A study into limits and possibilities of a steady state non-destructive test to evaluate implant stability.
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TITLE
A study into limits and possibilities of a steady state non-destructive test to evaluate implant stability.

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Chapter I

I.1 Introduction

Implant stability is a key factor for the success of implant therapy (Meredith, 1998). At placement, adequate primary stability of an implant is essential to allow undisturbed bone healing while thereafter, secondary stability, result of the osseointegration process, permits an optimal distribution of the functional loads through the bone implant interface (Meredith, 1998). Given the importance of this parameter the attention to its measure in the clinical practice has always been high. The first methods used to clinically evaluate implant stability were the tapping method (Adell, 1985), radiography and the Periotest (Gulden-Medizintechnik, Bensheim an der Bergstraße, Germany) (Schulte and Lukas, 1993). However, all these methods lack enough precision and repeatability in quantifying stability, therefore a precise and repeatable measure of implant stability was needed (Meredith, 1998).

Non-destructive vibration analysis has been widely used in engineering to evaluate the presence of internal flaws in composite materials (Cawley and Adams 1987). The first medical applications were in orthopaedics to identify the in vivo vibration modes of human tibiae (Van der Perre et al, 1983) and to determine the torsional stiffness of long bones (Lowet et al, 1993). The feasibility of the vibration analysis for monitoring of fracture healing (Cornelissen et al, 1987), bone integrity and osteoporosis evaluation (Van der Perre and Lowet, 1994, 1996) (Panteliou et al, 1999) (Panteliou et al, 2004) was also shown.

In 1994 Meredith introduced in the field of implant dentistry a vibration non-destructive testing method: resonance frequency (RF) (Meredith et al, 1994). Since 1999 this method of analysis has been commercially available as the Osstell™ equipment (Integration Diagnostics, Göteborg, Sweden). The
The technique is based on a small L-shaped transducer that contains two piezoelectric elements and is screwed on top of the implant or its abutment (Meredith et al, 1996). The first element is excited in the range of 5-15 KHz thus transmitting a microscopic and harmless vibration to the bone implant interface, the response to this vibration is then registered by the second element, transmitted through an output cable to a frequency/response analyser and transformed into an Implant Stability Quotient (ISQ). Receiving the output of the equipment in the form of ISQ is a great advantage over the experimental equipment that was used until 1999 and gave back a result that was expressed in Hz and in addition needed calibration if measures taken with different transducers were to be compared. Conversely, ISQ units are automatically calibrated for each different transducer and therefore easily and directly comparable. The ISQ units range from 1 to 100 with higher values indicating better stabilities. Today the Osstell™ has been updated with a new version called Mentor (Integration Diagnostics) that, while maintaining the ISQ scale, features wireless transducers that are electromagnetically excited.

After the possibility of measuring implant stability with resonance frequency was shown (Meredith et al, 1994), research was carried out to optimize the design of the transducer to maximize its sensitivity in the clinical conditions (Cawley et al, 1998) and to investigate the significance of such measures in the evaluation of implant stability and treatment outcome. The results of these early in-vitro researches showed how implants embedded in aluminium blocks with different exposed length result with different resonance frequencies (