 % of miniplates and was significantly higher for maxillary than mandibular anchors, but no significant difference in success rate was found according to loading. Mobility most often occurred during the transition between primary and secondary stability. pQCT showed higher BMD around mandibular vs maxillary implants, without significant difference in density between loaded and unloaded anchors. Furthermore, load direction did not lead to any significant difference in BMD.

Conclusions : These data confirm that stability of titanium orthodontic miniplates depends on the implantation site anatomy as well as on rigorous hygiene. As loading did not induce BMD variation, it can be excluded as a mobility risk factor. Moreover, loading does not strengthen bone density, thereby facilitating implant removal.

INTRODUCTION

Anchorage, which is of critical importance to fulfill orthodontic treatment goals, mainly relies on patient's compliance and dentition's integrity. Skeletal, "absolute" anchorage, by contrast, goes beyond these limits of classical orthodontics. Conventional dental implants were initially placed in edentulous (Willems et al. 1999), retromolar (Roberts et al. 1990) or palatal (Wehrbein et al. 1996) regions, but recent use of smaller devices such as miniscrews and miniplates (Melsen & Costa 2000, Sherwood et al. 2002), requiring lesser amount of bone, allows wider indications and reduced surgical trauma.

Among these temporary skeletal anchorage devices (TSAD), the originality of miniplates compared to miniscrews relates to their efficiency in *en masse* distalization of an entire dental arch (De Clerck & Cornelis 2006), maxillary protraction (Kircelli et al. 2006) and molar intrusion for open bite closure (Erverdi et al. 2006). However, whereas some studies detailed bone healing reactions and response to load around independent miniscrews (Cornelis et al. 2007), only one team (Daimaruya et al. 2001, Daimaruya et al. 2003) described bone reactions around a miniplate system, without quantitative evaluation. Even though prospective clinical trials bring evidence in terms of success rate and orthodontic efficiency (Choi et al. 2005, Sugawara et al. 2006), some issues such as influence of loading and time remain unanswered. Particularly, osseointegration must be sufficient to achieve stability for anchorage, but not excessive to allow removal of these TSAD at the end of the orthodontic treatment.

In the present study, we used orthodontic miniplates in dogs and assessed bone mineral density (BMD) around the screws differentially affected by magnitude and direction of load. We performed densitometry with peripheral Quantitative Tomography (pQCT), which is known to

characterize bone with accuracy in both humans (Banse 2002, Louis et al. 1996) and animals (Rosen et al. 1995, Schmidt et al. 2003). Thereby, we aimed to determine the influence of both load and direction of load on the local bone response. Our initial hypothesis was that loading would not influence bone density.

MATERIALS & METHODS

Ten 1-year-old male beagle dogs with similar weight were divided into a short-term (ST) and a long-term (LT) group of 5 dogs each. 80 titanium miniplates designed for orthodontic anchorage (Bollard, Surgi-Tec, Bruges, Belgium), were placed between the dental roots : two miniplates per jaw quadrant, each with two 5 mm long, 2.3 mm diameter titanium self-tapping screws (Surgi-Tec) (Fig. 1a-c).

Surgery was performed under general anesthesia with laryngeal intubation. After elevation of an L-shaped mucoperiosteal flap into the attached mucosa (Fig. 1c), pilot-holes were drilled in the cortical bone with a 1.6 mm diameter bur under saline irrigation. The screws were inserted with a screw-driver through the miniplate. One layer closure was obtained with 4/0 resorbable sutures over the miniplate. The fixation units, facing mesially, were bent in order to avoid cheek irritation and each quadrant was radiographed. After surgery, the dogs were given antibiotics and anti-inflammatory drugs for 5 days as well as a soft diet for 14 days. The anchors were daily sprayed with chlorhexidine until loading.

Two weeks after implantation, nickel-titanium coil springs generating a 125 g force were placed under sedation between the two fixation units of one upper quadrant and between those of the controlateral lower quadrant (Fig. 1d). Fluid composite and orthodontic wax were used to avoid gingival irritation. The anchors of the other quadrants remained unloaded and were considered controls. The distances between the

fixation units of the same quadrant were measured with a digital caliper. In order to maintain fair oral hygiene, the anchors were brushed four times a week during the loading period. During these sessions, the coils springs were checked and replaced if necessary, and miniplate mobility was assessed. The scale used for assessing plate mobility was : 0, ≤ 0.5 mm movement; 1, > 0.5 and ≤ 1 mm movement; 2, > 1 and ≤ 2 mm movement; 3, > 2 mm movement.

The dogs were euthanatized 7 (ST) or 29 weeks (LT) after implantation. The experimental procedure was approved by the Animal Experimentation Ethics Committee of the Université catholique de Louvain.

The distances between the fixation units were measured again after sacrifice. Jaw samples supporting the miniplates were dissected, dehydrated and embedded in methylnmethacrylate. Each quadrant sample was radiographed and scanned with a pQCT Research SA+ (Stratec, Pforzheim, Germany) in the sagittal plane in order to acquire 10 transversal, 0.5 mm apart, slices through the screws. With a slice thickness of 150 μ m and a pixel size of 0.070 x 0.070 mm, the translation of the X-ray source was 1 mm/sec. The slices were evaluated by two independent observers to assess bone-screw contact. The three most central slices through each screw (Fig. 1b) were analyzed with the built-in XCT 5.4 software of the pQCT. Eight square regions of interest (ROI) of 0.55 mm² were defined : 4 ROI tangential (T) to the screw section and located superior, inferior, mesial and distal, and 4 ROI immediately exterior (E) to the previous ones (Fig. 1e). The mean BMD, proportional to the attenuation of the X-ray beam within the corresponding voxels, was calculated for each ROI and expressed as mg hydroxyapatite/cm³. The values of the 3 slices were averaged for each ROI.

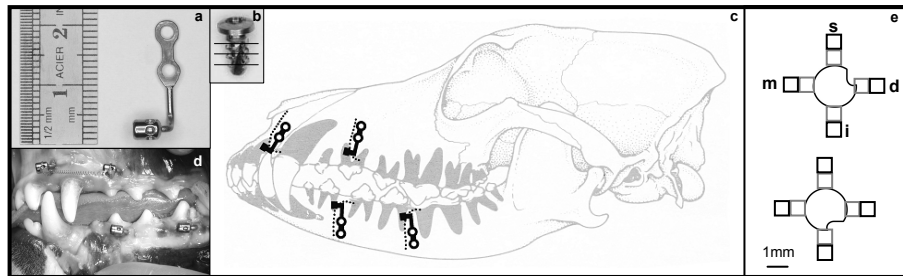


Figure 1.- Titanium miniplate, composed of a two-hole bone plate, a round connection bar and a cylindrical orthodontic fixation unit (a), miniscrew with the levels of the 3 pQCT transversal slices (b), schematic drawing of a dog skull with surgical incisions and miniplates localization (adapted from Emily P, Penman S (1992). *Dentisterie du chien et du chat*. Maisons-Alfort (France) : Ed. Du Point Vétérinaire) (c), upper loaded miniplates and lower control ones on the left side of one dog (d) schematic representation of the 4 tangential (T, grey) and the 4 external (E, white) ROI around 2 screws sections, in the superior (s), inferior (i), mesial (m) and distal (d) directions (e).

The cumulative survival of the miniplates was analyzed with the Kaplan-Meier method. Log-rank test was used to compare survival curves. Repeated measures of BMD values around the miniplates still present at the end of the experiment were averaged on a per-subject level. The authors then computed differences between means of ST and LT groups with *t* test for independent samples (degree of freedom proportional to n° of dogs/group). Differences between screws of the same dogs and differences between different zones around the same screws were tested with the paired *t* test (degree of freedom proportional to n° of dogs). All tests were 2-tailed and statistical significance was set at $p \leq .05$.

RESULTS

All the dogs remained healthy during the experiment, without any loss of weight. All miniplates were clinically stable after insertion. The anchorage success rate, determined by the survival functions and defined as the

percentage of stable implants at the end of the experiment, was 53 % (Fig.2).

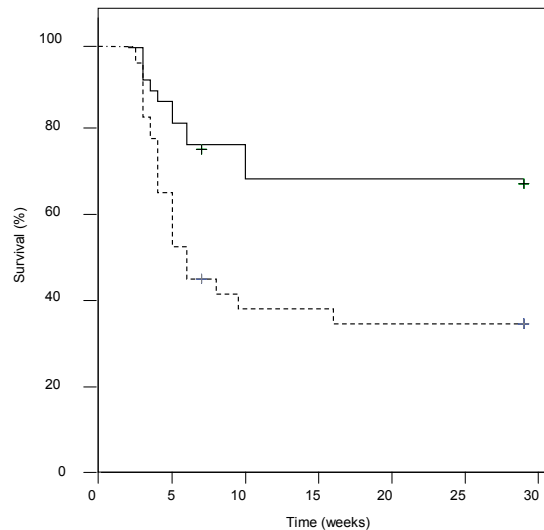


Figure 2.- Kaplan-Meier survival curves of maxillary (plain line) and mandibular (dotted line) miniplates.

It was significantly higher ($p < .05$) for maxillary (70 %) than for mandibular (38 %) anchors, in the whole cohort as well as in the ST and LT subgroups. No significant difference between loaded and unloaded miniplates was observed (57 vs 50 % respectively). All pairs of stable miniplates, with mobility score 0, showed an unaltered distance throughout the experiment, except in one mandibular loaded quadrant with decreased spacing between both stable miniplates. In this case, X-ray showed moving of the lower screw of the mesial miniplate.

Mobility, attested by scores 1-3 and a decreased distance between miniplates in the same quadrant, occurred 4.9 ± 2.8 (mean $\pm$ SD) weeks after surgery and was systematically associated with gingival inflammation.

The 37 mobile miniplates were distributed as follows : 24 ST and 13 LT, 17 loaded and 20 controls. Among them, 13 fell out.

pQCT revealed bone in contact of both screws of the implants considered stable at sacrifice (Fig. 3a & 3b). By contrast, all mobile implants showed absence of bone contact around one (Fig. 3c) or two screws (Fig. 3d). Most of them appeared surrounded by a broad radiotransparent space. In total, 90/160 screws showed bone-screw contact. pQCT scans also showed five screws, among which three were stable, in contact with the particularly long root of the maxillary canine.

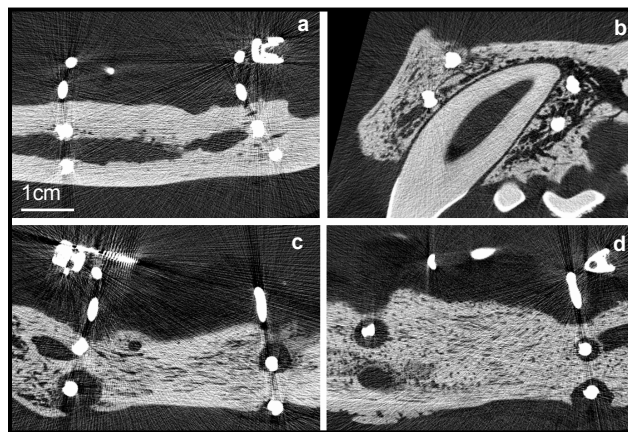


Figure 3.- pQCT slices through stable nonloaded plates of right mandible, LT dog (a), stable loaded plates of left maxilla, ST dog (b), mobile loaded plates of left mandible, ST dog (c), mobile nonloaded plates of right mandible, ST dog (d).

BMD was measured around both screws of the 67 miniplates still present at the end of the experiment. No significant differences in BMD were found between the loaded and the control screws in any of the groups (ST and LT) for both maxilla and mandible, and for both T and E regions (Fig. 4a).

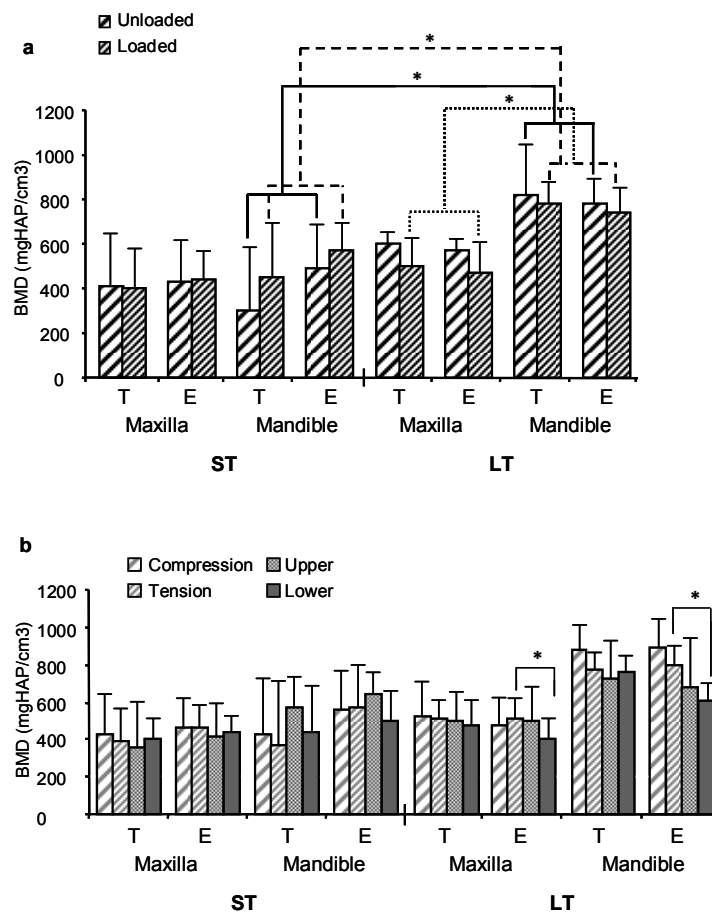


Figure 4.- Histograms of BMD (mean : plain bar / standard deviation : line), per subgroup. Since one ST and one LT dog lost their four lower miniplates, mandibular measurements were assessed for four dogs per group. Five other plates fell out in different quadrants : the average BMD values for those quadrants were based on the remaining plates. Comparison of loaded and unloaded screws (a). Comparison of the different regions of interest (ROI) around loaded screws : zones loaded in compression (compression), in tension (tension) and in shear stress either above (upper) or under (lower) the screws (b). BMD = bone mineral density; ST = short-term group; LT = long-term group; T = ROI tangential to the screws; E = ROI immediately exterior to the T zones; * = statistically significant ($p < 0.05$).

No significant difference was observed between T and E zones around both loaded and control screws, although the mandibular T zone was systematically less dense than the E zone in the ST group.

Around the loaded screws (Fig. 4b), mesial and distal ROI were classified as compression or tension zones regarding the direction of load, whereas superior and inferior ROI were considered shear stress zones. BMD did not vary significantly according to the compression, tension or shear stress.

BMD was higher in LT than in ST dogs, particularly in the mandible ($p < .05$) (Fig. 4a). In LT group, BMD values were higher in the mandibles than in the maxillas, but this difference was significant only for the loaded screws.

In the maxillary loaded screws, BMD was significantly higher around the upper screws than around the lower ones only in the LT group. This difference was not observed in the mandible.

DISCUSSION

This study is the first one to test a high number of orthodontic miniplates in animals and to yield quantitative data about peri-implant bone, particularly relating to loading. These informations are essential for TSAD use in orthodontic treatments, as load might constitute a mobility risk factor or induce excessive osseointegration impeding implant removal.

Despite its efficiency, clinical use of orthodontic miniplates has been supported by very few experimental data (Cornelis et al. 2007). In the present study, the total success rate of 53 % is lower than in clinical observations - 89 % (Cheng et al. 2004), 96.4 % (Miyawaki et al. 2003) and 92.5 % (Cornelis et al. 2008) - but oral hygiene and patient compliance might be responsible for this difference. Moreover, in the maxilla of patients, the Bollard system is usually designed with three screws instead of two (Cornelis et al. 2008). For these reasons, the success rate obtained in the present study should be interpreted with caution.

The healing period lasted two weeks which, regarding the relative bone turnover rate, corresponds to the usual clinical healing time of 3 weeks (De Clerck & Cornelis 2006). Mobility occurred on average 5 weeks after implantation (Fig. 2), like screw failure in another dog experiment (Deguchi et al. 2003). This time could represent the most critical stage in the transition period between primary and secondary stability (Schenk & Buser 1998), when anchorage success depends on bone remodelling completion. In our experiment, the radiotransparent space surrounding the mobile screws clearly attested to imbalance between bone resorption and formation (Fig. 3).

The mandibular success rate, lower than the maxillary one, could be attributed to the smaller amount of attached gingiva in the dog, supporting the idea that implant placement in non-keratinized tissue constitutes a risk factor (Turley et al. 1988). Indeed, the three implants which failed in the above-mentioned canine experiment were placed in the mandible (Deguchi et al. 2003). Furthermore, in some dogs, mandibular plates were slightly too long regarding to the mandibular body height (Fig. 3), which could also be responsible for mobility.

Screw-to-root contact, evoked as another possible factor for mobility of temporary skeletal anchorage (Deguchi et al. 2003), did not appear determinant in our results. On the other hand, inflammation, associated with mobility and likely to stimulate bone resorption, could play a role in the clinical evolution as oral hygiene was difficult to obtain (Choi et al. 2005).

Loading had no definite effect on stability since the success rate was not significantly higher in loaded vs unloaded plates. However, the only one loaded mandibular screw which moved during the experiment but still obtained bone-screw contact, suggested that loading does not impede osseointegration, even in difficult conditions like the mandibular basilar border.

Bone mineral density evaluated with pQCT has been shown to be a reliable predictor of the true apparent density and morphological properties of bone (Louis et al. 1996, Rosen et al. 1995, Schmidt et al. 2003). pQCT, which produces tomographies where the mineral density is quantitatively measured for each pixel, was preferred to microCT which assigns the pixel as being bone or non-bone (Banse 2002). Loading of miniplates was reported to enhance bone-implant contact (Daimaruya et al. 2001), but no quantitative assessment of the bone-screw interface with miniplates could be found in the literature. As observed in quantitative studies evaluating orthodontically loaded palatal or conventional implants (Aldikacti et al. 2004, Cattaneo et al. 2007, De Pauw et al. 1999, Deguchi et al. 2003, Hurzeler et al. 1998, Melsen & Lang 2001, Ohmae et al. 2001, Oyonarte et al. 2005, Roberts et al. 1989, Saito et al. 2000) or mini-implants (Buchter et al. 2006, Yano et al. 2006) our experiment did not lead to significant difference between loaded and unloaded implants. Our initial hypothesis was thus confirmed : orthodontic loading of miniplates did not influence the local bone response in terms of BMD. Furthermore, absence of difference in density between zones loaded in compression and those loaded in tension (Fig. 4b) is consistent with the results obtained with orthodontically loaded dental implants (Akin-Nergiz et al. 1998, Aldikacti et al. 2004, De Pauw et al. 2002, Gotfredsen et al. 2001, Gotfredsen et al. 2001, Majzoub et al. 1999, Oyonarte et al. 2005, Saito et al. 2000) and miniscrews (Melsen & Costa 2000, Melsen & Lang 2001).

The slight increase in BMD around the maxillary screws from ST to LT (Fig. 4a-b) could be interpreted as the result of a balanced remodelling sequence achieving stability. The significantly lower values observed around the mandibular ST screws are likely due to the high number of mobile screws in this group. However, even when considering only the stable mandibular screws, BMD significantly increased with time, confirming the previously described progression of osseointegration with time (Melsen & Costa 2000).

Despite a higher bone density in the mandible than in the maxilla, the better maxillary than mandibular success rates, observed not only in this experiment, but also in clinical conditions (Choi et al. 2005, Cornelis et al. 2008), suggest once more that successful anchorage does not only depend on density or osseointegration index, but also on specific features of the implantation site. In this perspective, trabecular maxillary bone could be more propitious than compact mandibular bone to ensure transition between primary and secondary stability.

Differences in BMD between E and T zones were not significant, although these zones appeared different, particularly in the scans of the mobile implant.

To conclude, as miniplate stability and BMD of the surrounding bone were not significantly influenced by loading, orthodontic loading does not appear to increase risk for mobility nor to enhance bone density hindering implant removal. The first weeks of loading, concomitant with transition between primary and secondary stability, could constitute the most critical time in the implant survey. Further histological analyses will be carried out in order to quantify the bone-screw contact and to investigate the tissular mechanisms involved in osseointegration of these TSADs.

ACKNOWLEDGMENTS

We thank G. Araujo and Prof. J.P. Dehoux for animal housing, Dr. C. De Clercq and Dr. F. Nsimba for surgical assistance, and D. Dienst for pQCT technical help. This research was supported by the Special Research Fund (Université catholique de Louvain). The miniplates were provided by Surgi-Tec.

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Orthodontic loading of titanium miniplates in dogs : microradiographic and histological evaluation

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Clinical Oral Implants Research (in press)

Orthodontic loading of titanium miniplates in dogs : microradiographic and histological evaluation

ABSTRACT

Objectives : The objectives of this animal study were to evaluate if orthodontic loading has an impact on osseointegration of screws supporting miniplates, and to describe the histological components of the bone-screw interface.

Materials and methods : Eighty orthodontic miniplates were placed in the jaws of 10 dogs. After 2 weeks, a 125 g force was applied between the miniplates of one upper quadrant of each dog and between those of the contralateral lower quadrant. The other, nonloaded miniplates, were considered controls. Five dogs were sacrificed 7 weeks after implantation and the remaining 5 dogs after 29 weeks (respectively Short Term/ST and Long Term/LT groups). Fluorochromes were injected at implantation and at sacrifice. Jaw quadrants were dissected, embedded, cut into undecalcified transverse sections through the screws and finally submitted to microradiographic analysis to allow assessment of bone-implant contact (BIC) and bone volume/total volume (BV/TV). The sections were observed under UV light and stained in order to be examined under ordinary light.

Results : Osseointegration occurred around 90/160 screws and consisted mainly in limited repair and remodelling processes of lamellar bone, without inflammation. Wide variations were observed in BIC and BV/TV, but without any significant difference, neither between the loaded and the nonloaded screws, nor according to the direction of load, whereas they were significantly higher in the Long Term (LT) than Short Term (ST) group. Nonosseointegrated screws were surrounded by fibrous tissue. Osteoblastic activity, when present in front of these screws, was not sufficient to achieve stability.

Conclusions : Osseointegration underlying orthodontic anchorage was not affected by loading. BIC increased with time and varied according to implantation site. Particularly the tight-fitting screw insertion appeared crucial in determining the appropriate bone healing response.

INTRODUCTION

Clinical orthodontics currently appeals to skeletal anchorage when either compliance or dentition is not sufficient to plan treatment with conventional means (Heymann & Tulloch 2006). Temporary skeletal anchorage devices (TSADs) include palatal (Wehrbein et al. 1996) and retromolar (Roberts et al. 1994) implants, limited to specific indications, as well as miniscrews and miniplates, that are cheaper and have wider applications (Cornelis et al. 2007). The latter were documented mostly by case-reports, and more seldom by retrospective (Kuroda et al. 2007a, Kuroda et al. 2007b, Miyawaki et al. 2003, Tseng et al. 2006) or prospective clinical series (Cheng et al. 2004, Choi et al. 2005, Cornelis et al. 2008, Liou et al. 2004, Luzi et al. 2007, Park et al. 2006a). Orthodontic miniplates are modified osteosynthesis plates which allow connection to the orthodontic appliance (De Clerck & Cornelis 2006, Erverdi et al. 2006, Sherwood et al. 2002, Sugawara et al. 2002). Miniplates require a more invasive placement surgery than miniscrews, but have the advantage of their fixation screws being placed at a safer distance from the roots (Chung et al. 2002, De Clerck et al. 2002, Umemori et al. 1999). Whereas bone reactions around osteosynthesis plates used for fracture stabilization or rigid fixation after orthognathic surgery have been documented (Kim et al. 1997), only one team tested orthodontic miniplates for molar intrusion in dogs and hardly described bone-to-metal contact around the screws supporting the system (Daimaruya et al. 2001). In particular, influence of loading on bone-screw interface is of critical importance, since a negative effect could decrease miniplate stability, whereas a positive impact could compromise removal of the device once the anchor is no longer needed.

We recently showed that bone density around screws supporting miniplates in dogs did not vary with loading (Cornelis et al. submitted for publication). The purpose of the present study was to strengthen these

findings at the microscopic level by microradiographic, histological and morphometric assessment of the bone-screw interface. Our hypothesis was that loading would not influence the local bone response.

MATERIALS & METHODS

The experimental procedure was approved by the Animal Experimentation Ethics Committee of the Université catholique de Louvain. Eighty titanium orthodontic miniplates (Bollard, Surgi-Tec, Bruges, Belgium) were placed in ten 1-year-old male beagle dogs. Two miniplates were placed per jaw quadrant, between the dental roots (between upper 3rd incisor and canine, above upper 2nd premolar, between lower 2nd and 3rd premolars, between lower 4th premolar and 1st molar), each with two 5-mm-long, 2.3-mm-diameter TiAl6V4 self-tapping screws (Surgi-Tec, Bruges, Belgium) (Fig. 1a).

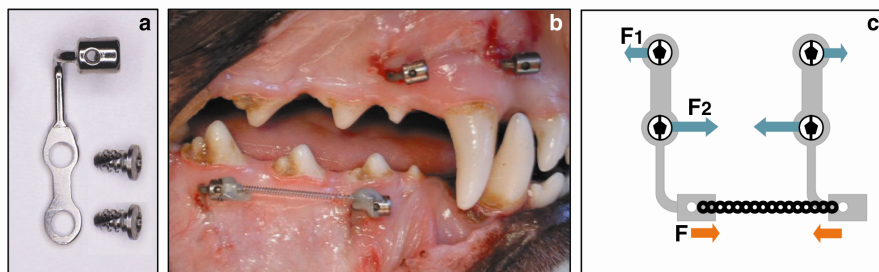


Figure 1.- (a) Bollard miniplate (Surgi-Tec, Bruges, Belgium) with 2 5-mm-long screws.
(b) Upper nonloaded and lower loaded right quadrants of a short term dog, 2 weeks after miniplate placement.
(c) Schematic representation of the vectors exerted on the upper (F1) and lower (F2) screws by the force (F) applied by the coil spring on the miniplate in the studied model.

Under general anesthesia, L-shaped mucoperiosteal flaps were elevated, and pilot-holes were drilled with a 1.6-mm-diameter bur under saline

irrigation. The screws were inserted with a screwdriver through the miniplate, and the incisions were sutured over the miniplate. After surgery, the dogs were given antibiotics and anti-inflammatory drugs for 5 days as well as a soft diet for 14 days. The anchors were daily sprayed with chlorhexidine for 2 weeks. Nickel-titanium coil springs generating a 125 g force were placed two weeks after implantation between the two anchors of one upper quadrant and between those of the contralateral lower quadrant (Fig. 1b), while the other, nonloaded quadrants, were considered controls. The miniplates were brushed four times a week to enhance hygiene conditions.

Five dogs were euthanatized by intravenous injection of T61 (Intervet, Mechelen, Belgium) 7 weeks after implantation (Short Term/ST Group) and the remaining 5 dogs 29 weeks after implantation (Long Term/LT Group). Stability of the miniplates was checked at sacrifice. Two fluorescent markers of osteogenesis were given: calcein green at the time of implantation (intraperitoneally, 20 mg/kg) and alizarin complexone 30 minutes before sacrifice (intravenously, 30 mg/kg).

Jaw samples with the miniplates were dissected, fixed in 70 % methanol, dehydrated and embedded in methylmethacrylate without preliminary decalcification. After polymerization, they were cut with a diamond saw (Leitz, Wetzlar, Germany) into 350- μ m-thick sections, perpendicular to the screw axis. The sections were reduced to a uniform thickness of 80 μ m with a rotating grinding machine (Planapol 2, Struers, Copenhagen, Denmark) and microradiographed by placing the sections in contact with a fine grain emulsion (VRP-M, Slavich-Geola, Lithuania), exposed to long wavelength X radiations produced by a Machlett tube (Baltograph BF-50/20, Balteau, Liège, Belgium) at 14 kV and 15 mA. The exposure lasted 50 minutes for a film-focus distance of 106 mm. The films were developed in SM-6 developer (Kvant Ltd, Bratislava, Slovakia), fixed, rinsed in tap water and dried before mounting like histological samples.

The sections were observed under UV light in order to highlight the fluorescent markers. They were then superficially stained with 1 % fuchsin alcoholic solution followed by a 1 % aqueous solution of methylene blue buffered with potassium biphthalate at pH 4.8, and were observed under ordinary light.

The term bone-implant contact (BIC, %) is used to designate the relative screw circumference in contact with bone. It was measured on the microradiographs of the 2 most central sections through each screw. Bone Volume/Total Volume (BV/TV, %) was assessed in the same sections with a Zeiss integration ocular in 980- μ m-diameter zones tangential to the screw, located mesial, distal, above and under the screw.

Statistical analysis

The study had a split-mouth design, and each dog provided 2 pairs of loaded miniplates (8 screws), and 2 pairs of nonloaded miniplates (8 screws). The association between the proportion of osseointegrated screws (BIC > 0 vs. BIC = 0) and experimental factors (loaded vs. nonloaded, ST vs. LT, maxilla vs. mandible) was tested in both ST and LT groups combined, with the Mantel-Haenszel statistic.

Subsequent analyses were limited to screws in contact with bone (BIC > 0) or screws presenting some bone within the measured area (BV/TV > 0). Given the data structure, i.e. repeated measures in a small number of dogs, effects of experimental factors on BIC and BV/TV were studied with ANOVA for repeated measures, considering dog identity as a random effect (SAS procedure Mixed). The BIC and BV/TV values obtained for the 2 sections analyzed were averaged. Each screw from a loaded miniplate had a surface with adjacent bone loaded in compression (screw located centrally to the plate : region between the miniplates - screw located at the extremity of the plate : region exterior to the miniplates), the opposite surface with bone in tension, and the regions located above or under the screw loaded with

shear stresses (Fig. 1c). This allowed analysis of differences in bone subjected to compression versus tension versus shear stress, for all 80 loaded screws, with analysis of variance tests. All tests were 2-tailed and statistical significance was set at $p \leq 0.05$. The Statistical Analysis System was used for the statistical computations (SAS 9.1 release, SAS Institute Inc., Cary, NC, USA).

Figure 2.- Upper right loaded quadrant of a short term dog.

(a) Microradiograph of a section through the 4 screws of the mesial (M) and distal (D) miniplates, as well as the canine root (Ca).

(b) Enlargement of frame b in Fig. 2a : osseointegration of the lower screw of the distal miniplate, mostly constituted by lamellar bone, with remnants of old bone (OB) close to the screw surface.

(c) Frame c of Fig. 2b, enlarged and observed in the corresponding stained section : old, brittle bone (OB) in contact with the screw.

(d) Frame d of Fig. 2b, enlarged and observed in the section under fluorescent light : new bone in contact with the screw, marked by alizarin complexone (orange arrows). Some old bone (OB) is still present in contact with and close to the screw, and is diffusely marked by calcein green.

(e) Frame e of Fig. 2d, enlarged and observed in the stained section : newly deposited lamellar bone (LB), with osteoblasts (black arrows), on the preexisting old bone (OB). Blood vessels (V) are present.

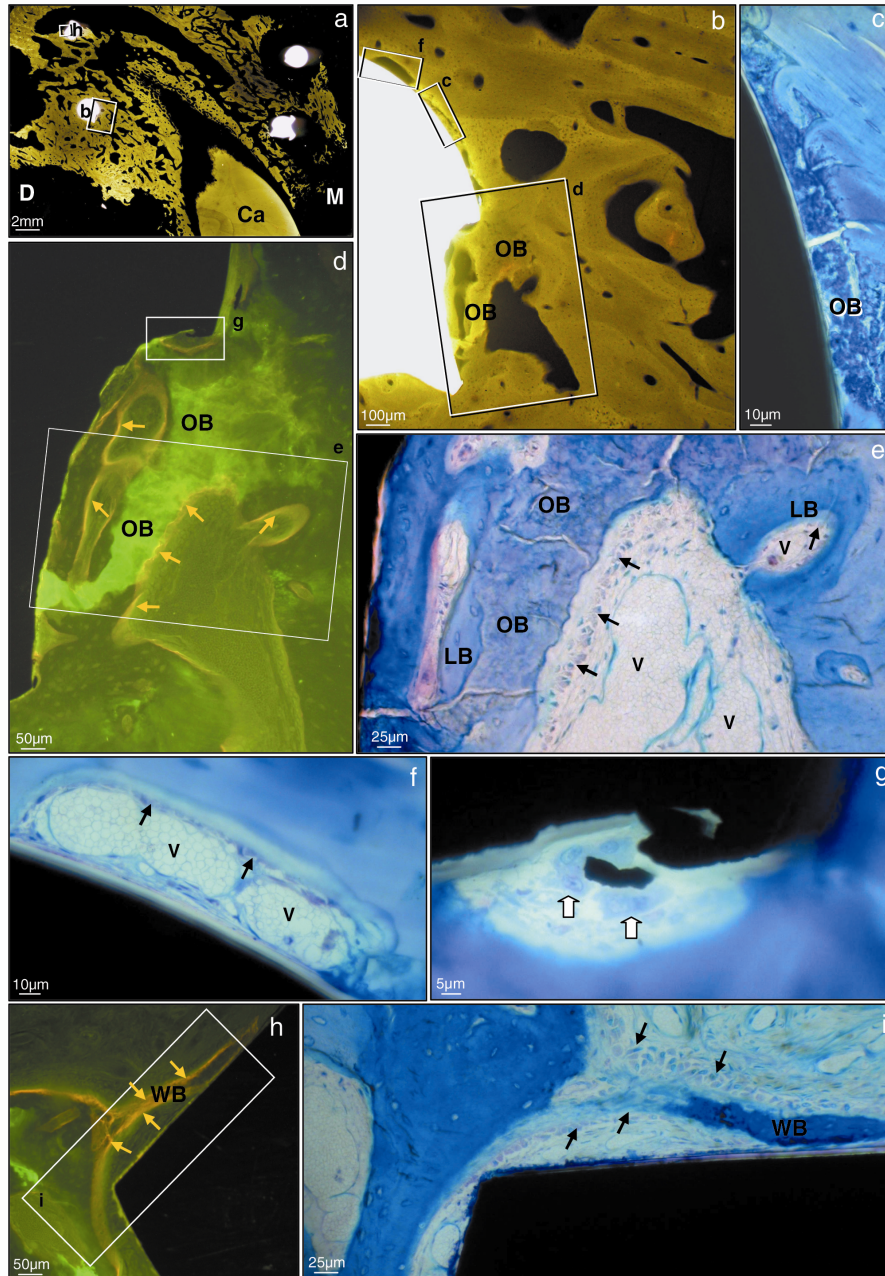
(f) Frame f in Fig. 2b, enlarged and observed in the stained section : gap in the bone-implant interface, with blood vessels (V) and osteoblasts (arrows) lining the preosseous layer.

(g) Frame g of Fig. 2d observed in the stained section : metallic fragment close to the screw surface, surrounded by large multinucleated cells (large arrows).

(h) Frame h from Fig. 2a, enlarged and observed in the section under U.V. light : woven bone (WB) in direct contact of the upper screw of the distal miniplate, labelled by alizarin complexone (orange arrows).

(i) Frame i of Fig. 2h, enlarged and observed in the stained section : woven bone (WB) lined with osteoblasts (black arrows).

RESULTS



All 80 miniplates were clinically stable immediately after insertion. Forty-three miniplates were stable when the dogs were euthanatized, whereas 24 were mobile and 13 fell out before the end of the experiment.

Microradiographic analysis showed some bone in contact with 90 screws. Bone metal interface was most often constituted by lamellar bone (Fig. 2a-b). Old bone (OB) which was damaged at implantation appeared as hypermineralized islets nearby or against the screws. These islets, diffusely labelled in green by calcein, were frequently cracked and showed a disrupted matrix organization with empty osteocyte lacunae (Fig. 2c-e). Their outlines were scalloped and lined with new lamellar bone (LB), preosseous layer and osteoblasts (arrows) and bone apposition on their surface was attested by alizarin complexone labelling (orange arrows). Gaps between bone and screws, outside the zones of direct bone-implant contact, were filled with blood vessels and marrow cells (Fig. 2f). Preosseous layers covered by osteoblasts were often found on the bone surfaces bordering these gaps (arrows). Metallic fragments were also visible in the gaps and were sometimes associated with large multinucleated cells (Fig. 2g). Few resorption foci were observed.

In some cases, woven bone trabeculae (WB) were present at the bone-implant interface (Fig. 2h-i). They were also labelled by alizarin complexone (orange arrows) and lined with osteoblasts (black arrows). In 12 screws, bone-screw contact was mostly constituted by woven bone, recognizable to its irregular trabeculae and its numerous large osteocyte lacunae (Fig. 3a-c). These trabeculae were lined by alizarin complexon (orange arrows), attesting presence and activity of osteoblasts (black arrows). No calcein-labelled old bone was seen nearby the screw and the boundary between new and pre-existing bone was more distant from the screw than in the lamellar bone interface type. The marrow spaces were filled with blood vessels (V) and mesenchymal cells. This osseointegration variant did not show any correlation with time or loading, but was often

observed when the screw was localized at some skeletal limits, like sinusal cavity, mandibular canal or *basis mandibulae*, or when redrilling had been necessary to adapt the implant to the dog jaw.

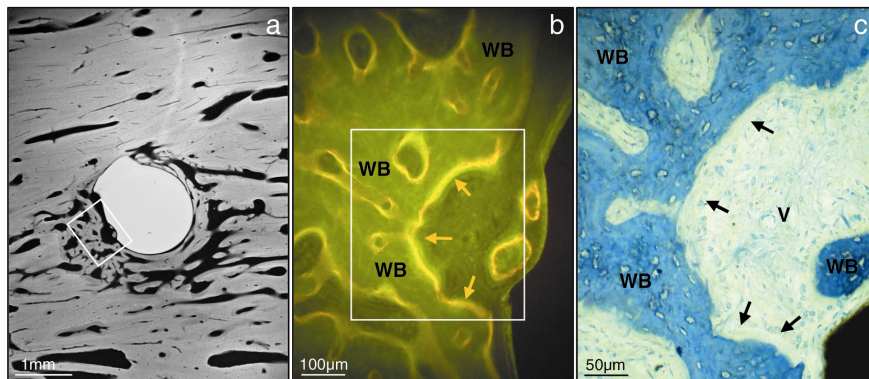


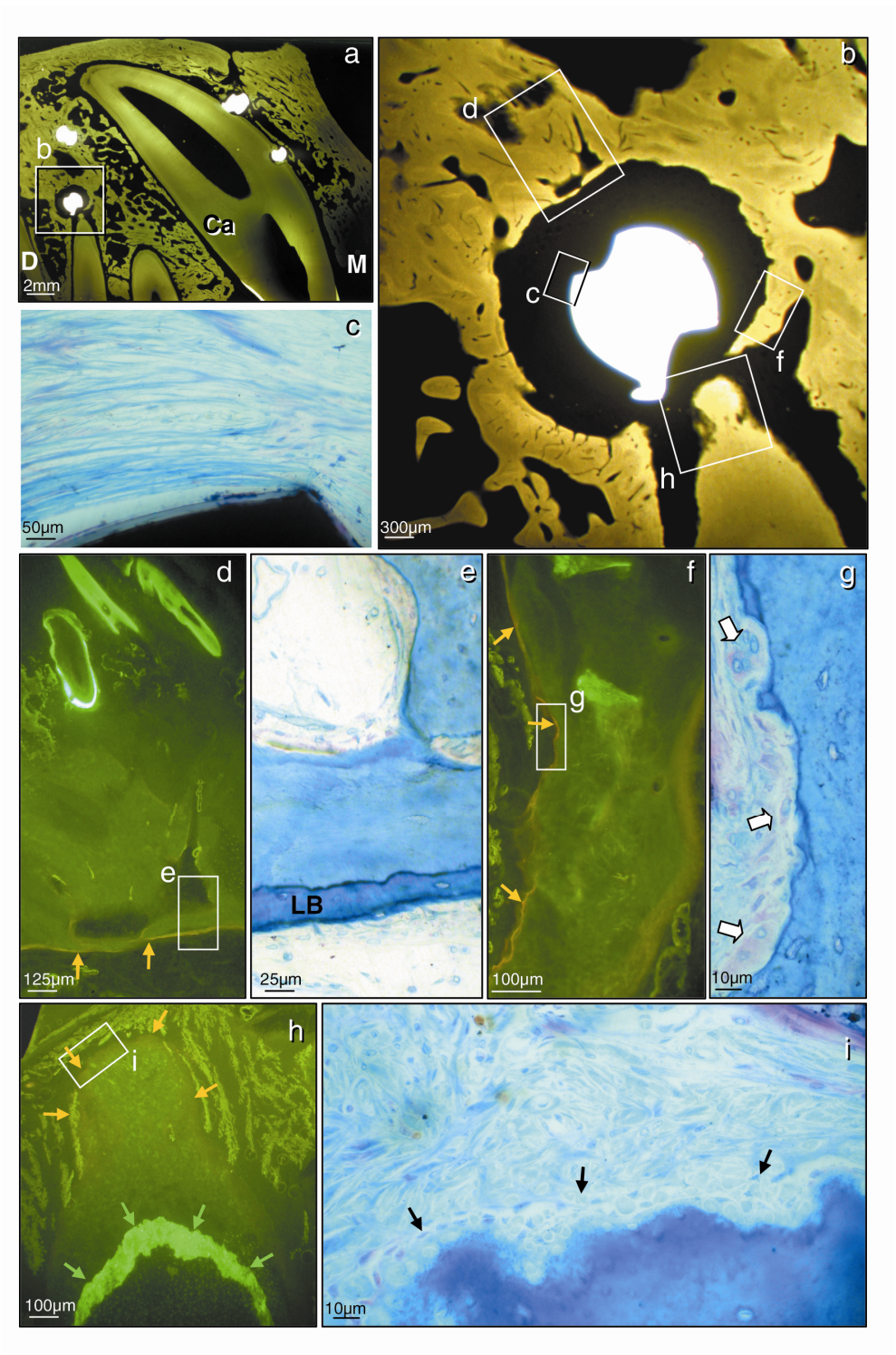
Figure 3.- Lower left nonloaded quadrant of a short term dog.

(a) Microradiograph of a section through the upper screw of the distal miniplate : woven bone trabeculae surrounding the screw, lamellar bone more peripheral.

(b) Enlargement of framed area of Fig. 3a, observed in the section under U.V. light : woven bone (WB) close to the screw and lined by alizarin complexone (orange arrows). No calcein-labelled bone is observed.

(c) Framed area of Fig. 2b, enlarged and observed in the stained section : woven bone (WB) close to the screw and lined by osteoblasts (black arrows). Blood vessels (V) are present in the marrow spaces.

Finally, one plate showed both screws in contact of the upper canine root, without any bony contact (Fig. 4a). Fragments of dentin and cement resulting from pre-drilling were nearly completely enclosed in new cementum and no extensive root destruction was observed.



These 90 screws, considered osseointegrated, were significantly more numerous in the maxilla (57/80) than in the mandible (33/80) ($p < 0.05$). Although their number was higher among the loaded screws (49/80) than among the nonloaded ones (41/80), this difference was not significant. In total, 38 clinically stable miniplates had both their screws in contact with bone or, in one case, with dental root. Five more miniplates were stable even though one out of two screws did not show any bone-screw contact. However, bone was not far from these non-osseointegrated screws and was even detected in direct contact of one of those miniplates. In 9 miniplates, osseointegration of only one screw was not sufficient to ensure stability.

Figure 4.- Upper right nonloaded quadrant of a long term dog.

- (a) Microradiograph : both screws of the mesial (M) miniplate in contact with the canine root (Ca), upper screw of the distal (D) miniplate osseointegrated and lower one non-osseointegrated and close a premolar root.
- (b) Enlargement of frame b from Fig. 4a : lower screw of the distal miniplate surrounded by a radiotransparent space connecting to the premolar root alveolus.
- (c) Frame c of Fig. 4b, enlarged and observed in the stained section : fibrous encapsulation of the screw.
- (d) Frame d of Fig. 4b, enlarged and observed in the section under U.V. light : bone in front of the screw, labelled with alizarin complexone (orange arrows) along the interface and with calcein green further away from the screw.
- (e) Enlargement of frame e of Fig. 4d, observed in the stained section : a thin layer of lamellar bone (LB) in front of the screw, without osteogenic activity.
- (f) Frame f of Fig. 4b observed in the section under U.V. light : bone trabecula lined by alizarin complexone (orange arrows), with some scalloped outlines in front of the screw.
- (g) Enlargement of frame g of Fig. 4f observed in the stained section : Howship lacunae with osteoclasts (thick arrows) along the scalloped bone surface.
- (h) Frame h of Fig. 4b, enlarged and observed under U.V. light : apex of an upper premolar nearby the lower screw of the distal miniplate. Apposition of cementum is attested by alizarin complexone labelling (orange arrows) at some distance from calcein green (green arrows). No root resorption is observed.
- (i) Enlargement of frame i of Fig. 4h, observed in the stained section : periodontal ligament fibers and cementum, lined by cementoblasts (black arrows).

The 24 mobile miniplates had either one or 2 screws without bone contact. These non-osseointegrated screws did not show a particular distribution according to time, jaw or loading. They were surrounded by a radiotransparent space filled with thick fibrous bundles but few cells and blood vessels (Fig. 4a-g). Bone facing the screws showed irregular outlines labelled with alizarin complexon (orange arrows), but rarely lined by preosseous layer and osteoblasts. The most scalloped part of bone surface consisted in Howship lacunae, containing osteoclasts (thick arrows). Around 17 of these non-osseointegrated screws, mainly in the LT group, woven bone was formed in part or whole circumference of the lacuna, but never achieved osseointegration.

In some cases, implantation clearly disrupted the alveolar wall but did not lead to dental root resorption (Fig. 4b). New alizarin-labelled cementum was apposed by cementoblasts (Fig. 4h-i, arrows).

In some miniplates, resorption was also observed on bone facing the connection bar.

BIC, measured around the 90 screws presenting some bone-screw contact, ranged from 1 to 77 %. No significant differences were found between the loaded and the nonloaded screws, neither between the 2 screws of the same miniplates. BIC was significantly higher in the LT group compared to the ST group ($p < 0.001$), and in the mandible compared to the maxilla ($p < 0.005$) (Fig. 5a-c).

BV/TV was assessed on the 122/160 screws presenting some bone within the tangential 980- μ m-diameter zones measured mesial, distal, above and below the screws. BV/TV was significantly higher in the LT group than in the ST group ($p < 0.05$) (Fig. 5d-f). No significant differences were observed between maxilla and mandible, between loaded and nonloaded screws, or between 2 screws of the same plate. Around the 80 loaded screws, BV/TV did not vary significantly according to compression, tension or shear stress.

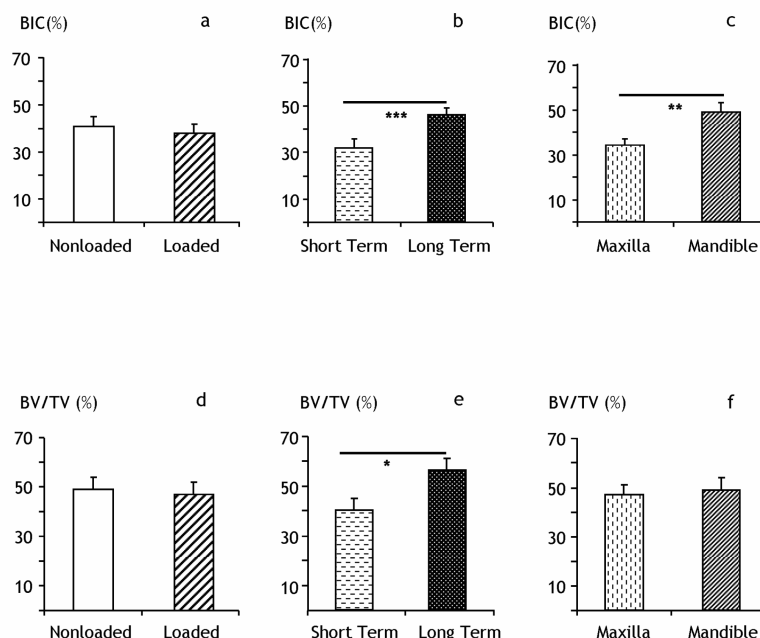


Figure 5.- Histograms of bone-implant contact (BIC, %) and bone volume/total volume (BV/TV, %). Mean : plain bar; standard deviation : line.

(a) BIC of the nonloaded and loaded screws (N = 90). Not significant ($p > 0.05$).

(b) BIC of the ST and LT screws (N = 90). *** : $p < 0.001$.

(c) BIC of the maxillary and mandibular screws (N = 90). ** : $p < 0.005$.

(d) BV/TV of the nonloaded and loaded screws (N = 122). Not significant ($p > 0.05$).

(e) BV/TV of the ST and LT screws (N = 122). * : $p < 0.05$.

(f) BV/TV of the maxillary and mandibular screws (N = 122). Not significant ($p > 0.05$).

DISCUSSION

New bone formation and direct bone-screw contact have been observed around titanium screws supporting osteosynthesis miniplates used in maxillofacial surgery (Cheung et al. 1995, Hirai et al. 2001, Hwang et al. 2000). To the best of our knowledge, there are no histological and morphometric data about the contact condition between titanium screws

and surrounding bone in orthodontically loaded miniplates, although one team mentioned some bone-to-metal contact around orthodontic miniplates used to intrude molars in dogs (Daimaruya et al. 2001). Miniplates used for orthodontic purposes require stability to provide anchorage, but also need to be easily removed once the orthodontic goals are achieved. How load affects bone reactions around the screws is important since excessive bone resorption might affect plate stability, and abundant osseointegration might impede plate removal. The present study, which completes a previous densitometric analysis (Cornelis et al. submitted for publication), showed that loading does not affect bone healing and screw osseointegration.

Microscopic analysis of bone-metal interface of 76 screws showed alternation of new lamellar bone, remnants of damaged bone and gaps (Fig. 2). Necrotic bone close to the screw was observed in both ST and LT groups, and attested the traumatic character of implantation. Although its direct contact with part of the screw surface contributed to primary stability, its brittleness, even artifactual, and disorganized structure, could not ensure long term stability. However, like activation of remodelling had previously been demonstrated as consequence of mechanical fatigue damage (Mori & Burr 1993), the necrotic bone islets likely triggered the remodelling cycle, resulting in lamellar bone apposition on their surface and progressively leading to secondary stability. The gaps between screw and bone contained classical marrow elements, i.e. blood vessels and mesenchymal cells, as well as osteoblasts lining preosseous layers. All these features correspond to a healing process highly similar to the one described around conventional implants (Brunski et al 2005) and miniscrews (Deguchi et al 2003). The only difference was the very small amounts of woven bone observed along the screw surface, whereas intramembranous bone was considered the main healing tissue in the interfacial gaps. It could be due to the tight-fitting holes, conferring a high

primary stability while reducing the gap size as well as the drilling-related bone damage. Indeed, rare woven bone trabeculae were observed when the screw reached an anatomical limit of bone, like the sinusal cavity or the mandibular canal. In the same way, the preponderant presence of woven bone around 12 screws might be due to similar locations, particularly at the periosteal surface of *basis mandibulae*. Woven bone was also apposed as a repair process when the initial hole was not drilled properly and required redrilling in a slightly different axis. Since this redrilling procedure is likely to produce some instability by increasing the surgical trauma, a drill-free technique might be preferred. Kim et al. (2005) found a higher bone-to-implant ratio correlated to the absence of preliminary drilling when comparing a procedure with or without drilling before placement of a miniscrew for orthodontic anchorage. Heidemann et al. (2001) showed that bone-screw contact with drill-free screws was superior to that of self-tapping screws used for osteosynthesis after orthognathic surgery or fracture.

Still regarding the implantation procedure, the connection bar of the plate must be correctly positioned in order to prevent inopportune bone resorption at its contact with the alveolar bone. The dental roots should also be avoided, although they did neither show extensive alterations nor affect osseointegration success or failure.

Screws without bone-screw contact, most often associated with miniplate mobility, were surrounded with a large radiotransparent space where bone had been or was still being resorbed, and showed little evidence of osteoblastic activity (Fig. 4). The screws were exclusively in contact with dense fibrous tissue. Fibro-integration of the screws was associated with miniplate instability. Bone resorption had also been described around fixation screws supporting distraction devices, and increased with time (Schulten et al. 2003). Woven bone was lining the osteolysis lacuna of 17 non-osseointegrated screws, and can be hypothesized as being the

initiation of a healing process, similar to the one found around the osseointegrated screws and due to proximity of anatomical surfaces, particularly the periosteal one. Mainly observed in the LT group, this healing process would require a longer follow-up to verify if it might finally obliterate the osteolytic space.

The metallic particles observed around screws could be artifacts resulting from section cutting and polishing. They could also be due to metallosis of titanium (Hirai et al. 2001, Kim et al. 1997, Matthew & Frame 2000) and likely generated a foreign body reaction, attested by the proximity of multinucleated giant cells (Fig. 2g). Miniplates differ from endosseous implants in that they are manipulated by bending instruments and come in contact with the screws, possibly releasing titanium (Kim et al. 1997). Rough metallic edges and protuberances found on osteosynthesis plates and screws (Ray et al. 1999) might come from the contact between the rotary bur and the miniplate during preparation of the screw holes (Matthew & Frame 2000). These titanium particles might undergo cellular uptake and lysosomal degradation, before being released when phagocytic cells die (Schliephake et al. 1993). However, it has been shown that titanium dioxide released by titanium bone plates did not produce any toxic side-effects (Rosenberg et al. 1993). This should thus not be a problem, especially in orthodontic applications with temporary miniplates.

Beside its structural component, osseointegration appeared functional since it was observed for both screws of 37 stable miniplates and one screw of 5 stable miniplates. No significant difference in BIC and BV/TV could be observed between loaded and nonloaded miniplates in the present sample, allowing acceptance of our initial hypothesis (Fig. 5). These results contrast with the only study concerning orthodontic miniplates, which suggested an effect of load, but did not corroborate it with quantitative data (Daimaruya et al. 2001). By contrast, they correspond to similar findings in experiments with single orthodontic

miniscrews (Buchter et al. 2006, Vande Vannet et al. 2007, Yano et al. 2006). Evaluation of the strain generated by orthodontic load on implants showed levels below the window inducing a biologic adaptive response (Cattaneo et al. 2007, Frost 1990), which might explain the absence of load effect observed in the present study. Consistently, around the screws of the loaded miniplates, no difference in BV/TV was observed between compression and tension zones, like around orthodontically loaded dental implants (Akin-Nergiz et al. 1998, Aldikacti et al. 2004, De Pauw et al. 2002, Gotfredsen et al. 2001a, Gotfredsen et al. 2001b, Majzoub et al. 1999, Oyonarte et al. 2005, Saito et al. 2000) and miniscrews (Melsen & Costa 2000, Melsen & Lang 2001). Beside the compression and tension mesio-distal loads, the screws also supported forces parallel to their long axis, as they are compressing the plate to the bone. This longitudinal load component could not be analyzed in the present transverse sections through the screws, but we can reasonably hypothesize that their magnitude was lower than the level arising bone reaction.

Both BIC and BV/TV increased from ST to LT, which appeared coherent with our relatively short experimental times. This increase confirmed previous observations with orthodontic miniscrews (Buchter et al. 2006, Melsen & Costa 2000) and likely result from the balanced remodelling sequence achieving stability.

Minimal integration index related to stability of orthodontically loaded implants was reported to be 5 % (Deguchi et al. 2003) to 10 % (Roberts et al. 1989). In the present study, the measured BIC of screws associated with a stable miniplate varied from 1 to 77 %. However, miniplate stability with a screw having a BIC as low as 1 % could be related to a higher percentage around the other screw, or to the presence of bone in contact with the miniplate. Moreover, assessment of BIC in this study was performed on two-dimensional microradiographs. Due to the thickness of the diamond saw and the short intrabony length of the screw, our evaluation was limited to 2

sections per screw. Percentages of BIC must thus be interpreted with caution. MicroCT scanning, which is a 3D alternative to histological sections, has been shown to be unable to evaluate BIC, since the regions close to the screws are hidden by a thin region of noise (Stoppie et al. 2005).

The number of osseointegrated screws was significantly higher in the maxilla than in the mandible, whereas the BIC was significantly higher in the mandible compared to the maxilla, suggesting that successful anchorage depends on specific parameters of the anchoring site. Other possible factors affecting stability were detailed in a previous report (Cornelis et al. submitted for publication).

Stability of most miniplates requiring bone in contact of both screws is in accordance with a correlation observed between the degree of microscopical osseointegration and macroscopic fixation of maxillofacial osteosynthesis miniplates in patients (Acero et al. 1999). Some miniplates were stable at the termination of the experiment, whereas bone-screw contact was observed in only 1 out of the 2 screws. It could be that some degree of BIC was present at a certain level of the screws although no BIC was found on the 2 sections analyzed. Bone overgrowth over the plate, due to periosteal reaction, might also explain why stability was obtained, as reported by Kim et al. (Kim et al. 1997). In some human clinical situations, excessive bone overgrowth over the miniplate impedes its removal (Cornelis et al. in press). Since BIC around the screws increased with time but not with loading, it is likely that bone overgrowth over the miniplate might extend with time, without being stimulated by loading.

To conclude, the present microradiographic, histological and morphometric data showed no effect of loading on orthodontic miniplate osseointegration. Osseointegration appeared optimal when the surgical trauma was minimal. BIC increased with time and was higher in the mandible than in the maxilla although the number of failures was higher in the mandible than in the maxilla. The miniplates should be removed as

soon as they are no longer necessary, osseointegration of the screws and bony overgrowth over the miniplates, even nonloaded, increasing with time.

ACKNOWLEDGMENTS

We acknowledge Prof. J.P. Dehoux and G. Araujo for animal housing, Dr. C. De Clercq and Dr. F. Nsimba for surgical assistance. We acknowledge the technical help of C. Benoît, M. Parisi and W. Hudders. We thank Drs. J.F.C. Tulloch, C.C. Ko and P. Cattaneo for discussion of this paper. This research was supported by the Special Research Fund (Université catholique de Louvain). The miniplates were provided by Surgi-Tec.

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Patients and orthodontists perceptions of miniplates used for temporary skeletal anchorage : a prospective study

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American Journal of Orthodontics and Dentofacial Orthopedics 2008, 133 : 18-24

Patients and orthodontists perceptions of miniplates used for temporary skeletal anchorage : a prospective study

ABSTRACT

Introduction : Temporary skeletal anchorage is a relatively recent addition to orthodontic treatment. Surgical miniplates, modified with intraoral attachments, provide an alternative to miniscrews for skeletal anchorage. This study was to determine patients' and providers' perceptions of miniplate use during orthodontic treatment.

Methods : Consecutive patients having miniplates placed as part of their treatment completed questionnaires regarding their experiences during surgery and orthodontic treatment. A total of 200 miniplates were placed for 97 patients. The 30 orthodontists treating these patients also completed questionnaires concerning miniplate success, handling complexity, and the degree to which these devices simplified treatment.

Results : The success rate was 92.5 %. The devices were well tolerated by the patients. After a year, 72 % of patients reported they did not mind having the implant and 82 % that the surgical experience was better than expected, with little or no pain. The most frequent problems were post-surgical swelling, lasting 5 days on average, and cheek irritation experienced initially by more than 1/3 of patients, but reducing over time. The clinicians reported these devices easy to use, greatly simplifying orthodontic treatment.

Conclusions : Miniplates are well accepted by patients and providers and are a safe and effective adjunct for complex orthodontic treatments.

INTRODUCTION AND LITERATURE REVIEW

Anchorage is one of the most challenging aspects of orthodontic treatment. Conventional anchorage methods generally rely on patient compliance, result in unwanted reciprocal tooth movements, and can be limited in patients with compromised dentitions. In an effort to overcome some of these problems, skeletal anchorage has been increasingly incorporated into orthodontic treatment for over twenty-five years.¹ The quest for absolute anchorage began with the use of conventional dental implants,² retromolar implants,³ and palatal implants.⁴ However, space limitations, cost of the implants and difficulties with connection to the orthodontic appliances rapidly argued in favor of smaller devices that could be placed in a variety of locations within the dental arch. Miniscrews⁵ and miniplates,⁶ specifically designed for orthodontic anchorage, satisfy some of those requirements, and are being progressively adopted into clinical practice.

The recent literature has tended to focus on miniscrews, perhaps because of their small size and apparent ease of placement.⁷⁻¹⁵ However, miniscrews have been associated with a fairly high failure rate,¹⁶ including fracture during placement,¹⁷ loosening under loading,¹⁸ and impingements on roots either during placement or during tooth movement.¹³ Miniscrews may also need to be repositioned during treatment to allow all intended tooth movements to be accomplished. To address some of these issues, surgical miniplates with intraoral attachments have been modified to serve as temporary skeletal anchorage devices (TSAD). Miniplates, which are placed at a safe distance from the roots, offer the advantages of reduced risk of root impingement, allow the free movement of roots past the TSAD, and are associated with a lower failure rate as compared with miniscrews.¹⁶ Claims have been made that miniplate anchorage simplifies

previously complex treatments,¹⁹ and permits correction of malocclusions previously thought beyond the scope of orthodontic therapy alone.²⁰⁻²³ While appearing safer, more stable, and extending treatment possibilities, there are few reports of the use of this type of TSAD, and fewer still of clinician or patient perceptions of their use. The majority of available publications on miniplates are case reports,^{6,24-32} or retrospectively assessed case series,^{16,19,22,33} with only one prospective clinical trial³⁴ reporting adverse events and outcomes during treatment, and only one report of patient's opinions and experiences.¹⁶ Also, there is only one other study reporting patient perceptions of TSAD use and this addresses palatal implants.³⁵ It may be that miniplate use has been limited due to the perception that they are difficult to place, unpleasant and difficult for the patient to tolerate, cumbersome for the orthodontist to use, and may not provide significant advantages for treatment.

This survey was undertaken to obtain information on both patient and provider experiences with miniplates used for temporary skeletal anchorage when used for a variety of clinical conditions. This present study documents both patient and orthodontist perceptions of the use of miniplates and evaluates the success of the system, identifying adverse events and outcomes associated with this adjunct to orthodontic practice.

MATERIAL AND METHODS

Questionnaires were presented to consecutive patients having miniplates placed as part of their orthodontic treatment, and to the clinicians providing their treatment at two university based orthodontic centers (University of North Carolina at Chapel Hill (UNC), USA, and Université catholique de Louvain (UCL), Brussels, Belgium). Patients were enrolled between August 2003 and April 2005 and completed questionnaires in their preferred language (English or French). Additional parental comments

were solicited for children under the age of 16. The study was approved by the Institutional Review Board at UNC and the Biomedical Ethics Commission at UCL.

Questionnaires were completed at approximately 1 month, 6 months and 1 year after TSAD placement (or upon removal of the anchor, if this occurred sooner). The questions related to the patient's discomfort and general experiences during surgery and orthodontic treatment. In addition the orthodontists were asked to assess handling complexity, the purpose for which the anchor was being used, success rate, their overall TSAD experience and the extent to which they felt these devices simplified or complicated their patient's treatment.

All subjects at UNC, and all but 3 at UCL agreed to participate in the study. One patient at UCL was later excluded because of their inability to understand the questionnaires. A total of 98.6 % of questionnaires were completed by the patients and orthodontists at both centers. Patients and providers perceptions were obtained using 4-point categorical scales. Medians, means, and standard deviations were calculated for perception data and frequencies were reported for categorical data.

The patients at UNC were paid \$20 upon completion of the third questionnaire

RESULTS

Sample demographics

A total of 97 patients were enrolled (30 at UNC, 67 at UCL (Table I)).

	UNC	UCL
Patients	30	67
Age mean [range] (yrs)	24.0 [12.2 - 48.1]	23.5 [9.8 - 46.9]
Females	73,3 %	73,1 %
Growing patients (♀ ≤ 15; ♂ ≤ 19)	8 (27 %)	24 (36 %)
Patients with 1 implant	3 (10 %)	17 (25 %)
Patients with 2 implants	26 (87 %)	38 (57 %)
Patients with 3 implants	0	1 (2 %)
Patients with 4 implants	1 (3 %)	11 (16 %)

Table I.- Demographics of patients receiving temporary skeletal anchorage devices at two centers.

The mean age of the patients was 23.7 years (range 9.8 - 48.1 years). One third of the sample were growing patients, (≤ 15 years of age for females; ≤ 19 years of age for males) and almost $\frac{3}{4}$ were females. The number, type, location and success of miniplates are given in Table II. A total of 200 TSADs were placed by 9 surgeons (4 at UNC, 5 at UCL). Two types of TSADs were used (Fig. 1) : 180 Bollards (Surgitec, Bruges, Belgium) (39 at UNC, 141 at UCL) and an additional 20 C-tubes (KLS Martin, Umkirch, Germany) were used for 10 patients at UNC.

	UNC	UCL
Bollards	39	141
C-tubes	20	0
Maxilla posterior	49	104
Mandible anterior	6	32
Mandible posterior	4	5
Time to loading (days)	23.0 ± 19.6	34.7 ± 26.1
Total number of failures	4	11
Due to mobility	2	5
Due to soft tissue ulceration	0	4
Due to anchor breakage	1	2
Due to poor location	1	0
In growing patients (♀ ≤ 15; ♂ ≤ 19)	3	8
In adults	1	3
Maxilla	4	5
Mandible	0	6

Table II.- Type, location, and failure of temporary skeletal anchorage devices at the two centers.

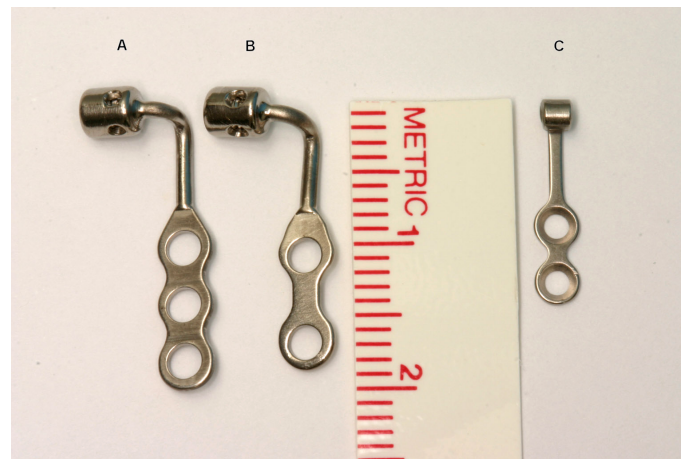


Figure 1.- Miniplates. Maxillary (A) and Mandibular (B) Bollard (Surgitec, Bruges, Belgium), C-Tube (KLS Martin, Umkirch, Germany) (C).

The majority (76.5 %) of the TSADs were placed in the maxilla. Implants were loaded approximately one month after surgery, and no plates were loaded immediately. The majority of the miniplates were in place for more than the one year study period. A total of fifteen bone plates were removed prematurely and only six of these were replaced. The success rate from August 2003 until the present was 92.5 %. The majority (73.3 %) of the failures occurred in growing patients. The percentage and location of failures was different at the two centers. A total of 30 orthodontists completed questionnaires (19 at UNC, 11 at UCL). The types of movement (Fig. 2) for which TSADs were placed included orthodontic (Fig. 3a) as well as orthopedic corrections (Fig. 3b). The Bollards were loaded with elastics, coil springs, elastic chains, ligature wires, or directly with an arch wire. The C-tubes were loaded only with coil springs or ligature wires.

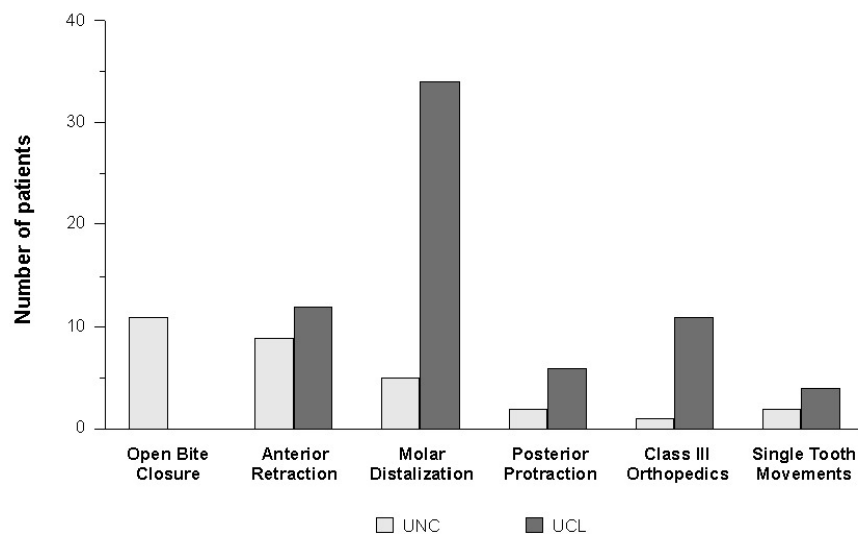


Figure 2.- Number of patients at the two centers receiving TSAD for different clinical conditions.

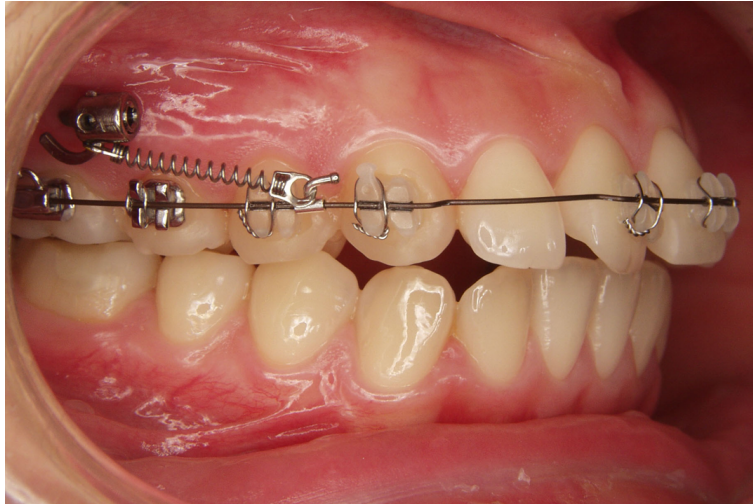


Figure 3a.- Distalization of premolars and molars with open coil spring placed between anchor and sliding tube.



Figure 3b.- Maxillary protraction with class III elastics placed between upper posterior and lower anterior miniplates.

Patient's perceptions

Surgical experience

The patients' perceptions of their surgical experience are given in Figure 4. Pain during surgery and orthodontic treatment was reported on a four-point scale from no pain to severely painful. The patients estimated their swelling after surgery as 1.8 on a 0-3 scale (0 : no swelling to 3 : lots of swelling), lasting for 5 days on average (4.8 ± 2.3 at UNC; 5.5 ± 3.0 at UCL). After surgery, either anti-inflammatory agents or painkillers (or both) were recommended, but taken by only 77.1 % of the patients.

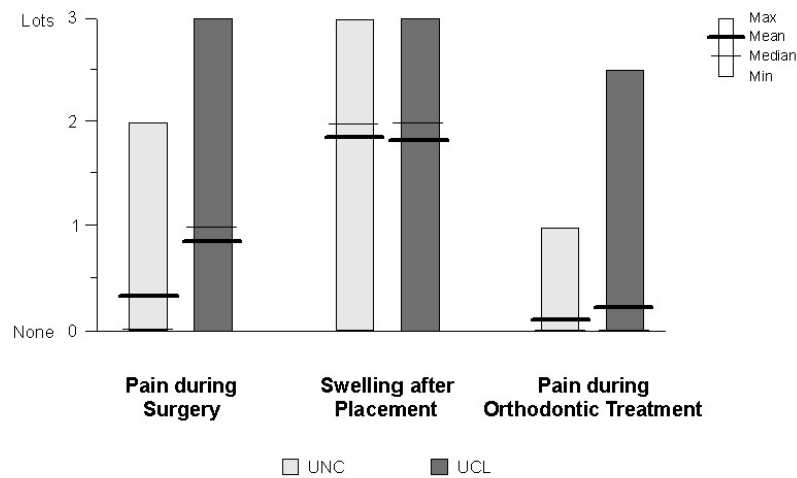


Figure 4.- Mean, median and range of patients' perceived pain after TSAD placement and during orthodontic treatment and the degree of swelling reported one month after placement.

General experience

In general TSADs were well tolerated by the patients. No patient requested to have an implant removed. After 1 year, 72 % of the sample (83.3 % at UNC and 66.7 % at UCL) reported that they did not mind having the implant in place, while some expressed mildly negative comments that included "having a foreign body in the mouth", irritation of cheek or lip, and food trapping around the device. Implant placement was reported to be better than expected by 82 % of the patients (93.1 % at UNC; 76.4 % at UCL) most frequently because they reported they had expected more pain. Of those patients that reported the implants to be worse than expected, post-surgical swelling or cheek irritation were the principal reasons.

Comparisons

Some of the patients had previously experienced other dental procedures, including extractions, headgear, braces, and cavity restorations. Patients were asked to make comparisons against those procedures with which they were familiar. The results are given in Figure 5 as the percent of the patients at each center finding TSADs better than other dental procedures with which they had experience.

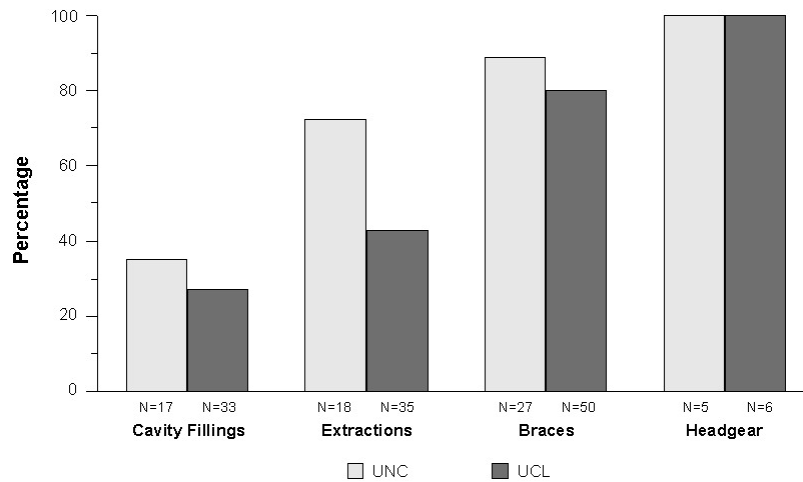


Figure 5.- Percent of patients indicating TSAD better than other previously experienced dental procedures.

Side effects

Patients were asked about any side effects they had at each time point (Fig. 6). The principal problem experienced was cheek irritation, which was most frequent soon after surgery, but decreased over time. Restricted mouth opening concerned 17 % of the patients initially, but became and remained minimal after six months and one year. Cleaning the anchors was a problem for 15 % of the patients, and this continued over time. Patients were specifically instructed not to touch the TSAD with their tongue to prevent loosening the miniplate. However, one-third of the patients admitted to doing this, and this habit frequently persisted throughout the year they were followed.

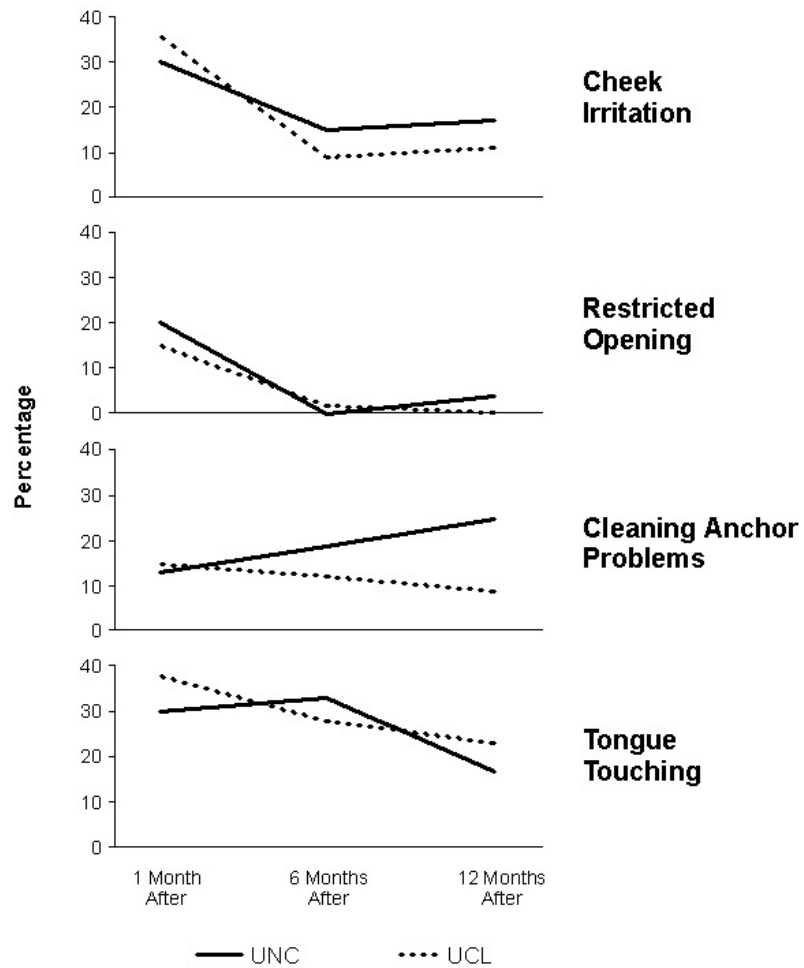


Figure 6.- Percentage of patients reporting side effects at different time points.

Orthodontist's perceptions

The orthodontist's perceptions of TSAD experience is illustrated in Figure 7a.

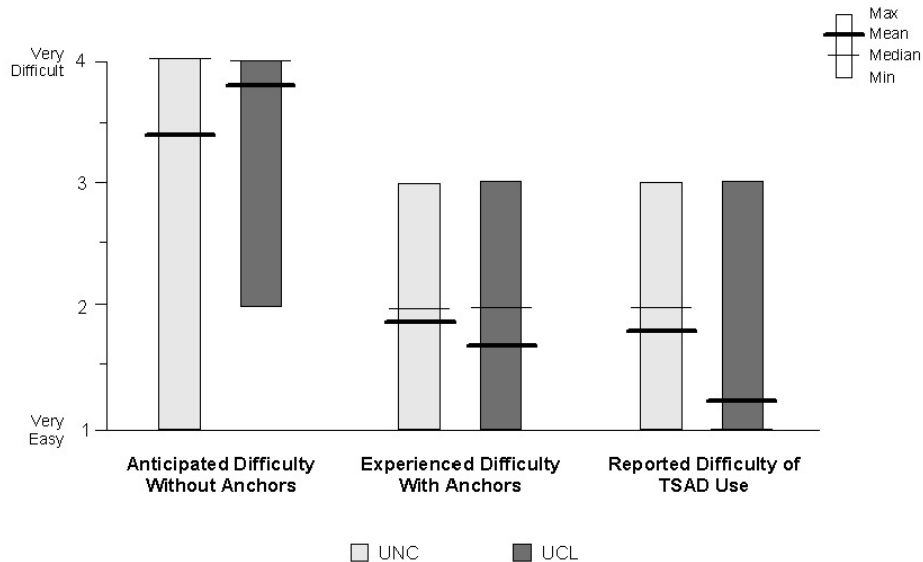


Figure 7a.- Mean, median and range of orthodontists' perceived difficulty of treatment with and without TSADs and the degree of difficulty they experienced using TSADs.

In their first questionnaire, the orthodontists were asked how difficult they anticipated the treatment of each case to be without TSADs. In general, the cases were initially anticipated to be somewhat to very difficult. However, after one year with the use of miniplates, the same cases were then considered by their orthodontist to be very to moderately easy. The orthodontists judged the overall handling complexity of the miniplates and their attachments on a four-point scale and reported them to be very to moderately easy over the different time points. The mobility of TSADs and soft tissue irritation evaluated by the orthodontists at several time points over a year stayed under the level of "mild" (Fig. 7b). All (100 %) of the orthodontists said they would use miniplates again and evaluated their average degree of satisfaction at 3.8 (3.6 at UNC; 3.9 at UCL) on a 1-4 point scale (3 : moderately satisfied - 4 : very satisfied) (Fig. 7b). If the

orthodontists reported that an initial orthodontic objective could not be obtained, the reasons given were implant failure or lack of patient compliance.

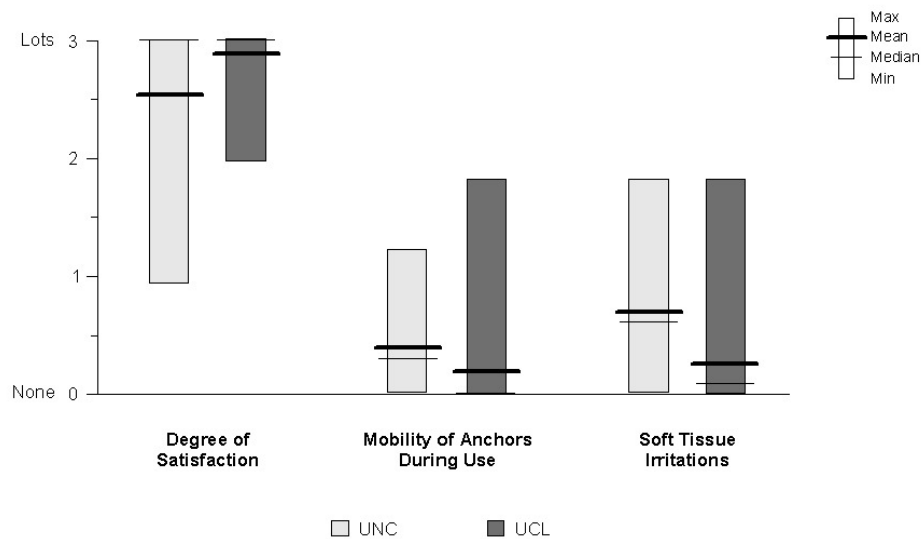


Figure 7b.- Mean, median and range of orthodontists' report of degree of satisfaction with TSAD and side effects observed in patients.

DISCUSSION

In general, patients, parents and providers were enthusiastic about their experiences with miniplates as a simplifying adjunct to orthodontic treatment. Miniplates were well tolerated by the patients and were associated with few adverse events. To place miniplates in the context of other dental procedures it would seem that they are always perceived as better than headgear, nearly always better than braces, better (UNC) or equivalent (UCL) to extractions, and about equal or worse than cavity restorations. Although the placement of miniplates requires surgery to

raise a mucoperiosteal flap and retract the tissues, these procedures appear to be associated with minimal peri-operative pain and inconvenience, and no major recurring problems during treatment.

This study was carried out at two university centers with both experienced and inexperienced orthodontists and surgeons and few problems occurred. The side effects reported were quite different from those reported by Gunduz et al³⁵ (difficulty in speaking, difficulty in eating, and injury to tongue) for palatal implants. Although some negative comments were recorded from some patients, it is not possible from this sample to determine if there was any consistent pattern suggesting an association between negative comments and age, insertion site, or type of treatment being undertaken. The principal adverse outcome was swelling, which persisted on average for 5 days following surgery. Even though anti-inflammatory agents were prescribed post-operatively, not all patients complied with this recommendation. It is probable that more aggressive management of post-operative edema, including the use of ice packs 1-2 hours postoperatively, the addition of pre-operative anti-inflammatory agents or corticosteroids delivered intravenously, could prevent or at least reduce this post-operative complication.

Cheek irritation was another frequently reported problem, but for only one patient was this considered severe enough to require removal of the TSADs. The initial location of the miniplates in the mandibular arch was between the canine and first premolar, which was later modified to between the lateral and canine. This new position decreased the occurrence of cheek irritation, likely because the miniplate head was then less prominent. When placed at the canine eminence the lip and cheek movement and pressure against the miniplate head had the potential to cause soft tissue irritation or ulceration. Moving the miniplates forward in the mandibular arch reduced this.

Our definition of failure was any case where the objectives could not be achieved with the initial implants. This included excess TSAD mobility (7), cheek ulceration (4), fractures (3), and undesirable position of the miniplate (1). Increased mobility was proportionally more frequently reported in the mandible than the maxilla, possibly related to the flap design. The initial mandibular surgical protocol at UCL was modified during the study to place the releasing incision in the attached gingiva and not in the sulcus. Three failures due to mobility were reported prior to this change, but no further failures were observed after this change. Four mobile maxillary miniplates, in one adult and three growing patients, were removed and subsequently replaced : one because of poor plate adaptation to the bone, leaving an open pathway for infection and the other three because infection occurred around one of the screws. The failure rate due to mobility in growing patients was higher than in adults. Although the surgeons were always instructed to place the attachment arm penetrating the tissue at the mucogingival junction, this may be more difficult in younger patients where the alveolar height tends to be shallow, the width of attached gingiva decreased and the access restricted. Moreover, the majority of miniplates in growing patients were in place for longer than 18 months. During this time a significant amount of bone remodelling can occur, which may also explain the higher failure rate.

In several cases, although the TSADs were described as being mobile throughout treatment, they were still sufficiently firm to provide the anchorage necessary to achieve the treatment objectives.

It is apparent that soft tissues play an important role in implant stability. Mucosal transfixion of the miniplate arm at the muco-gingival junction or 1 mm within the attached gingiva enables tight closure of the tissues, which appears necessary for good soft tissue healing.

Oral hygiene is another important factor for success. According to Miyawaki et al¹⁶, prevention of inflammation of the peri-implant tissue is a

critical factor regarding TSAD success rate. Many of the patients experienced persistent difficulties in cleaning their miniplate anchors. Precise recommendations as to careful brushing of the miniplate and surrounding mucosa using a soft toothbrush are important in preventing infection, which can lead to subsequent miniplate failure.

Out of the 180 Bollards placed, 3 fractured, all in the intraoral connector. One of the fractures occurred after the device had been subject to repeated bending to change the force vector.

Lastly, a patient who had an open bite needed to have a C-tube repositioned to allow the completion of the intrusion of the posterior teeth. Unlike the C-tube, the Bollard anchor is designed to accept auxiliary attachments and so provides greater flexibility in the point and direction of force application.

The overall success rate of 92.5 % in this study of 97 consecutive patients (with 200 TSADs) who were followed prospectively confirms the earlier findings of Miyawaki et al¹⁶ who reported a 96.4 % miniplate success rate in a retrospective study of only 17 miniplates. A prospective study by Cheng et al³⁴ following 44 patients (48 miniplates and 92 miniscrews), reported an 89 % success rate for both types of TSADs, but the miniplates were used in the more difficult situations.

It seems clear that both miniplates and miniscrews have the potential to augment or provide absolute anchorage and allow orthopedic correction and/or orthodontic tooth movements not traditionally thought possible with conventional anchorage methods. In addition, the unwanted reciprocal forces that almost always occur with more traditional anchorage devices are not observed. The problem of patient compliance is simplified to the ever present one of oral hygiene. For the majority of clinicians participating in this study, these cases represented their first experiences with skeletal anchorage. And yet there was a near unanimous report that

such devices simplified all treatments, sometimes to a remarkable extent. It may be that the use of TSADs really will expand the envelope of discrepancy in which orthodontic treatment can be successful.

It is clear that placement of a miniplate is a more complex procedure than the placement of a miniscrew. However, is this greater complexity warranted ? It would seem that the greater flexibility provided by the current design of miniplates is an advantage in certain circumstances. For example, during *en masse* movement of an entire arch by more than 2 mm, placing TSADs above the root apices would be preferable^{36,37}. Miniplate systems that accept arch wires also allow changes in point of force application or force vectors without the need to reposition the TSAD. As currently designed, miniplates seem to be associated with a lower failure rate than miniscrews¹⁶. The possibility raised by Liou et al, that miniscrews do not remain stationary under orthodontic forces¹⁸, does suggest that a safety zone regarding root or nerve proximity may be required. This could further restrict possible placement sites or limit the amount of tooth movement. For patients who are undergoing extensive orthopedic corrections or other treatments (ie maxillary protraction or intrusion) where the TSADs are expected to be in place for a long time, the force vectors need to be varied, or the roots need to slide past the anchors, then miniplates may be preferred. However, the relative effectiveness, efficiency and acceptability to patients of different temporary anchorage devices used for different clinical problems need to be evaluated in a systematic fashion.

CONCLUSIONS

This study was designed to explore patient and provider perceptions of the use of modified miniplates as TSADs. We conclude that : miniplates are well accepted by patients and providers, they offer safe and effective anchorage possibilities with a high success rate (92.5 %), and few side effects or problems during treatment. Even novice users found miniplates to both simplify orthodontic treatment and enhance the possibility of treatments that may have been considered unfeasible without skeletal anchorage. Although the surgery to place miniplates is more invasive than that used to place miniscrews, patients experience few undesirable sequelae, are enthusiastic about their use, and appear to regard their placement as a relatively trivial dental event. Details of the surgical placement and removal will be covered in a future paper.

ACKNOWLEDGEMENTS

Thanks to Debbie Price for data management from both sites.

This study was supported in part by a grant from the SAO, the Dental Foundation of the University of North Carolina and by a grant “Fonds Spéciaux de Recherche 2004” from the Université catholique de Louvain.

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Modified miniplates for temporary skeletal anchorage in orthodontics : placement and removal surgeries

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Journal of Oral and Maxillofacial Surgery (in press)

Modified miniplates for temporary skeletal anchorage in orthodontics : placement and removal surgeries

ABSTRACT

Purpose : Skeletal anchorage systems are increasingly used in orthodontics. This paper describes the techniques of placement and removal of modified surgical miniplates used for temporary orthodontic anchorage and reports surgeon's perceptions of their use.

Patients and Methods : Ninety-seven consecutive orthodontic patients having miniplates placed as an adjunct to treatment were enrolled. A total of 200 miniplates were placed by nine oral surgeons. Patients and surgeons completed questionnaires after placement and removal surgeries.

Results : Fifteen miniplates needed to be removed prematurely. Antibiotics and anti-inflammatories were generally prescribed after placement, but not after removal surgery. Most surgeries were performed under local anesthesia. Placement surgery lasted on average between 15 and 30 minutes per plate, and was considered by the surgeons to be very to moderately easy. The surgery to remove the miniplates was considered easier and took less time. The patient's chief complaint was swelling, lasting on average 5.3 ± 2.8 days after placement and 4.5 ± 2.6 days after removal.

Conclusions : Although miniplate placement/removal surgery requires the elevation of a flap, this was considered an easy and relatively short surgical procedure that can typically be performed under local anesthesia without complications, and may be considered a safe and effective adjunct for orthodontic treatment.

INTRODUCTION

One of the most challenging problems in orthodontics is to find sufficient anchorage to achieve planned tooth movements. Conventional approaches take advantage of the differential anchorage potential in the dentition where a larger number of teeth can resist movement of a smaller number. This often requires the additional use of compliance dependent auxiliary devices such as intermaxillary elastics and/or headgear. In many adult patients with partial or periodontally compromised dentitions, the available anchorage is further reduced. To widen orthodontic treatment possibilities or reduce the need for compliance dependent devices, first prosthetic implants¹, and later retromolar² and palatal implants³ were incorporated into orthodontic treatment. These devices are relatively expensive, require a healing period before orthodontic loading, and often provide only indirect anchorage. More recently, Temporary Skeletal Anchorage Devices (TSADs)⁴, which are smaller, cheaper, and require shorter healing periods, have been specifically designed for orthodontic use. A mini- or micro-screw is a small bone screw, most usually made of titanium or titanium alloy, between 1.2 and 2.2 mm in diameter and 5-15 mm length. These screws are placed transmucosally with an attachment mechanism exposed in the oral cavity⁵. Miniscrews are very popular because of their ease of placement, often by orthodontists themselves. However, miniscrews have been associated with a high risk of failure when placed in unattached gingiva⁶, root injury can occur when they are placed in keratinized mucosa and their position can limit the amount and direction of tooth movement. In addition, moments on the miniscrews should be avoided as they may cause screw loosening⁵. Miniplates⁷⁻⁹, which are modified osteosynthesis fixation devices, by contrast, present an advantage because their fixation screws are generally placed apical to the roots and so do not interfere with tooth movement : the roots can easily

slide past the anchorage device¹⁰. The connection bar of the miniplate passes through the attached gingiva and the attachment unit is close to the dental arch (Fig. 1).



Figure 1.- Miniplate with connection bar coming through the gums at the muco-gingival junction. The attachment unit, located close to the dental arch, serves as anchorage to distalize the premolars and molars with a coil spring.

Miniplates may provide more secure anchorage when higher forces, such as orthopedic forces are needed¹¹. However, miniplates should be placed by a surgeon because this is a technique sensitive surgery requiring flap elevation and strict asepsis. The patients' and orthodontists' perceptions of the healing process and the orthodontic treatment were previously reported¹². However, the surgical technique and surgeon's opinion have so far not been detailed in the existing literature. The purpose of this paper is to describe the surgical technique for placement and removal of miniplates for temporary skeletal anchorage, and to report the surgeons' perceptions of these procedures.

PATIENTS AND METHODS

Consecutive patients having miniplates placed as TSADs as part of their orthodontic treatment were identified at 2 university based orthodontic departments. Inclusion criteria only required the subjects (and the parents of minors) to comprehend and complete a series of questionnaires. The study was approved by both institutional review boards.

		UNC N=30 patients	UCL N=67 patients
Patients	Mean age [range] (yrs)	24.0 [12.2 - 48.1]	23.5 [9.8 - 46.9]
	Females (%)	73	73
	Growing patients* (%)	27	36
	Patients completing placement questionnaire	30	67
	Patients completing removal questionnaire	7	42
Types of miniplates	Bollards**	39	141
	C-tubes***	20	0
Miniplates location	Maxilla posterior	49	104
	Mandible anterior	6	32
	Mandible posterior	4	5

*♀ ≤ 15; ♂ ≤ 19 - **Surgitec, Bruges, Belgium - ***KLS Martin, Umkirch, Germany

Table I.- Patient's and TSAD's demographics

A total of 101 patients were identified, 3 declined to participate, and one was excluded because of problems understanding the forms. The remaining 97 patients, 30 from the University of North Carolina at Chapel Hill (UNC) and 67 from the Université catholique de Louvain, Brussels (UCL), were enrolled (Table I).

One third of the patients were considered to be still growing. Patients completed questionnaires, in their preferred language (English or French), about swelling and medications taken after TSAD placement and removal. All patients completed the initial questionnaires, 53 patients had had their plates removed by the end of the data collection period, and 49 of these completed the removal questionnaires.

In all, 200 miniplates of 2 designs were placed (Table I). Both devices are made of titanium. The Bollard has either 2 (mandibular model) or 3 (maxillary model) fixation holes, a round connecting bar that perforates the mucosa and an orthodontic attachment unit with a locking screw (Fig. 2).

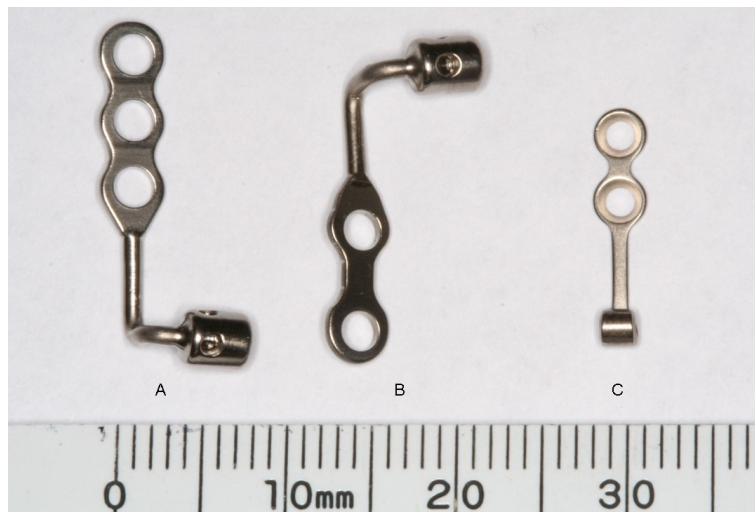


Figure 2.- Miniplates. Maxillary (A) and mandibular (B) Bollard, C-Tube (C).

The C-tube is a 2-hole titanium miniplate with a flat connection bar and a tube to allow attachment to the orthodontic appliance (Fig. 2). Different types of fixation screws were used, but all were self-tapping and made of uncoated titanium (none were sandblasted or acid-etched) and were between 5 and 7 mm in length. In the maxilla, the plates were centered on the infrazygomatic crest. In the mandible, the miniplates were positioned parallel to and between the roots of neighboring teeth.

The surgical placements of the TSADs in the maxilla and mandible were carried out according to the following protocol :

- L-shaped incisions were made with the horizontal part of the incision located 1 mm into the attached gingiva (Fig. 3a).
- Mucoperiosteal flaps were elevated for bone exposure (Fig. 3b).
- The plate was bent to fit the bone surface; importantly the connection bar must be slightly bent at the lower limit of the plate (Fig. 4, arrow a) to ensure tight contact with the bone surface where the bar emerges through the mucosa (Fig. 4, arrow b), and good soft tissue healing.
- The hole for the middle screw for the 3-hole plates, or the screw located closest to the attachment unit for the 2-hole plates, was drilled first (Fig. 3c).
- The first screw was not completely seated to allow some rotation and adjustment of the plate to an ideal position, prior to placing the other screws (Fig. 3d).
- All screws were subsequently tightened with a hand driver without torque control.
- After rinsing with saline solution, closure was obtained in one plane with resorbable sutures (Fig. 3e).

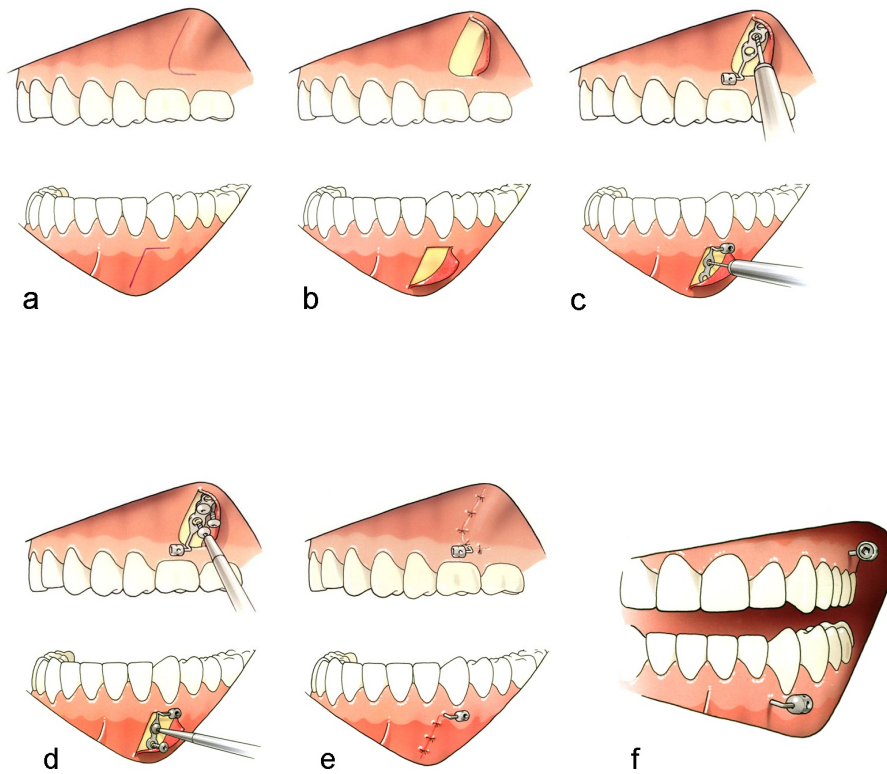


Figure 3.- Placement surgery in the maxilla and mandible. L-shaped incisions with the horizontal part of the incision being 1 mm into the attached gingiva (a), mucoperiosteal flap (b), drilling of middle hole (for the 3-holes plates) or hole located closest to the attachment unit (for the 2-holes plates) (c), insertion of the screws (d), closure with resorbable sutures (e), Bollards with the attachment units facing anterior in the posterior maxilla and posterior in the anterior mandible (f).

Bollards were placed with the attachment units facing anteriorly in the posterior maxilla and mandible. In the anterior mandible (between lateral incisor and canine), the attachment units faced distal to reduce cheek and lip irritation (Fig. 3f).

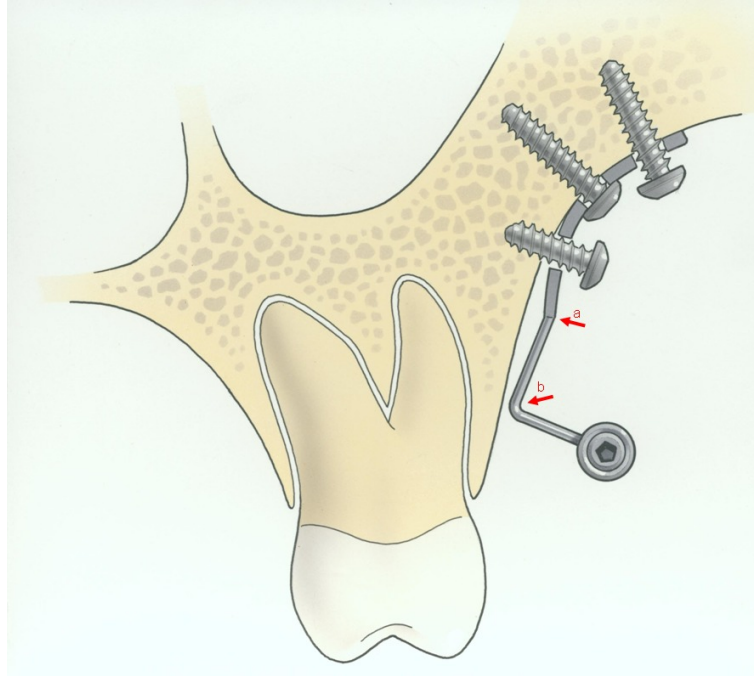


Figure 4.- Schematic cross-section through miniplate placed on the infra-zygomatic crest. The connection bar is slightly bent at the lower limit of the plate (arrow a) to ensure tight contact between the end of the connecting bar and the bony surface at the emergence point through the mucosa (arrow b).

Miniplate placement was never combined with extractions near the TSAD placement site. If extractions had to be performed close to the site, they were performed at least 2 weeks before TSAD placement.

Patients were instructed to brush their TSADs at least twice a day. Chlorhexidine mouth rinses were recommended during the first week after placement. TSADs were loaded approximately one month after surgery ($23.0 \text{ days} \pm 19.6 \text{ (UNC)}$ and $34.7 \text{ days} \pm 26.1 \text{ (UCL)}$).

Miniplate removal required a short mucoperiosteal incision to expose the plate and the screws. The incision was sutured after removal and rinsing

with a saline solution. Patients were instructed to use chlorhexidine mouth rinses again for 3 days after surgery.

Nine different oral surgeons placed the devices (4 residents and 5 attending faculty). The surgeons were asked to complete a questionnaire as soon after placement and removal as possible. The questionnaires addressed the procedure complexity, the time necessary, any complications experienced, as well as specific details on anesthesia and medications prescribed. In addition, at removal, the surgeons evaluated the TSAD mobility, bone covering the miniplates, inflammatory response, and the resistance of the screws removed. The total time the TSADs were in place was noted. Questionnaires were completed for all placements and for 45 out of 53 removals.

The surgeons and patients perceptions were obtained using 4-point categorical scales and are reported as frequencies.

The patients at UNC were paid \$20 upon completion of the last questionnaire.

RESULTS

The success rate was 92.5 % : fifteen bone plates were removed prematurely. Eleven of these failures occurred in growing patients. One hundred (15 at UNC - 85 at UCL) of the 200 miniplates placed were removed during this study period, on average 1.5 years after placement (1.5 ± 0.7 years at UNC, 1.5 ± 0.6 years at UCL).

The medications taken by the patients are summarized in Table II. Although antibiotics were often prescribed after the placement surgery, some patients did not follow these recommendations. Anti-inflammatories and painkillers were prescribed for over half of the patients, and again not all patients followed these recommendations.

The majority of the surgeries were performed under local anesthesia, with a few performed under IV sedation, or general anesthesia, typically for younger patients having more than 2 TSADs placed (Table II).

			Placement (%)	Removal (%)
Medications	Before surgery	Antibiotics	30.9	6.5
		Antiinflammatories	17.5	13
	After surgery	Antibiotics prescribed	92.8	19.6
		Antibiotics taken	71.9 (for 5.2 days $\pm$ 1.7)	10.2 (for 3.6 days $\pm$ 1.8)
		Antiinflammatories prescribed	72.2	58.7
		Painkillers prescribed	61.9	67.4
		Antiinflammatories and/or painkillers taken	76.3 (for 6.5 days $\pm$ 5.3)	30.9 (for 5.2 days $\pm$ 4.3)
Anesthesia	Local anesthesia		82.5	100
	IV sedation and local anesthesia		5.1	0
	General sedation		12.4	0
Time for surgery	< 15 minutes		57.5	81.4
	15-30 minutes		37.2	14
	30-40 minutes		5.3	4.6

Table II.- Surgery

The percentage of patients experiencing swelling is shown in Figure 5a, with the intensity of swelling on a 4-point scale. Swelling was reported to last on average 5.3 ± 2.8 days after placement and 4.5 ± 2.6 days after removal.

Surgical complexity (Fig. 5b) was reported on a scale from very easy to very difficult.

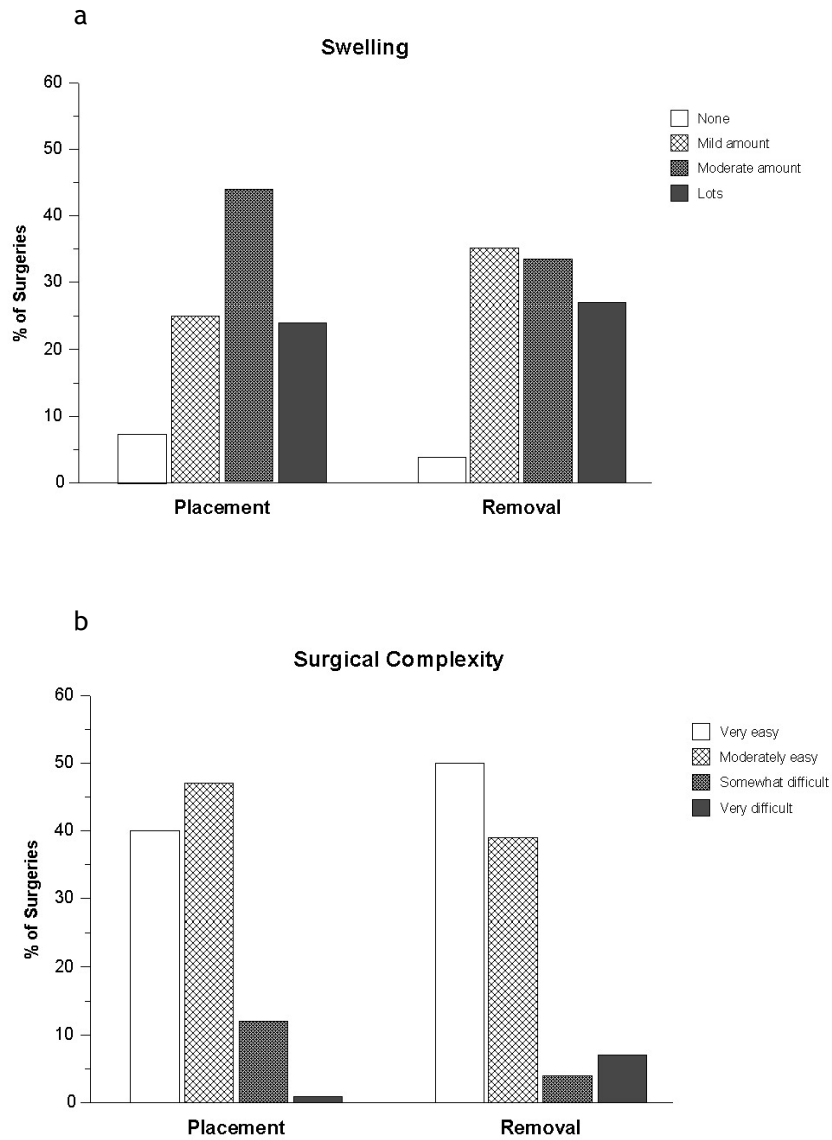


Figure 5.- Swelling reported by patients (a) and surgeon's perceptions of surgical complexity (b). Frequencies for both placement and removal surgeries.

More than 80 % of the placement surgeries were considered by the surgeons to be very to moderately easy. This percentage was higher for removal. Problems were reported in less than one in five of the placement surgeries (2 Bollards fractured during placement manipulation, 4 mandibular Bollards were reported to be too long for the patient's anatomy, and patient compliance was a problem twice when the TSADs were being placed under local anesthesia). Encounters with unexpectedly thin bone at the zygomatic buttress and failure to exit the bone anchor attachment arm at the mucogingival junction did occur, which all required relocation of the miniplate and hence extended surgical time. Problems were reported in 6 out of 45 removal surgeries; in 3 patients, bone overgrowth over the miniplate was reported to be a problem when removing the screws. In one of those patients, the screws were partially left inside the bone. One plate fractured during removal. The surgical time, recorded in 10 or 15 minute increments, is given in Table II.

At removal, miniplate mobility, overlying bone, inflammation, and screw resistance were evaluated, and this was scored on a 4 point scale (Fig. 6). The majority of plates were stable with very little or no bone overlying the plates and no inflammation. However, more than half of the screws exhibited at least mild to moderate resistance to removal.

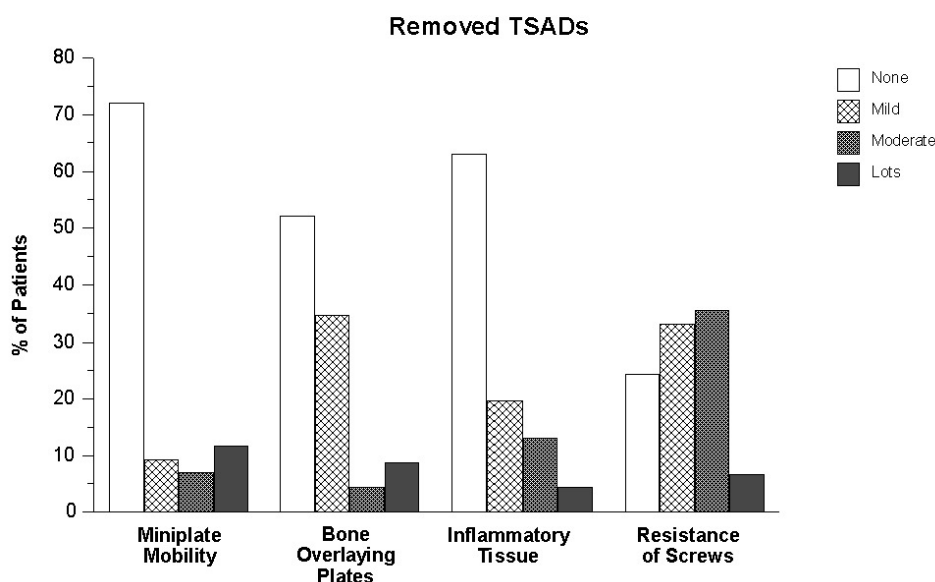


Figure 6.- Evaluation of TSADs at removal surgery. Frequencies for mobility of miniplate, bone overlaying plates, inflammatory tissue and resistance of screws.

DISCUSSION

The role of a temporary skeletal anchorage device is to provide reliable stability when loaded with orthodontic forces, without damage to the adjacent structures, and allow easy connection to orthodontic appliances with minimal discomfort to patients. From this investigation, it would seem that miniplates do respect the peri-implant structures and roots while providing an orthodontic attachment unit close to the dental arch. The soft tissue irritation generated by the anchorage devices was usually very mild¹², with the location of connecting bar emerging at the muco-gingival junction or within the attached gingiva being a key factor for good soft tissue management¹⁴. Both plate systems used in this study allowed easy connection to orthodontic appliances unlike some indirect anchorage

systems (e.g. soldered TPA with palatal implants), and could easily be adapted for a large range of orthodontic applications and varied during treatment. The Bollard, which is designed to accept auxiliary wires, may perhaps provide greater flexibility in the point and direction of orthodontic force application than the C-tube (Fig. 7), but is a little more bulky. Regarding patient discomfort, although miniplate placement does require a mucoperiosteal flap, the surgery appears to be associated with minimal peri-operative pain and inconvenience¹², but post-operative swelling was a problem that was frequently encountered.



Figure 7.- Bollard's attachment unit with slots for insertion of wires, allowing in the present case the displacement of the point of application of the force to the distal.

Most of the placement surgeries can be performed under local anesthesia, with occasional use of IV sedation in combination with local anesthesia to aid in comfort for both adults and young children. However, it was apparent that general sedation was preferred in very young children for

whom 4 miniplates must be placed for orthopedic tractions. Removal surgeries can routinely be performed under local anesthesia alone.

The present paper aims at describing the surgical technique and includes a summary of several important surgical parameters necessary for miniplate success. Locating the horizontal component of the incision at the muco-gingival junction, or 1 mm within the attached gingiva appears to be important (Fig. 3). If the connecting bar emerges through the unattached mucosa, it may predispose the site to inflammation and subsequent failure¹⁴. However, to avoid interference with the orthodontic appliance, this incision should not be too close to the teeth. This is particularly so if tooth intrusion is intended. Good adaptation of the connecting bar to the bone at the exit point into the oral cavity is highly recommended (Fig. 4). This prevents dehiscence exposing the connecting bar which can lead to peri-implant inflammation. In the posterior maxilla, centering the miniplate on the zygomatic buttress ensures the best stability¹⁰. The Bollard's attachment unit allows the orthodontist to vary the point of force application by means of the auxiliary wire configuration (Fig. 7). Varying the plate's position on the buttress is not recommended.

To reduce cheek irritation, the attachment units of the Bollards should always be bent parallel to the dental arch. In the anterior mandible, attachment units facing posteriorly generated less cheek irritation than those facing anteriorly, probably because of reduced protrusion in the region of the orbicularis oris musculature.

The question as to whether self-drilling or self-tapping screws should be used cannot be answered by this study since most of the miniplates' screws were inserted after drilling. However, recently, animal data has shown that drill-free screw insertion procedures have better success rates than drilling procedures¹⁶. For this reason, a drill-free technique should be evaluated in the future. In this sample, combining miniplate placement with extractions in the same area was avoided to reduce the risks of

infection at the TSAD's site. This seems prudent since the inflammation around the extraction socket may interfere with bone and soft tissue healing. Finally, in agreement with several authors¹⁷, excellent oral hygiene is mandatory for success. Recently, crevices around titanium orthodontic plates have been shown to be supportive of anaerobic growth of bacteria, likely stimulating peri-implant inflammation and possibly implant loosening¹⁸.

From this survey, although antibiotic coverage appeared to be the preferred protocol after placement surgery, patient compliance was inconsistent. The high success rate even without antibiotics suggests antibiotic prophylaxis might not be so important. Clinical trials should be conducted to confirm this hypothesis. Concentration on surgical asepsis would probably further reduce the risk of introducing inflammatory pathogens at the surgical site. One quarter of the patients did not take any postoperative anti-inflammatories and/or painkillers, even when prescribed. While this may suggest that pain was not intense, swelling was a rather consistent problem, reported by the majority of the patients as mild or moderate after placement, and only slightly less of a problem after removal. Swelling is likely a side effect of the surgical flap and tissue retraction. Anti-inflammatories were given before surgery to some patients to reduce edema, but whether or not this goal was obtained cannot be deduced from this study. It can be hypothesized that a more systematic use of peroperative anti-inflammatories and aids such as ice packs could reduce edema. If so, this would reduce the negative sequelae patients report.

The surgical placement was considered very to moderately easy by the surgeons, even recognizing that for one third of the surgeries, this was the one of the first ten TSAD placements for that surgeon. As with all surgical techniques, there seemed to be a learning curve. The removal surgery appeared both easier and less time-consuming, the main difficulty

encountered being bone overgrowth over the plates. Bone covering 25 % or more of the plate was reported for more than 1 in 10 of the patients, but did not seem to be correlated with the location of the plate (maxilla or mandible, anterior or posterior) or with the age of the patient. As long as titanium is used, even uncoated, some degree of bone-screw contact does occur⁴, and might even extend to the plate. In the present study, the degree of bone overgrowth varied considerably from one patient to another. The reason why this phenomenon happens unequally in patients is unexplained. It is known from the experimental literature that osseointegration increases with time¹⁵. It is thus recommended that these plates be removed as soon as they are no longer needed. Although bone overgrowth complicated the access to the screws, the resistance of the screws themselves was not reported to be a problem (resistance was only mild to moderate). Whether or not this would be so if the devices were left in place for a long time, as might occur with young children having orthopedic corrections, is not yet known.

CONCLUSION

The aim of this study was to describe the surgical placement and removal of orthodontic miniplates. Most of the surgeries were simple and performed under local anesthesia. At removal, there was no or only a mild inflammatory response. The screws did not show a high resistance during removal, but almost half of the plates were partially covered by bone overgrowth, and this was reported to be a problem during removal for 3 of 45 patients. Additional efforts to control post-operative swelling are advisable as this was the most frequent complication reported.

ACKNOWLEDGEMENTS

We acknowledge Dr. Calix De Clercq (St-Jan's hospital, Bruges, Belgium) and Dr. Ramon Ruiz (University of North Carolina, Chapel Hill, USA), who contributed to the development of the surgical technique. Thanks to Debbie Price for data management of both sites. This study was supported in part by a grant from the SAO, the Dental Foundation of the University of North Carolina and the *Fonds Spéciaux de Recherche 2004* from the Université catholique de Louvain.

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Chapter 9

General discussion

General discussion

In the **experimental study** of the present thesis, miniplates were placed in dogs' maxillas and mandibles, left to heal for 2 weeks, and then orthodontically loaded with 125 g. According to the relative remodelling cycles in dogs and in humans, this healing period corresponds to the 3 weeks of healing respected in most clinical studies.

The proportion of stable, successful miniplates was 53 %, which is low compared to the 92 % success rate obtained in the clinical part. However, a recent experiment with miniscrews in dogs reported similar success rates, most likely related to the difficult conditions of hygiene in animals (Vande Vannet et al. 2007). The success rate was significantly higher in the maxilla than in the mandible. This is consistent with the results obtained in the clinical part, and in previous experimental (Owens et al. 2007) and clinical (Chen et al. 2006, Chen et al. 2007, Cheng et al. 2004) publications. The success rate was not affected by the application of orthodontic load.

Ninety out of the 160 screws supporting miniplates showed partial osseointegration, consisting mainly in limited repair and non-inflammatory remodelling of lamellar bone. The remaining screws were fibro-integrated and clinically associated with lack of stability.

Bone implant contact and bone density varied among the sample, but without any significant difference, neither between the loaded and the nonloaded screws, nor according to the direction of load. Recent experimental studies showed no influence of loading on the bone implant interface around miniscrews (Freire et al. 2007, Vande Vannet et al. 2007, Wu et al. 2007), but no comparative data are available for miniplates.

Bone density and bone implant contact increased with time, as a result of bone remodelling.

These parameters were higher in the mandible than in the maxilla, consistently with the available literature (Park et al. 2008), although the number of failures was higher in the mandible than in the maxilla, as mentioned before. The higher failure rate in the mandible could be correlated to the smaller amount of attached gingiva, since placement in nonkeratinized mucosa has been pointed out as a risk factor (Cheng et al. 2004, Freire et al. 2007, Turley et al. 1988). It might also be that the maxillary trabecular bone responds better to skeletal miniplates placement than the mandibular cortical bone, by privileging the contact osteogenesis process. The different results in the maxilla and mandible might finally be attributed to different locations of the miniplates within the jaw : the chewing pattern of the dog could have better impact on miniplates placed in the upper jaw as compared to those placed in a more posterior area in the lower jaw.

The experimental data of this thesis established that success of orthodontic miniplates depends on the anatomy of the implantation site, but not on loading within the range of orthodontic forces. The first weeks of loading, probably corresponding to the transition from primary to secondary stability, seem to constitute the most decisive ones for success. Osseointegration appeared optimal when the surgical trauma was reduced, underlining the crucial role of non-invasive surgery and good primary stability. Improper implant site preparation associated to an increased amount of necrotic bone in the implant periphery has been described, which may lead to the loss of the implant (Tehemar 1999).

Finally, these animal experiments pointed out that the miniplates should be removed as soon as they are no longer necessary, since osseointegration of the screws increased with time.

The **clinical study** was designed to analyze the success rate of orthodontic miniplates, as well as patient's, orthodontist's and surgeon's perceptions of their use. The questionnaires used in this clinical prospective series of 97 patients are appended in appendices 2 and 3. The success rate was 92.5 % : 15 out of 200 miniplates were removed before orthodontic goals were achieved.

The devices were well tolerated by the patients : 72 % of the patients reported they did not mind having the implant. The surgical experience of 82 % of the patients was better than expected, with little or no pain. Similarly, pain related to placement of miniscrews was shown to be often overestimated (Lee et al. 2008). Patients appeared to regard their placement as a relatively simple dental procedure : for example, more than half of the patients reported that miniplates placement was better than extractions. By comparison with extractions, pain during placement of an Onplant was rated similar, placement of a palatal implant generated significantly less pain (Feldmann et al. 2007), while pain after insertion of miniscrews was very mild (Gelgor et al. 2004). Seventy-eight percent of the patients treated with miniscrews (Lee et al. 2008) and 86 % of the patients treated with palatal implants (Gunduz et al. 2004) would recommend the treatment to other patients.

Patients experienced few side effects. The most frequent problem was post-surgical swelling, lasting on average 5 days after placement and 4 days after removal : efforts to control post-operative swelling might be recommended. Cheek irritation was experienced initially by more than 1/3 of patients, but reduced over time.

Orthodontists, even inexperienced with the use of miniplates, scored these devices as easy to use, reducing orthodontic treatment complexity, and widening the possibility of feasible treatments. Providers' opinions were not reported previously in the literature.

Antibiotics and anti-inflammatories were generally prescribed after placement, but not after removal surgery. Placement and removal surgeries, mostly performed under local anesthesia, were short and considered easy by the surgeons. Miniscrews and miniplates placed with a flap were reported to be associated with more pain than the ones placed without, suggesting the role played by flap elevation in perceived pain (Kuroda et al. 2007a).

The screws themselves were not difficult to unscrew, but almost half of the plates were partially covered by bone overgrowth, which sometimes complicated removal.

From these experimental and clinical approaches, **clinical take-home messages** can be summarized as follows.

- Before surgery, patients should be informed about post-operative swelling. They might be reassured about pain, which is usually milder than expected.
- Surgery should respect strict guidelines and avoid excessive trauma. Re-drilling in particular, associated with bone remodelling healing reactions, has to be avoided in order to optimize primary stability.
- When possible, the maxilla should be preferred to the mandible as receptor site, since the number of failures was higher in the mandible than in the maxilla in both experimental and clinical studies.
- Placement in children is more subject to failures than in adults, as revealed by the clinical studies. If 4 miniplates have to be placed for maxillary protraction in children, sedation or general anesthesia might be recommended to avoid compliance problems.

- In the maxilla, 3-holes miniplates should be selected instead of 2-holes miniplates when possible, as the experimental study showed that failure of one screw in a 2-holes miniplate is generally associated with anchor mobility. In the mandible, use of 3-holes miniplates is usually not possible due to the limited height of available alveolar bone.
- Oral hygiene is of major importance to avoid inflammation of the soft tissues. If patient's compliance is reduced compared to alternative anchorage devices, it remains essential in terms of plaque control.
- After a 3 weeks healing period, loading within the range of orthodontic forces should not be delayed since it does not affect osseointegration of the screws and subsequently miniplate stability.
- By contrast, it is recommended to remove the miniplates as soon as they are no longer necessary, since the experimental studies showed that osseointegration of the screws increased with time, and since bone overgrowth impeded miniplate removal in some cases of the clinical series.

Several questions remain unanswered and open **perspectives** for new research areas.

Regarding to the surgical protocol, the superiority of a drilling or a non-drilling procedure to achieve primary stability could not be established from the present work since the screws were placed after drilling in both experimental and clinical studies. Insertion of a screw without drilling might lead to increased risk of screw fracture (Chen et al. 2008), whereas drilling of a pilot hole could be responsible for over-heating if not associated with adequate cooling. It is known that bone implant contact

around orthodontic miniscrews (Chen et al. 2008, Kim et al. 2005) is higher in absence of pre-drilling, arguing in favour of non-drilling protocols. However, this has not been established for orthodontic miniplates and might represent an area for future research.

The use of a bur for drilling increases the risk of root damage compared to the insertion of a self-drilling screw without pre-drilling. Repair after moderate or severe damage of the root or periodontal ligament has been poorly documented (Asscherickx et al. 2005) and needs further investigations. Moreover, root contact has been pointed out a factor for miniscrew failure, either because less bone is surrounding the screw, or because of transmission of occlusal forces to the screws (Kuroda et al. 2007b). This might be studied for miniplates as well.

Other complications like local bone or soft tissue infections and maxillary sinus perforation are of high interest.

With respect to the loading protocol, several questions are still to be answered in terms of healing time before loading and magnitude of load. Palatal implant stability under orthodontic load was recently shown to initially decrease, and then gradually increase after 6 weeks, the second and third weeks being the worse, arguing in favour of immediate loading protocols (Crismani et al. 2006). For miniscrews, immediate loading was as successful as loading after few weeks of healing (Freire et al. 2007, Owens et al. 2007, Vande Vannet et al. 2007, Wu et al. 2006, Wu et al. 2007). However, various healing times after miniplates placement were not compared in the experimental literature.

Magnitude of force, initially in the range of orthodontic forces, is now pushed to the level of orthopedic forces, e.g. for maxillary protraction. An ongoing clinical prospective study is meant to investigate the result of such tractions. The bone reaction underlying orthopedic forces, as well as the threshold of force associated with failure, should be investigated parallel to this clinical approach.

Miniplate material properties might be investigated in more detail. In the studies reported in the present thesis, miniplates made of titanium grade 2 (Astm F-65, ISO 5832-2) were fixed with titanium grade 5 screws (TiAl6V4, Astm F-136, ISO 5832-3). TiAl6V4 alloy was used instead of commercially pure titanium due to its superior strength. Both experimental and clinical studies showed bone overgrowth over the plates, possibly impeding miniplate removal. Other biomaterials could be tested in the future. Beside this, in order to better understand the mechanisms of bone apposition on orthodontic miniplates, analysis of bone deposited on miniplates removed from patients is currently ongoing.

Finally, preliminary data demonstrated that finite element modelling of miniplates would be of high interest to better understand the distributions of stress and strain within the screws, plates and their supporting bone.

To conclude, the clinical investigations of the present thesis showed that miniplates favourably answer patients and practitioners expectations. Their success rate is high, and few side effects occur during treatment. Their use seems to enlarge the envelope of discrepancy for classical orthodontic treatment (Proffit & Sarver 2007).

From the experimental studies, it can be concluded that loading does not affect bone density and bone implant contact around the miniplates' screws. The higher success rate in the maxilla than in the mandible, revealed by both clinical and experimental studies, whereas bone density and bone implant contact are higher in the mandible compared to the maxilla, suggest that the success of the system relies more on local characteristics of the recipients site, than on bone density or miniplate loading.

Confrontation of both clinical and animal studies contributed to an evidence-based validation of the use of miniplates for orthodontic anchorage.

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Summary

Summary - Résumé

Summary

Since the introduction of temporary skeletal anchorage in orthodontics during the eighties, osteosynthesis miniplates, modified with orthodontic attachments, have been increasingly used. However, no quantitative data about bone reactions around loaded miniplates, and only few prospective clinical studies with small numbers of patients, were found in the literature. Therefore, this project was set up to scientifically emphasize the use of miniplates for orthodontic anchorage with combined experimental and clinical approaches.

The specific objectives of the experimental chapters of this thesis were to evaluate if orthodontic loading has an impact on bone reactions around screws supporting miniplates, and to describe the histological components of the bone-screw interface. The clinical chapters aimed to determine patients', orthodontists' and surgeons' perceptions about miniplates, to assess their success rate and to describe the surgical techniques of placement and removal.

The experimental study involved eighty miniplates, placed in the jaws of 10 dogs : 2 miniplates per jaw quadrant. After 2 weeks, coil springs applying a 125 g force were placed between the miniplates of an upper quadrant and the contralateral lower quadrant of each dog. The other miniplates were not loaded and were considered controls. Five dogs were sacrificed 7 weeks after implantation and 5 dogs after 29 weeks. Fluorochromes were injected at implantation and at sacrifice. Jaw quadrants were scanned with peripheral Quantitative Computed Tomography. Undecalcified sections were carried out and submitted to microradiographic analysis to assess bone-implant contact and bone volume/total volume. The sections were finally observed under UV light, stained and examined under ordinary light.

The success rate in this animal study was 53 % and the proportion of stable miniplates was significantly higher in the maxilla than in the mandible. No

significant difference in success rate was found between loaded and nonloaded miniplates. Mobility occurred on average 5 weeks after placement. Bone mineral density was higher around mandibular than around maxillary miniplates, but was not significantly different around loaded and nonloaded miniplates. Bone implant contact and bone volume/total volume did not differ significantly neither between the loaded and the nonloaded screws, nor according to the direction of load, whereas they increased with time. Fifty-six percent of the screws were osseointegrated. Healing reactions showed mainly limited remodelling of lamellar bone. The remaining screws were fibro-integrated. Stability and osseointegration of titanium orthodontic miniplates were thus influenced by the recipient site anatomy, but not by loading.

The clinical study focused on ninety-seven consecutive patients treated with miniplates, who completed questionnaires. A total of 200 miniplates were placed by nine oral surgeons, who filled out questionnaires after placement and removal surgeries. The 30 orthodontists treating these patients also completed questionnaires concerning miniplate success, handling complexity, and effectiveness.

The success rate obtained in this clinical survey was 92.5 %. Placement surgery, generally performed under local anesthesia, lasted on average 15-30 minutes per plate, and was considered by the surgeons to be very to moderately easy. Patients tolerated the miniplates well : 72 % of patients said they did not mind having the implant and 82 % reported that the surgical experience was better than expected, with little or no pain. The chief complaints were post-surgical swelling, lasting 5 days on average, and cheek irritation. The orthodontists rated these devices as easy to use and simplifying treatment. The removal surgery was shorter and considered easier than the placement surgery. Miniplates were thus well accepted by patients and providers, and were considered a useful tool especially for difficult treatments.

Résumé

La notion d'ancrage squelettique temporaire, introduite en orthodontie dans les années 80, a abouti à l'utilisation de plus en plus courante de plaques d'ostéosynthèse modifiées par adjonction d'un attachement orthodontique. Cependant, la littérature ne fait état d'aucune évaluation quantitative des réactions osseuses autour de miniplaques mises en charge et ne compte que quelques études cliniques prospectives avec un nombre de patients restreint. Face à cette lacune, le présent projet fut développé pour améliorer le cadre scientifique de l'usage de miniplaques comme ancrage squelettique, par une approche combinée expérimentale et clinique.

La partie expérimentale de cette thèse a eu pour objectifs d'évaluer si la mise en charge orthodontique a un impact sur les réactions osseuses autour des vis maintenant les miniplaques, et de décrire les composants histologiques de l'interface os-vis. Le volet clinique a cherché à déterminer les perceptions des patients, des orthodontistes et des chirurgiens concernant les miniplaques, à en chiffrer le taux de succès et à décrire les techniques chirurgicales de placement et de dépose.

Dans l'étude expérimentale, 80 miniplaques ont été placées dans les mâchoires de 10 chiens à raison de 2 miniplaques par quadrant. Après 2 semaines, des ressorts appliquant une force de 125 g ont été placés entre les miniplaques d'un quadrant supérieur et du quadrant contro-latéral inférieur de chaque chien. Les autres miniplaques, non mises en charge, furent considérées comme contrôle. Cinq chiens ont été sacrifiés 7 semaines après implantation et 5 chiens après 29 semaines. Des marqueurs fluorescents ont été injectés lors de l'implantation et lors du sacrifice. Les quadrants de mâchoires ont été scannés par *peripheral Quantitative Computed Tomography*. Des coupes non-décalcifiées furent réalisées et microradiographiées afin de quantifier le contact os-implant et le volume osseux/volume total. Les coupes ont ensuite été observées en lumière

ultra-violette, colorées et enfin examinées en lumière ordinaire. Le taux de succès de cette étude animale a été de 53 %, avec un pourcentage d'implants stables significativement plus élevé dans le maxillaire que dans la mandibule. Aucune différence significative n'a été observée entre le taux de succès des miniplaques mises en charge et celui des miniplaques non mises en charge. La mobilité est apparue en moyenne 5 semaines après placement. La densité minérale osseuse était plus élevée autour des miniplaques mandibulaires que maxillaires, mais n'était pas significativement différente autour des miniplaques mises en charge et non mises en charge. Le contact os-implant et le volume osseux/volume total ne différaient pas significativement ni entre les vis mises en charge et non mises en charge, ni en fonction de la direction de la traction, mais ces deux paramètres augmentaient avec le temps. Cinquante-six pour cent des vis étaient ostéointégrées. Les réactions de cicatrisation ont consisté principalement en un remaniement limité de l'os lamellaire. Les vis restantes étaient fibro-intégrées. La stabilité et l'ostéointégration de miniplaques orthodontiques en titane étaient donc influencées par l'anatomie du site récepteur, mais pas par la mise en charge.

L'étude clinique a porté sur 97 patients consécutifs traités par miniplaques, qui ont complété des questionnaires. Deux cents plaques au total ont été placées par 9 chirurgiens, qui ont rempli des questionnaires après les interventions de placement et de dépose. Les 30 orthodontistes traitant ces patients ont, eux aussi, répondu à des questionnaires concernant le succès, la complexité de manipulation et l'efficacité des miniplaques. Le taux de succès de cette étude clinique a été de 92.5 %. La chirurgie de placement, généralement réalisée sous anesthésie locale, a duré en moyenne 15-30 minutes par plaque, et était considérée par les chirurgiens comme étant très facile à modérément facile. Les miniplaques ont été bien tolérées par les patients : 72 % des patients ont dit ne pas être dérangés par la présence de l'implant, et 82 % ont rapporté que l'expérience chirurgicale était plus positive qu'attendue, générant peu ou

pas de douleur. Les plaintes principales étaient le gonflement post-chirurgical, durant en moyenne 5 jours, et l'irritation jugale. Les orthodontistes ont considéré ces dispositifs comme étant faciles à utiliser et simplifiant le traitement. L'intervention de dépose était plus courte et plus aisée que celle de placement. Les miniplaques ont donc été bien acceptées tant par les patients que par les praticiens, et considérées comme un outil utile, particulièrement pour les traitements complexes.

Appendices

Appendix 1

Systematic review of the experimental use of temporary skeletal anchorage devices in orthodontics

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Introduction: Our aim was to review the experimental literature to determine what is known about functional and morphological tissue reactions around orthodontically loaded temporary skeletal anchorage devices. **Methods:** The PubMed electronic database and the reference citations in published articles were searched to the end of April 2006. The inclusion criteria were animal studies about orthodontically loaded skeletal anchorage consisting of metallic bone plates or screw implants of 2.2 mm diameter or less. Data on healing time, force application, stability, side effects, and osseointegration were collected by 2 independent readers. **Results:** Eight articles met the selection criteria. The healing times ranged from 0 to 12 weeks, and the amount of force varied from 25 to 500 g. Implant stability was generally achieved without severe side effects. Direct bone-screw contact was reported to be 10% to 58%, and osseointegration increased with loading time. Nevertheless, no significant difference in bone-screw contact was found between loaded and unloaded screw implants, or between tension and pressure sides of loaded implants. **Conclusions:** This review highlights some positive experimental findings that apply in clinical practice. However, questions concerning optimal force systems, surgical techniques and placement, and healing times remain. Future research should be well controlled and based on standardized protocols to test specific hypotheses. (Am J Orthod Dentofacial Orthop 2007;131:00)

The need for orthodontic treatment requiring minimal patient compliance has encouraged research into the use of implants as tools to reinforce anchorage. Dental implants, which have been well described in the prosthodontic literature, are also used in orthodontic practice. More recently, smaller implants were introduced as temporary skeletal anchorage devices (TSADs). There are substantial differences between conventional implants and TSADs: conventional prosthodontic implants, generally loaded after osseointegration, are intended to be permanent, whereas implants for orthodontic anchorage are usu-

ally loaded long before osseointegration is achieved and are intended to be removed relatively soon. Conventional implants are subject to high intermittent forces of mastication, but forces acting on orthodontic anchors are light and continuous. The direction of loading and the size of the implants also vary between the 2 systems. These fundamental differences highlight several questions about the use of implants for orthodontic anchorage that cannot be answered in the prosthodontic literature alone.

Initially, endosseous implants located in edentulous,¹ palatal,² or retromolar regions³ were introduced in orthodontics to enhance anchorage. Because of their relatively large size, those implants require sufficient bone. To widen clinical applications in orthodontics and decrease surgical trauma, smaller devices that can be placed at various locations near the dental arch have been developed. Moreover, some studies suggest that the healing periods of these smaller implants can be shortened or even avoided, compared with dental, palatal, or retromolar implants.⁴⁻⁶

Currently, 2 types of TSADs are used in orthodontics: screw implants^{7,8} and bone plates.^{9,10} Although the clinical literature has been systematically reviewed,¹¹ no review has yet summarized experimental animal studies describing the tissue reactions around orthodontically loaded temporary skeletal anchors. There are

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Submitted, December 2005; revised and accepted, May 2006.

0889-5406/\$32.00

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doi:10.1016/j.ajodo.2006.05.033

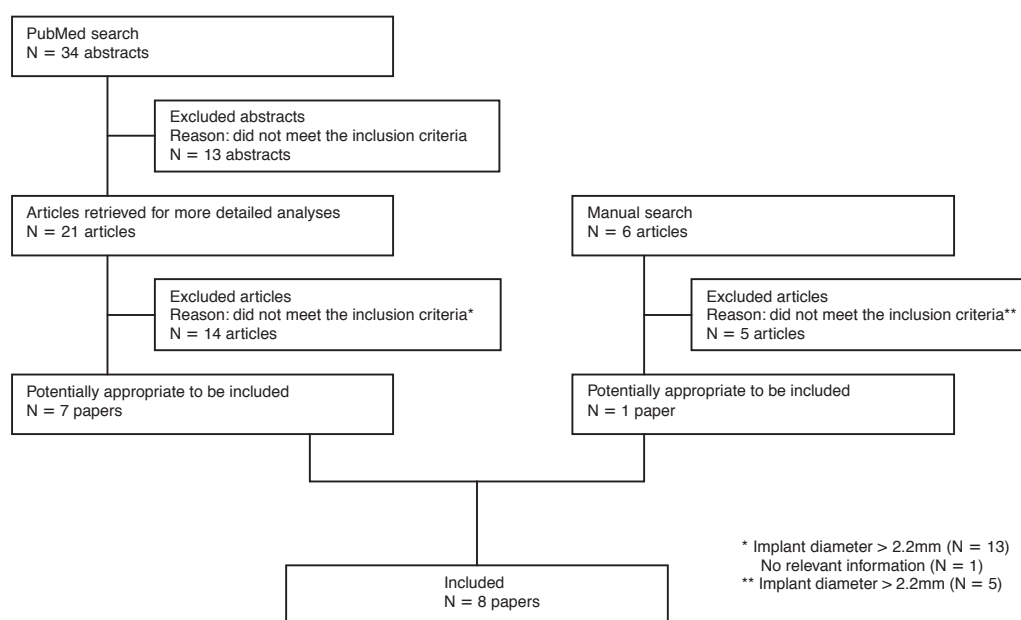


Fig. QUOROM flow diagram.

important differences between humans and animals that should be considered when translating experimental facts to clinical use—eg, the animal's size and the rate of bone turnover. Experimental animal studies are important, however, because they are generally controlled and frequently allow histologic evaluation of the bone implant interface under carefully controlled conditions.

The purpose of this systematic review of the experimental literature was to examine the available evidence to characterize functional and morphological tissue reactions around TSADS to determine guidelines that might be useful to clinicians.

MATERIAL AND METHODS

The PubMed electronic database was searched for original articles to the end of April 2006. For inclusion in this review, articles had to meet the following criteria: animal studies on orthodontically loaded skeletal anchorage, consisting of metallic bone plates or screw implants of 2.2 mm diameter or less. This maximum diameter was established to focus on small devices designed for orthodontics and to exclude all types of palatal, retromolar, or prosthetic implants. Foreign language articles were excluded. MeSH terms “Dental implants,” “Bone screws,” and “Bone plates” were chosen to cover the terms “mini-implant,” “micro-implant,” “screw,” “screw-implant,” and “miniplate,” because there is no agreement yet on the nomenclature. The headings sequence “Dental implants” [MeSH] OR

“Bone screws” [MeSH] OR “Bone Plates” [MeSH] AND “Orthodontics” [MeSH] AND “animal study” was selected.

The titles and abstracts of all potentially relevant articles were reviewed. The full text of all relevant articles and articles with ambiguous titles and abstracts were collected and reviewed. The search was augmented by screening the reference citations of each identified article for additional articles that might have been missed by the electronic search. Each article was reviewed independently by 2 readers, and the information was compared. Any difference between readers was resolved by rereading and discussion.

RESULTS

The search results are shown in the flow diagram (Fig). A total of 34 abstracts were identified through PubMed with the selected terms. Thirteen of these were excluded because they did not meet the inclusion criteria. The complete articles of the 21 remaining studies were read. Fourteen of these also did not meet the inclusion criteria (implant diameter exceeding the 2.2-mm limit or lack of information¹²). Screening the citations of the remaining 7 articles identified an additional 6 potentially relevant articles¹³⁻¹⁸ of which only 1 actually fit the implant diameter inclusion criteria,¹⁵ for a total of 8 articles for review: 6 on orthodontic screw implants (devices described as “screw,” “mini-implant,” and “screw-implant”)^{15,19-23} and 2 on miniplates.^{24,25} A summary of the sample and TSADs' characteristics is shown in Table I.

Table I. Sample and TSAD characteristics

<i>Authors and year published</i>	<i>Animal model</i>	<i>Number of animals</i>	<i>Number of loaded TSADs</i>	<i>Number of unloaded TSADs</i>	<i>TSAD type</i>	<i>Manufacturer</i>	<i>Implant material</i>	<i>Length × diameter (mm)</i>
Büchter et al, ¹⁹ 2005	Minipig	8	160	32	Screw implants	Absoanchor, Dentos, Taegu, Korea; Dual-Top, Jeil, Seoul, Korea	Titanium	10 × 1.1/1.6
Daimaruya et al, ²⁴ 2001	Dog	6	6	6	Miniplates and bone screws	Sankin, Tokyo, Japan; Leibinger, Freiburg, Germany	Titanium	5/7 × 2 (3/plate)
Daimaruya et al, ²⁵ 2003	Dog	6	6	6	Miniplates and bone screws	Sankin, Tokyo, Japan; Leibinger, Freiburg, Germany	Titanium	5/7 × 2 (3/plate)
Deguchi et al, ²⁰ 2003	Dog	8	48	48	Screw implants	Stryker Leibinger, Kal-amazoo, Mich	Titanium	5 × 1
Kim et al, ²¹ 2005	Dog	2	32	0	Screw implants	Osas, Epoch Medical, Seoul, Korea	Titanium	N/A × 1.6
Melsen and Costa, ¹⁵ 2000	Monkey	4	16	0	Screw implants	Aarhus screw, Medident, Hellerup, Denmark	Titanium-vanadium	8 × 2.2
Melsen and Lang, ²² 2001	Monkey	6	10	2	Screw implants	Straumann, Waldenburg, Switzerland	Titanium, TPS surface	6 × 2.2
Ohmae et al, ²³ 2001	Dog	3	12	24	Screw implants	Sankin, Tokyo, Japan	Titanium	4 × 1

Table II. Loading protocols and outcomes of loaded TSADs

<i>Authors and year published</i>	<i>Time before loading (wk)</i>	<i>Amount of force (g)</i>	<i>Length of loading (wk)</i>	<i>Failures in primary stability</i>	<i>Failures after loading</i>	<i>Osseointegration index of stable implants (%)</i>
Büchter et al, ¹⁹ 2005	0	100, 300, 500	3–10	N/A*	5/160	N/A
Daimaruya et al, ²⁴ 2001	12	100–150	16–28	0	0	N/A
Daimaruya et al, ²⁵ 2003	12	80–100	16–28	0	0	N/A
Deguchi et al, ²⁰ 2003	3, 6, 12	200–300	12	3/96	0	30.7–40.2
Kim et al, ²¹ 2005	1	200–300	11	N/A	3/32	23.4–43.7
Melsen and Costa, ¹⁵ 2000	0	25–50	4, 8, 16, 24	N/A*	2/16	10–58
Melsen and Lang, ²² 2001	12	100, 200, 300	11	0	0	40–45
Ohmae et al, ²³ 2001	6	150	12–18	0	0	25

*Immediate loading.

Three animal models were used (dogs,^{20,21,23–25} minipigs,¹⁹ and monkeys^{15,22}); the numbers of animals per sample ranged from 2²¹ to 8.^{19,20} The number of loaded screw implants per study ranged from 10²² to 160,¹⁹ with the number of unloaded implants used as controls varying from 0 in 2 studies^{15,21} to 48.²⁰ Six loaded plates and 6 controls were used in both miniplate studies.^{24,25} All but 2 studies used TSADs made of uncoated titanium. Two studies tested either titanium-vanadium screws¹⁵ or titanium implants with titanium plasma-sprayed (TPS) surface.²² The diameters of the screw implants ranged from 1^{20,23} to 2.2 mm,^{15,22} and their lengths varied from 4²³ to 10 mm.¹⁹

The miniplates were all fixed with 3 screws (5 or 7 mm length, 2 mm diameter).^{24,25}

Critical issues for clinicians are healing time, amount of force, stability, side effects associated with the TSADs, and degree of osseointegration.

The included studies allowed between 0^{15,19} and 12^{20,22,24,25} weeks of healing before loading (Table II). The studies involving immediate loading^{15,19} and a 1-week healing period²¹ had some failures (Table II), whereas 100% stability after loading was reported in the remaining 5 studies with healing times from 3 to 12 weeks.^{20,22–25} One study that tested 3-, 6-, and 12-week healing periods

showed that a 3-week period before loading was sufficient to resist orthodontic forces in the dog.²⁰

There was great variability (25–500 g) in the amount of force applied to the implants (Table II). In the monkey model, immediate loading with relatively light forces (25–50 g) resulted in loss of 2 of 16 implants, and no osseointegration of 2 other implants.¹⁵ In the minipigs, 5 of 160 immediately loaded miniscrews were lost, but these failures occurred with 300-g loading forces, whereas no failure was reported with a 100-g force.¹⁹ Moreover, the same authors varied not only the force levels but also the screw insertion depths, and observed that failures were correlated with a tipping moment (force x lever arm) of 900 cNmm.

The 2 studies that used immediate loading protocols were excluded from the evaluation of primary stability. All but 1 of the 6 remaining articles addressed this question.²¹ Overall, 4 studies^{22–25} showed good primary stability (Table II), and 1²⁰ reported 3 failures of 96.

Good stability was maintained after loading in 5 of the 8 studies, whereas the 3 studies loading at 0 or 1 week reported failure rates of 3% to 19% after loading (Table II).^{15,19,21}

Some slight inflammation was noted in 6 studies, but no severe inflammatory reactions were reported.^{15,19,22–25} No root resorption was observed. Büchter et al¹⁹ mentioned 8 screw fractures during placement: 6 with 1.1-mm diameter screws and 2 with 1.6-mm diameter screws.

Of the 8 articles included in this systematic review, all but 2 performed histologic analyses of the bone implant interfaces.^{19,25} In these studies, osseointegration of the stable screws was attested by the presence of vital organized bone in close contact to the implants, without interposition of fibrous tissue. The osseointegration index, which measures the percentage of bone-implant contact, evaluated in 5 articles, varied from 10% to 58% (Table II).

Factors proposed as possible influences on osseointegration include time before loading, load applied, type of stress, influence of surgical placement, and location of the TSAD. The impacts of various healing and loading times on osseointegration were discussed in 2 articles.^{15,20} By using the dog as the experimental animal, 1 study reported no difference in osseointegration index with respect to time before loading and concluded that a 3-week healing period was sufficient for orthodontic loading, at least in the dog.²⁰ Another experiment with monkeys and lower forces (25–50 g) reported that the degree of osseointegration increased with the time the implant was loaded.¹⁵

The influence of orthodontic loading itself on osseointegration was addressed in 4 of the 8 articles; 1 re-

ported qualitative results,²⁴ and 3 provided quantitative data.^{20,22,23} In the qualitative report, loading was suggested to increase bone metal contact.²⁴ Although bone-implant contact was shown to be slightly increased in loaded screw implants compared with unloaded ones,²³ none of the 3 quantitative studies found statistically significant differences in the osseointegration index. However, in terms of bone turnover, 2 studies showed significant increases around loaded vs unloaded screw implants.^{22,23} An additional study testing the effect of force magnitude compared forces of 25 and 50 g, without unloaded control implant, and found no difference in bone response.¹⁵ The type of stress, whether pressure or tension, was not associated with significant differences in bone response in the 2 reports addressing that question, although the authors commented that bone-implant contact tended to be higher on the pressure than the tension side.^{15,22}

The effect of various placement sites was addressed by only 1 investigation comparing osseointegration of maxillary and mandibular screw implants.²⁰ The authors concluded that the osseointegration index was significantly higher in the mandible than in the maxilla.

Only 1 article studied osseointegration according to the surgical procedure with or without drilling before placement of a self-drilling screw and found that a higher bone-to-implant ratio correlated to the absence of preliminary drilling.²¹

DISCUSSION

This review of the experimental literature highlights pertinent information concerning screw implants and miniplates for orthodontic anchorage. It focused particularly on the important clinical questions of time to loading, optimal force systems, stability, and side effects. It became apparent that osseointegration and how bone remodeling around implants is affected by orthodontic forces were important issues. The first experimental data on TSADs were published in 2000, and only 8 subsequent studies could be found relating to the use of miniscrews or miniplates for TSAD. This is somewhat surprising considering the recent sharp increase in interest concerning the clinical applications of these devices.

The literature in this review does support that titanium devices offer direct structural and functional anchorage as defined by Branemark.²⁶ The selected articles differed considerably in terms of animal model, type of skeletal anchorage, magnitude of force applied, healing time, and duration of loading. Nevertheless, all results agreed on the clinical stability of the devices under orthodontic loading, with some histologic osseointegration. We can conclude that titanium TSADs do, in general, resist orthodontic displacement forces, maintaining their initial positions without marginal bone loss. This

contradicts the results of Liou et al,²⁷ who stated that screws are clinically stable but not absolutely stationary when loaded.

In general, the results reflect a short follow-up, and the complete bone remodeling cycle generally requires longer observation than is typical in these studies. Because bone remodeling plays a crucial role in long-term implant stability, and as the clinical applications for skeletal anchorage increase, longitudinal histomorphometric studies are needed to distinguish transitory reactions to loading from long-term implant adaptation.

Temporary skeletal anchorage appears to be gaining rapid acceptance in orthodontic practice, but many questions remain unanswered. The literature, when summarized, provides interesting insights into the application of skeletal orthodontic anchorage and its management in clinical practice.

Is there an optimal time that should elapse before loading an implant? In dogs, a 3-week healing period seemed to be sufficient for orthodontic loading, despite an intense healing reaction and the presence of immature woven bone around the implants.²⁰ When transposing this time period to the human bone remodeling cycle, one could infer that a 4- to 5-week healing period is sufficient to sustain the light forces generally used in orthodontic tooth movement. This is considerably shorter than the recommended healing period of 6 weeks in rabbits,¹⁶ equivalent to 12 weeks in dogs, generally recommended for larger conventional implants. With 4-mm diameter implants in the rabbit model, osseointegration is apparently achieved with a high percentage of direct bone-to-implant contacts after only a 2-week healing time and 8 weeks of loading.²⁸ This raises the question as to whether immediate loading could or should be recommended. Melsen and Costa,¹⁵ using a monkey model, demonstrated 12 stable mini-implants of 16 with immediate loading with relatively low forces (25–50 g). Büchter et al¹⁹ did not observe any failure in a minipig model after immediate loading when the tipping moment applied on the screws remained under 900 cNmm. On the other hand, Roberts et al¹⁶ observed spontaneous fractures after immediate loading of implants in rabbit femurs and advised against immediate loading. However, in this experiment, the load (100 g) and the implant diameter (3.2 mm) were quite high with reference to a rabbit's size. Thus, if immediate loading is clinically important, it would seem acceptable, particularly considering the magnitude of the forces required for orthodontic tooth movement.

With regard to forces, the reports with wide variations in magnitude, particularly when considering the sizes of the animals, make interpretation of these findings difficult. Correlations of finite element analysis to

histologic observations suggest that both very low and very high strain values result in a high incidence of resorption and a negative remodeling balance.²² Between these extremes, an increase in strain is followed by an increase in bone remodeling, generating a positive balance. Although forces from 25 to 500 g have been successfully used, it is impossible to determine from the available evidence the lower and upper thresholds that would switch a positive balance to a negative one. This is an important area for future research, because the application of TSADs in orthodontics has already broadened to include single-tooth^{29,30} or whole-arch intrusion,³¹ and orthopedic correction of skeletal problems.³² These applications might call for very different force systems, and determining the threshold for resorption or negative remodeling under each scenario is clearly important.

Another practical consideration for the clinician is whether some critical degree of implant stability is required for functional efficiency. Implant stability depends not only on osseointegration, but also on the mechanical stability achieved at placement. Comparisons of the osseointegration index determined with different morphometric techniques are tenuous at best. Osseous contact with an implant as low as 5% was shown to resist orthodontic loads.²⁰ Ohmae et al²³ reported that an integration index of 25% would provide reliable anchorage. However, they also reported that 6 of their mini-implants were easily removed with a screwdriver; this could certainly not have been possible with extensive osseointegration. Complete osseointegration would clearly be undesirable for a TSAD, and it is apparent that implants can be functional, even with a very low integration index. Osseointegration rates appeared lower around mini-implants, ranging from 10% to 58%, in contrast to the reported osseointegration index of 75.5% around orthodontically loaded palatal implants in humans.³³ For the clinician, a decrease in implant diameter will both increase the number of potential insertion sites and facilitate the surgical removal. However, a too-small diameter also increases the risk of screw fracture. This idea seems supported by the clinical literature³⁴ and confirmed by Büchter et al,¹⁹ who experienced 3 times more fractures during placement of 1.1-mm rather than 1.6-mm-diameter screws. It seems established that the length of the screws does not relate to stability^{4,35} whereas diameter does.⁴

Only 1 experiment studied TPS-surfaced implants and found no difference in stability or osseointegration index.²² However, there is some evidence from studies with larger implants. The highest bond strength and mature bone compactness appear at the interface with hydroxyapatite-coated implants compared with TPS and

uncoated implants.³⁶ Lower bone-implant contact, bone density, and bone heights were observed around machined surface implants compared with TPS implants.³⁷ Porous-surfaced implants showed increased bone contact around coronal subregions³⁸ and decreased mineral apposition rates³⁹ compared with machine-threaded implants. From these studies, we can speculate that uncoated implants might be preferred to prevent excessive osseointegration and complicated later surgical removal.

Beside metallic TSADs included in this review, bioabsorbable polylactic acid screws were shown to adequately withstand orthodontic forces during 6 months in the dog, theoretically avoiding the need for removal surgery.⁴⁰

An effect of load on degree of osseointegration²⁴ was not supported by the quantitative analyses currently available,^{20,22,23} nor were consistent differences between tension and pressure sides observed in bone response around the implants.^{15,22} This tends to confirm the possibility of using TSADs for absolute orthodontic anchorage in various clinical applications.

The question as to which factors determine stability or failure remains largely unanswered. In addition to the healing time and force range, some hypotheses can be advanced from this systematic review. Failure could be correlated with surgical technique, such as drilling or not drilling before screw insertion, as well as the diameter of the drilled hole. Kim et al²¹ compared surgical techniques with and without drilling and found significantly higher bone-implant contacts associated with better stability with self-drilling screws. The diameter of the pilot hole was noted in only 3 of the 8 studies.^{15,20,21} The only 1 reporting a hole diameter equal to the screw experienced some failures in primary stability.²⁰ No failures were reported when the hole was narrower.^{15,21} It might be that hole depth, which determines the tipping moment exerted by the load, is directly related to failure.¹⁹

The placement location might also be critical because the highest rate of mobile screws (4 of 16) was reported in the only study that placed implants in non-keratinized mucosa,¹⁵ and immediate loading of a completely submerged TSAD (screws and coil-springs covered by soft tissues) showed a lower failure rate (5 of 160),¹⁹ suggesting the importance of TSAD location. Turley et al¹⁸ also recommended implant placement in keratinized tissues. Kim et al²¹ reported better screw stability in the mandible than in the maxilla; however, this contradicts the clinical literature.³⁴ Finally, healing time might be a critical parameter: the only studies reporting instability after loading were those with 1-week healing times or less, suggesting that immediate loading is possible but might increase the risk of failure.^{15,19,21}

Side effects were infrequently reported in this literature. Bone microfractures, microcracks, and microcalli were observed around loaded implants in a clinical study.⁴¹ The authors attributed the microcalli to micro-repair after orthodontic loading. No root resorption was mentioned in the selected articles, although Deguchi et al²⁰ suggested that contact of the screws with the roots during placement might be a failure factor. Roberts et al¹⁷ detected root resorption on microradiographic images of a conventional implant placed close to the adjacent periodontal ligament. However, cementum repair and implant osseointegration occurred, despite surgical impingement on the root. Another experiment in dogs, not included in this review because no loading was applied on the orthodontic miniscrews, showed almost complete repair of the periodontal structure within 12 weeks after root damage caused by the screws.⁴²

CONCLUSIONS

1. Titanium TSADs do offer direct structural and functional anchorage according to Branemark's definitions.²⁶
2. Clinical stability sufficient for orthodontic anchorage can be achieved even with levels of osseointegration as low as 5%. Under 25% of osseointegration, screws remain easy to remove.
3. Long-term bone implant adaptation is not yet well categorized.
4. There is little agreement about the optimum loading and the minimum healing period needed for stability. However, immediate loading seems to be acceptable with reduced forces.
5. Implant failure remains largely unexplained and varied from 0% to 19% in the included studies. However, factors such as implant site, surgical technique, healing period, and magnitude of force might influence the success rate.
6. Side effects such as peri-implant inflammation and resorption of adjacent roots are infrequent.
7. Future research should target specific issues by using well-controlled experimental models.

We thank Gavin Heymann for help with reading and data extraction.

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Appendix 2

SCHOOL OF DENTISTRY

PART 2: 6 Months After Implant Placement

CASE CODE #:

--	--	--

TODAY'S DATE:

--	--

/

--	--

/

--	--	--	--

Orthodontist's Name:

[illegible]

1. Have any of the implants prematurely been removed or fallen out?

☐ Yes

☐ No

If yes, why?_____

COMMENTS: (Please include any events / situations you think were significant)

SCHOOL OF DENTISTRY

PART 3: Prior to Implant Removal or 12 Months After Implant Placement

CASE CODE #:			
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TODAY'S DATE: / /

[illegible]

1. Difficulty of treatment using implants for orthodontic anchorage:

☐ Very easy ☐ Moderately easy ☐ Somewhat difficult ☐ Very difficult

☐ Very easy ☐ Moderately easy ☐ Somewhat difficult ☐ Very difficult

3. Were you able to obtain your orthodontic objectives using the implants?

☐ Yes

☐ No

If no, why not? _____

4. Have any of the implants prematurely been removed or fallen out?

☐ Yes

☐ No

If yes, why? _____

5. Have you experienced any problems using the implants?

☐ Yes

☐ No

If yes, what? _____

6. Degree of satisfaction of using implants for orthodontic anchorage:

☐ Very satisfied ☐ Moderately satisfied ☐ Somewhat disappointed ☐ Very disappointed

7. Would you use implants again for orthodontic anchorage?

☐ Yes

☐ No

Why? _____

RECORDS (Progress dates only if applicable)

1. Panoramic X-ray: Date(s) taken: Start: / /

Progress: / /

Progress: / /

2. Lateral Ceph: Date(s) taken: Start: / /

Progress: / /

Progress: / /

3. Pictures: Date(s) taken: Start: / /

Progress: / /

Progress: / /

4. Study models: Date(s) taken: Start: / /

Progress: / /

Progress: / /

COMMENTS: (Please include any events / situations you think were significant)

Université Catholique de Louvain

USAGE D'ANCRAGE ORTHODONTIQUE

PARTIE 1:

Avant Activation de L'Implant

PATIENT

CODE PATIENT#:

DATE D'AUJOURD'HUI:

 / /

Instructions: Veuillez utiliser un bic pour remplir le formulaire. **NOIRCISSEZ COMPLETEMENT** les cercles correspondant à vos réponses. Veuillez inscrire les chiffres exclusivement à l'intérieur des cases prévues à cet effet.

PLACEMENT CHIRURGICAL DE L'/DES IMPLANT(S)

1. Douleur pendant l'intervention: ☐ aucune ☐ peu de douleur ☐ douleur modérée ☐ douleur importante

2. Intervention chirurgicale dans son ensemble:

- ☐ Très désagréable, je n'accepterais plus jamais le placement d'un implant
☐ Désagréable, mais j'accepterais une nouvelle intervention sans me réjouir de celle-ci
☐ Peu désagréable; je supporterais une nouvelle intervention si nécessaire

INCONFORT LA SEMAINE SUIVANT L'INTERVENTION

1. Absence à l'école/ au travail: (nombre de jours)

2. Avez-vous pris des médicaments après le placement du/des implant(s)?

☐ Oui ☐ Non

Si oui, lesquels? ☐ Antidouleurs?

(nombre de jours)

☐ Antibiotiques?

(nombre de jours)

☐ Anti-inflammatoires?

(nombre de jours)

3. Gonflement des lèvres/joues: ☐ aucun gonflement

☐ léger gonflement

☐ gonflement modéré

☐ gonflement important

Si gonflement,

(nombre de jours)

4. Avez-vous eu un quelconque autre problème avec l'/les implant(s)?

☐ Oui ☐ Non

Si oui, lequel? ☐ Inflammation

☐ Sensation de mobilité

☐ Perte de l'implant

☐ Limitation de l'ouverture buccale

☐ Difficulté pour nettoyer le/les implant(s)

☐ Irritation des joues

☐ Autre

5. Touchez-vous fréquemment l'/les implant(s) avec la langue?

☐ Oui ☐ Non

6. L'/les implant(s) sont-ils sensibles à ce jour ?

☐ pas de douleur

☐ douleur légère

☐ douleur modérée

☐ douleur importante

7. L'/les implant(s) vous dérangent-ils plus ou moins que les plaquettes?

☐ Plus ☐ Moins

8. Avez-vous déjà eu des extractions dentaires précédemment?

☐ Oui ☐ Non

Si oui, quel acte vous a le plus gêné?

☐ Les extractions

☐ Le placement du/des implant(s)

INCONFORT LA SEMAINE SUIVANT L'INTERVENTION (suite)

9. Avez-vous déjà porté une force extra-orale?

☐ Oui ☐ Non

Si oui, préférez-vous la force extra-orale ou le/les implant(s)? ☐ Force extra-orale ☐ Implant(s)

Veuillez expliquer: _____

10. Est-ce que vous avez déjà eu des obturations dentaires

☐ Oui ☐ Non

Si oui, quel acte vous a gêné le plus? ☐ Obturations ☐ Placement du/des implants

11. Les implant(s) sont-ils mieux ou moins bien tolérés que ce à quoi vous vous attendiez?

☐ Mieux ☐ Moins bien

Veuillez expliquer pourquoi: _____

12. Cela vous dérange-t-il d'avoir des implants en bouche?

☐ Oui ☐ Non

Si oui, pourquoi ? _____

COMMENTAIRES DES PARENTS POUR LES PATIENTS AGES DE MOINS DE 16 ANS:

Université Catholique de Louvain

USAGE D'ANCRAGE ORTHODONTIQUE

CODE PATIENT#:

PARTIE 2:

6 Mois Apres Placement de L'Implant

DATE D'AUJOURD'HUI:

 / /

PATIENT

Instructions: Veuillez utiliser un bic pour remplir le formulaire. **NOIRCISSEZ COMPLETEMENT** les cercles correspondant à vos réponses. Veuillez inscrire les chiffres exclusivement à l'intérieur des cases prévues à cet effet.

INCONFORT GENERE PAR L'/LES IMPLANT(S) PENDANT LE TRAITEMENT ORTHODONTIQUE

1. Prenez-vous ou avez-vous pris des médicaments pour l'/les implant(s)? ☐ Oui ☐ Non

Si oui, lesquels? ☐ Antidouleurs?

(nombre de jours)

☐ Antibiotiques?

(nombre de jours)

☐ Anti-inflammatoires?

(nombre de jours)

2. Irritation des joues/lèvres:

☐ pas d'irritation

☐ faible irritation

☐ irritation modérée

☐ irritation importante

3. Gonflement des lèvres/joues:

☐ aucun gonflement

☐ léger gonflement

☐ gonflement modéré

☐ gonflement important

Si gonflement,

(nombre de jours)

4. Fréquence de présence d'infection/de gonflement des gencives autour de l'/des implant(s):

☐ Jamais

☐ Occasionnellement

☐ Souvent

☐ Tout le temps

5. Avez-vous eu un quelconque autre problème avec le/les implant(s)?

☐ Oui

☐ Non

Si oui, lequel?

☐ Inflammation

☐ Sensation de mobilité

☐ Perte de l'implant

☐ Limitation de l'ouverture buccale

☐ Difficulté pour nettoyer le/les implant(s)

☐ Irritation des joues

☐ Autre

6. Touchez-vous fréquemment l'/les implant(s) avec la langue?

☐ Oui

☐ Non

7. Inconfort en général à ce jour:

☐ Aucun inconfort

☐ Inconfortable

☐ Légèrement douloureux

☐ Très douloureux

8. L'/les implant(s) vous dérangent-ils plus ou moins que les plaquettes?

☐ Plus

☐ Moins

9. Avez-vous déjà porté une force extra-orale?

☐ Oui

☐ Non

Si oui, préférez-vous la force extra-orale ou le/les implant(s)?

☐ Force extra-orale

☐ Implant(s)

Veuillez expliquer:

INCONFORT GENERE PAR L'/LES IMPLANT(S) PENDANT LE TRAITEMENT ORTHODONTIQUE (suite)

10. Les implant(s) sont-ils mieux ou moins bien tolérés que ce à quoi vous vous attendiez? ☐ Mieux ☐ Moins bien

Veillez expliquer pourquoi: _____

11. Cela vous dérange-t-il d'avoir des implants en bouche? ☐ Oui ☐ Non

Si oui, pourquoi ? _____

12. Comment nettoyez-vous les implants ? ☐ brosse à dent ☐ Bain de bouche ☐ Spray

Combien de fois par jour ?

13. Accepteriez-vous encore le placement d'implants? ☐ Oui ☐ Non

Si non, pourquoi pas? _____

COMMENTAIRES DES PARENTS POUR LES PATIENTS AGES DE MOINS DE 16 ANS:

Université Catholique de Louvain

USAGE D'ANCRAGE ORTHODONTIQUE

PARTIE 3A:

1 An Apres Placement de L'Implant

PATIENT

CODE PATIENT#:

DATE D'AUJOURD'HUI:

 / /

Instructions: Veuillez utiliser un bic pour remplir le formulaire. NOIRCISSEZ COMPLETEMENT les cercles correspondant à vos réponses. Veuillez inscrire les chiffres exclusivement à l'intérieur des cases prévues à cet effet.

INCONFORT GENERE PAR L'/LES IMPLANT(S) PENDANT LE TRAITEMENT ORTHODONTIQUE

1. Prenez-vous ou avez-vous pris des médicaments pour l'/les implant(s)? ☐ Oui ☐ Non

Si oui, lesquels? ☐ Antidouleurs?

(nombre de jours)

☐ Antibiotiques?

(nombre de jours)

☐ Anti-inflammatoires?

(nombre de jours)

2. Irritation des joues/lèvres:

☐ pas d'irritation

☐ faible irritation

☐ irritation modérée

☐ irritation importante

3. Gonflement des lèvres/joues:

☐ aucun gonflement

☐ léger gonflement

☐ gonflement modéré

☐ gonflement important

Si gonflement,

(nombre de jours)

4. Fréquence de présence d'infection/de gonflement des gencives autour de l'/des implant(s):

☐ Jamais

☐ Occasionnellement

☐ Souvent

☐ Tout le temps

5. Avez-vous eu un quelconque autre problème avec le/les implant(s)?

☐ Oui

☐ Non

Si oui, lequel?

☐ Inflammation

☐ Sensation de mobilité

☐ Perte de l'implant

☐ Limitation de l'ouverture buccale

☐ Difficulté pour nettoyer le/les implant(s)

☐ Irritation des joues

☐ Autre

6. Touchez-vous fréquemment l'/les implant(s) avec la langue?

☐ Oui

☐ Non

7. Inconfort en général à ce jour:

☐ Aucun inconfort

☐ Inconfortable

☐ Légèrement douloureux

☐ Très douloureux

8. L'/les implant(s) vous dérangent-ils plus ou moins que les plaquettes?

☐ Plus

☐ Moins

9. Avez-vous déjà porté une force extra-orale?

☐ Oui

☐ Non

Si oui, préférez-vous la force extra-orale ou le/les implant(s)? ☐ Force extra-orale

☐ Implant(s)

Veuillez expliquer:

INCONFORT GENERE PAR L'/LES IMPLANT(S) PENDANT LE TRAITEMENT ORTHODONTIQUE (suite)

10. Les implant(s) sont-ils mieux ou moins bien tolérés que ce à quoi vous vous attendiez? ☐ Mieux ☐ Moins bien

Veuillez expliquer pourquoi: _____

11. Cela vous dérange-t-il d'avoir des implants en bouche? ☐ Oui ☐ Non

Si oui, pourquoi ? _____

12. Accepteriez-vous encore le placement d'implants avec votre expérience actuelle? ☐ Oui ☐ Non

Si non, pourquoi? _____

COMMENTAIRES DES PARENTS POUR LES PATIENTS AGES DE MOINS DE 16 ANS:

Université Catholique de Louvain

USAGE D'ANCRAGE ORTHODONTIQUE

PARTIE 3B:

2 Semaines Apres Depose de L'Implant

PATIENT

CODE PATIENT#:

DATE D'AUJOURD'HUI:

 / /

Instructions: Veuillez utiliser un bic pour remplir le formulaire. **NOIRCISSEZ COMPLETEMENT** les cercles correspondant à vos réponses. Veuillez inscrire les chiffres exclusivement à l'intérieur des cases prévues à cet effet.

DEPOSE CHIRURGICALE DE L'/DES IMPLANT(S)

1. Douleur pendant l'intervention: ☐ aucune ☐ peu de douleur ☐ douleur modérée ☐ douleur importante

2. Intervention chirurgicale dans son ensemble:

- ☐ Très désagréable, je n'accepterais plus jamais la dépose d'un implant
- ☐ Désagréable, mais j'accepterais une nouvelle intervention sans me réjouir de celle-ci
- ☐ Peu désagréable; je supporterais une nouvelle intervention si nécessaire

INCONFORT LA SEMAINE SUIVANT LA DEPOSE

1. Absence à l'école/ au travail: (nombre de jours)

2. Avez-vous pris des médicaments après la dépose du/des implant(s)?

☐ Oui ☐ Non

Si oui, lesquels? ☐ Antidouleurs?

(nombre de jours)

☐ Antibiotiques?

(nombre de jours)

☐ Anti-inflammatoires?

(nombre de jours)

3. Gonflement des lèvres/joues: ☐ aucun gonflement

☐ léger gonflement

☐ gonflement modéré

☐ gonflement important

Si gonflement, (nombre de jours)

4. Avez-vous eu mal après la dépose du/des implant(s)?

☐ Oui ☐ Non

Si oui, quelle intensité de douleur? ☐ Légère ☐ Modérée

☐ Importante

Si oui, pendant combien de temps? (nombre de jours)

5. L'/les implant(s) vous ont-ils dérangé plus ou moins que les plaquettes?

☐ Plus ☐ Moins

6. Avez-vous éprouvé des difficultés à nettoyer l'/les implant(s)?

☐ Oui ☐ Non

Si oui, veuillez expliquer pourquoi?

INCONFORT LA SEMAINE SUIVANT LA DEPOSE (suite)

7. Les implant(s) étaient-ils mieux ou moins bien tolérés que ce à quoi vous vous attendiez? ☐ Mieux ☐ Moins bien

Veillez expliquer pourquoi: _____

8. Cela vous a-t-il dérangé d'avoir un/des implant(s) en bouche? ☐ Oui ☐ Non

Si oui, pourquoi ? _____

9. Accepteriez-vous encore le placement d'implants avec votre expérience actuelle? ☐ Oui ☐ Non

Si non, pourquoi? _____

COMMENTAIRES DES PARENTS POUR LES PATIENTS AGES DE MOINS DE 16 ANS:

Appendix 3

Université Catholique de Louvain

SCHOOL OF DENTISTRY

USE OF ORTHODONTIC ANCHORAGE
PART 1: Placement of Skeletal Anchorage

CASE CODE #:

TODAY'S DATE: / /

SURGEON

Directions: Please use a pen to complete form. **COMPLETELY FILL IN CIRCLES** that correspond to answers. Please keep numbers within boxes.

Surgeon's Name:

Specialty: ☐ Surgeon ☐ Periodontist ☐ Orthodontist ☐ Generalist ☐ Other

SURGICAL PROCEDURE

1. Date of surgical procedure: / /

2. Brand / type of anchor(s):	Dimensions	Total # Placed
☐ Surgi-Tec Bone Anchor (miniplate)	☐ Mx Long (31.5 mm)	
	☐ Mx Short (26.5 mm)	
	☐ Md Long ((26.5 mm)	
	☐ Md Short (23.5 mm)	
☐ KLS Martin C-Tube	☐ Standard	
☐ Aarhus Anchor	☐ L: mm x W: mm	
☐ Absoanchor	☐ L: mm x W: mm	
☐ Other _____	☐ L: mm x W: mm	

3. Brand / type of screw(s):	Dimensions	Total # Placed
☐ Surgi-Tec Bone Screws	☐ 5 mm x 2.3 mm	
	☐ 7 mm x 2.3 mm	
☐ KLS Centre / Cross Drive Screws	☐ 4 mm x 1.5 mm	
	☐ 5 mm x 1.5 mm	
	☐ 6 mm x 1.5 mm	
	☐ 7 mm x 1.5 mm	
☐ Leibinger	☐ L: mm x W: mm	
☐ Jeil Bone Anchor Screw	☐ L: mm x W: mm	
☐ Other _____	☐ L: mm x W: mm	

4. Anatomic site(s) / Location at Site:**mm Distance from Jxn**

(- = attached gingiva)

(+ = mucosa)

Upper Jaw**Location**☐ Posterior Butress☐ Left

B/W tooth #

 & ☐ Right

B/W tooth #

 & ☐ Anterior Paranasal☐ Left

B/W tooth #

 & ☐ Right

B/W tooth #

 & ☐ Midline

B/W tooth #

 & ☐ Alveolar Bone Region

B/W tooth #

 & ☐ Other _____ **mm Distance from Jxn**

(- = attached gingiva)

(+ = mucosa)

Lower Jaw**Location**☐ Posterior Mandibular Body☐ Left

B/W tooth #

 & ☐ Right

B/W tooth #

 & ☐ Anterior Mandibular Body☐ Left

B/W tooth #

 & ☐ Right

B/W tooth #

 & ☐ Midline

B/W tooth #

 & ☐ Alveolar Bone Region

B/W tooth #

 & ☐ Other _____ **5. Other procedures performed at time of surgery:**☐ Extractions, Teeth #: _____☐ Other (specify): _____**6. Anesthesia (indicate all that apply):** ☐ Local anesthesia ☐ N2O/ O2 sedation ☐ IV sedation**7. Components of surgical procedure (indicate all that apply):**☐ Mucoperiosteal flap ☐ Suture ☐ Pilot drill ☐ Other _____

8. Medication:**Before surgical procedure:**

☐ Antibiotics ☐ Anti-inflammatory agent ☐ Other _____

After surgical procedure:

☐ Antibiotics ☐ Anti-inflammatory agent ☐ Analgesics
☐ Chlorhexidine / other mouth rinse ☐ Other _____

9. X-ray(s) taken after placement: ☐ Lateral ceph ☐ Panoramic ☐ Periapical ☐ Other

SURGICAL EXPERIENCE:**1. Complexity of the surgical procedure:**

☐ Very easy ☐ Moderately easy ☐ Somewhat difficult ☐ Very difficult

2. Length of time of the surgical procedure:

☐ < 15 minutes ☐ 15-30 minutes ☐ 30-45 minutes ☐ 45-60 minutes ☐ > 60 minutes

3. Your previous experience placing skeletal anchorage units:

☐ None ☐ 1-2 cases ☐ 3-5 cases ☐ 6-10 cases ☐ 10-20 cases ☐ > 20 cases

4. Problems encountered?

☐ Yes ☐ No

If yes, please explain: _____

COMMENTS:

SURGICAL EXPERIENCE:

1. Complexity of the surgical procedure:

☐ Very easy ☐ Moderately easy ☐ Somewhat difficult ☐ Very difficult

2. Length of time of the surgical procedure:

☐ < 15 minutes ☐ 15-30 minutes ☐ 30-45 minutes ☐ 45-60 minutes ☐ > 60 minutes

3. Your previous experience removing skeletal anchorage units:

☐ None ☐ 1-2 cases ☐ 3-5 cases ☐ 6-10 cases ☐ 10-20 cases ☐ > 20 cases

4. Problems encountered?

☐ Yes ☐ No

If yes, please explain: _____

COMMENTS:

Appendix 4

Maxillary molar distalization with miniplates assessed on digital models: A prospective clinical trial

Marie A. Cornelis^a and Hugo J. De Clerck^b

Brussels, Belgium

Introduction: The purpose of this prospective study was to evaluate the effects of maxillary molar distalization in patients treated with a miniplate skeletal anchorage system. **Methods:** Thirty-one miniplates were placed on the infrazygomatic crests of 17 nongrowing patients consecutively selected for Class II treatment with skeletal anchorage. Three weeks after surgery, a 150-g force was applied to distalize the molars. No appliances were placed in the mandible. Models made before treatment and after molar distalization were scanned. Linear measurements were made on the digitized casts. Molar movement was measured on the superimposed maxillary arches before and after distalization, coregistered on the untreated mandibular models. **Results:** A molar hyper Class I relationship was reached in all patients 7.0 ± 2.0 months after miniplate loading. The maxillary molars were moved distally a mean distance of 3.27 ± 1.75 mm. In patients without contact between the maxillary and the mandibular incisors, overjet decreased by 0.99 ± 1.32 mm. Intermolar width increased by 2.78 ± 1.38 mm. **Conclusions:** Maxillary molar distalization with miniplates for skeletal anchorage is an efficient, noncompliance-dependent, and predictable treatment modality for patients with Class II molar relationship. (*Am J Orthod Dentofacial Orthop* 2007;132:373-7)

Conventional distalization mechanics either rely on considerable patient compliance¹ or generate unwanted reciprocal movement of anchor teeth in the anterior segment.²⁻⁴ Moreover, once molar distalization has been achieved, distalization of the anterior teeth without molar anchorage loss is challenging.⁵ Commonly, headgear is used to distalize posterior teeth and to avoid anchorage loss during retraction of the anterior segment. Absolute skeletal anchorage, available 24 hours a day, offers an alternative method for molar distalization. Miniscrews, which are generally placed between the roots, can limit the amount of distalization possible. Miniplates, which are by contrast fixed at a distance from the root apices, allow distalization of the whole arch because there is no interference between the fixation device and the roots of the teeth.⁶⁻⁸

The purposes of this prospective study were (1) to evaluate the effects on the dentition of maxillary molar

distalization with miniplate anchorage in nongrowing patients and (2) to quantify molar movement achieved on digitized models coregistered on the untreated mandibular arch.

MATERIAL AND METHODS

Seventeen consecutive nongrowing patients (15 women (>16 years of age) and 2 men (>19 years of age), treated in a private practice by the same orthodontist with miniplate anchorage, were prospectively included according to these criteria: (1) unilateral or bilateral Class II molar relationship with crowding or protruded incisors in the maxilla, (2) no or minor crowding in the mandible, and (3) both first and second maxillary molars present on the side(s) with a Class II relationship. The mean age of the sample at the beginning of treatment was 27 years 3 months (range, 17-45 years). Ten patients had contact between the maxillary and the mandibular incisors before treatment, and 7 patients did not.

Two months before surgery, a partial fixed appliance was placed in the maxilla, including the first and second molars, the canines, and the labially crowded incisors. No appliances were placed in the mandible. Thirty-two titanium miniplates designed for orthodontic anchorage (Fig 1) were placed under local anesthesia on the zygomatic buttress. Fifteen patients had 2 miniplates, and 2 patients had only 1. Because 1 bilaterally implanted patient lost a miniplate before

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^bPrivate practice, Brussels, Belgium.

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Submitted, February 2007; revised and accepted, April 2007.

0889-5406/\$32.00

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doi:10.1016/j.ajodo.2007.04.031

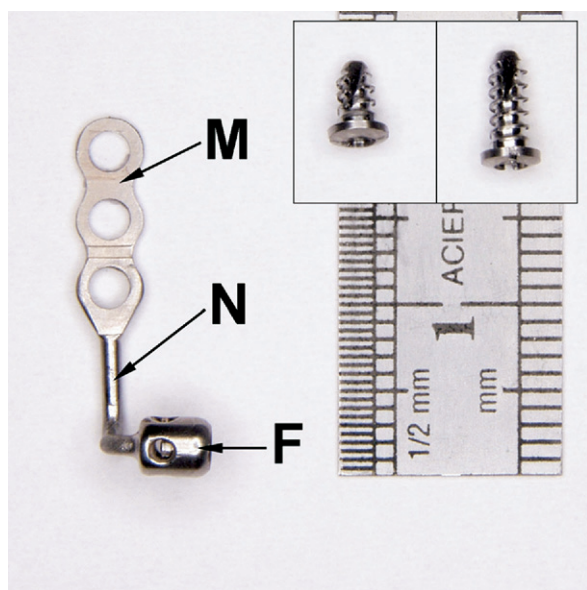


Fig 1. Bollard miniplate and screws (left, 5-mm length; right, 7-mm length). M, miniplate; N, neck; F, fixation unit.

loading, 31 miniplates remained for molar distalization and were evaluated in this study. Three weeks after surgery, elastics generating a 150-g force were applied between the miniplate and a sliding hook anterior to a closed-coil spring on a .016-in round stainless steel archwire to distalize the molars by sliding mechanics (Fig 2).

Plaster casts made before treatment and after molar distalization were digitized (Fig 3, A and B) (DigiModel, OrthoProof, Albuquerque, NM). Overjet, overbite, and maxillary intercanine and intermolar widths were measured before and after treatment by using the built-in measurement tools of the software (Fig 3, C and D). One patient was excluded from the intercanine width assessment because of an impacted canine. The untreated mandibular arches before and after maxillary molar distalization were coregistered on 3 points positioned on the mandibular first molars and 1 mandibular canine of both models with the superimposition tool of the software (Fig 4). The images of the superimposed maxillary arches were then exported and analyzed with ImageJ software (NIH, Washington DC). The distances between the mesial aspect of the maxillary first molars before and after distalization and between the maxillary first premolars before and after distalization were measured on the images of the superimposed arches after coregistration of the mandibular models. Maxillary molar distalization was also measured on the plaster casts in occlusion before and



Fig 2. Molar distalization with elastic placed between miniplate and sliding tube and closed coil spring. Initially, only partial bonding is used; appliance system was not consistent from patient to patient.

after distalization. Continuous variables were expressed as means $\pm$ standard deviations, tested for normality with Kolmogorov-Smirnov tests and compared with paired-sample *t* tests. Correlation between measurements of molar distalization on the digital and plaster models was evaluated with the Pearson correlation coefficient. Bias of measurements on the digital models was evaluated with the Bland-Altman plot.

RESULTS

The molars were moved into an overcorrected Class I occlusion for all patients after a mean period of 7.0 ± 2.0 months (range, 3.2-9.9 months). No signs of infection were observed around the miniplates, and none of the plates showed increased mobility over this period.

Thirty-one maxillary molars were moved over a mean distance of 3.3 ± 1.8 mm (range, 0.3-7.8 mm) (Fig 5). All values measured were normally distributed (Kolmogorov-Smirnov, $P > .12$). Measurements of molar distalization on the digital and the plaster models were well correlated ($R = 0.80$) with no significant difference between the measurement methods (3.3 ± 1.8 and 3.5 ± 1.5 mm, respectively, $P = .37$) (paired-sample *t* tests). Bias between both techniques was small (absolute bias, -0.18 ± 1.10 ; relative bias, $5.5\% \pm 3.9\%$). Unbonded first premolars were spontaneously distalized an average of 1.4 ± 1.2 mm.

In the 10 patients without contact between the maxillary and the mandibular incisors before treatment, overjet decreased significantly (Fig 5, A), whereas it did not in the remaining 7 patients (Fig 5, B). Overbite slightly decreased. The intercanine and the intermolar widths increased significantly (Table).

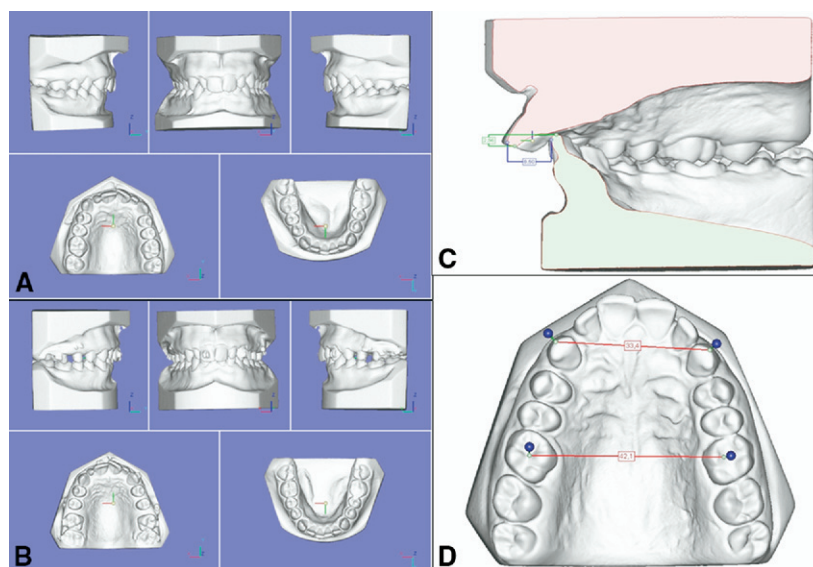


Fig 3. Digital models: **A**, before and **B**, after molar distalization. **C**, Overjet and overbite measurements. **D**, Intercanine and intermolar widths measurements.

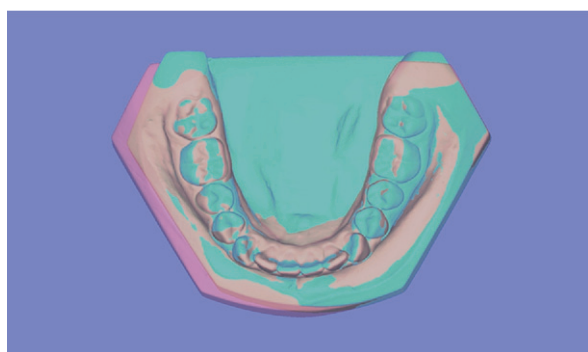


Fig 4. Coregistration of mandibular models before and after maxillary molar distalization.

DISCUSSION

No controls were available in this study; however, distal movement of the maxillary relative to the mandibular molars would not have been expected in this nongrowing group of Class II patients.

This study showed that molar distalization assessed on digital models was reliable compared with plaster models. This agrees with the results of other authors who stated that digital models are a clinically acceptable replacement for plaster casts.⁹

A Class I molar relationship was achieved in every patient. Distalization values obtained in this study in an average period of 7.0 months show that miniplates can be an effective alternative for headgear; even in adults with the maxillary second molars erupted. Skeletal

anchorage reduces the demands on a patient's compliance and increases overall control and predictability of the orthodontic treatment.

Even though the maxillary premolars were not bonded, their spontaneous distal drift was observed in 84.4% of the patients. This might be attributed to the stretching of the elastic supracrestal fibers connecting the first molars to the premolars and the canines.³ However, in patients with tight interdigitation or occlusal interference with the mandibular teeth, spontaneous drift appeared more restricted. The simultaneous distal movement of the maxillary canines and reduction of anterior crowding and overjet occurred in patients who had no contact between the maxillary and mandibular incisors. These movements were surprising, and we assumed that they are related to binding at the interface between the molar tubes and the archwire after initial distal crown tip, because the distalizing force was applied away from the molar's center of resistance.⁸ This binding generates a couple responsible for root uprighting and friction that pulls the archwire to the distal, resulting in reduction of overjet. In other words, the 150-g force applied on the maxillary molars is sufficient not only to push the molars backward into an overcorrected Class I position but also to start the retraction of the premolars, canines, and incisors. The spontaneous migrations of the premolars, canines, and incisors might reduce the treatment time needed to distalize the anterior segment after molar distalization. During this second phase of treatment, we did not observe mesialization of the molars, suggesting that there

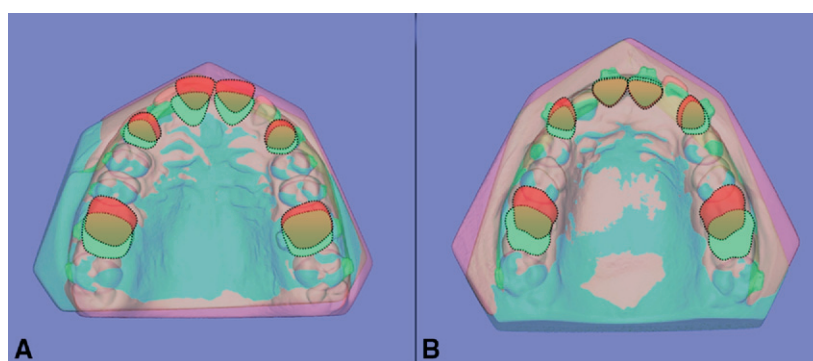


Fig 5. Maxillary models, before (red) and after (green) distalization. Note canine expansion and premolar distalization. **A**, Overjet reduction related to absence of contact between maxillary and mandibular incisors. **B**, No reduction in overjet related to contact between maxillary and mandibular incisors.

Table. Overjet, overbite, and intercanine and intermolar widths before and after molar distalization (paired-sample *t* tests)

	Initial (mm)	Final (mm)	Difference (mm)	P value	Significance
Overjet (if no initial contact between I and i)	5.1	3.7	-1.4	.0138	S
Overjet (if initial contact between I and i)	3.5	3.8	0.3	.4838	NS
Overbite	2.9	2.5	-0.5	.1449	NS
Intercanine width	32.5	34.2	1.7	.0004	S
Intermolar width	43.6	46.44	2.8	<.0001	S

S, Significant, $P < .05$; NS, not significant, $P > .05$; I, maxillary incisors; i, mandibular incisors.

is reduced risk of compromising the Class I molar occlusion with the miniplate for anchorage rather than previously distalized molars. Maintaining Class I molar occlusion while retracting anterior teeth is usually challenging with conventional distalization techniques.⁵

In general, overbite was only slightly reduced; this is in contrast to the bite opening that can occur with extrusion of the maxillary molars with cervical headgear.¹⁰

The increases in intercanine and intermolar widths can partially be explained because these teeth were moved along the alveolar ridge; this tends to widen to the distal. However, the line of force from the skeletal anchorage units is oriented buccally and therefore is also responsible for part of the expansion observed. With the distalization force from the anchor unit directly pushing the buccal tube of the molar distally, mesiobuccal molar rotation is easily corrected, perhaps because the premolars were not bonded and a light archwire was used.

No infection was observed around the miniplates, and none of the miniplates became mobile after loading. This high success rate is similar to previous studies.^{7,11,12} The gingival health around this particular skeletal anchor, which has a round connection bar

perforating the mucosa perpendicular to the cortical bone, is generally good.⁷

Although the miniplate system offers a technical advantage when all posterior teeth must be distalized, the patient's possible discomfort during the surgery required for miniplate placement might be a disadvantage. However, patients generally appear to accept miniplate placement well, and they report preferring miniplates to headgear.⁷

CONCLUSIONS

Miniplates provide a simple and reliable method for distal movement of the entire maxillary dentition in nongrowing patients. This approach would further reduce the need for extractions in patients with crowding or protrusion of the anterior teeth.

We thank J. F. Tulloch for critical reading and discussion of the manuscript.

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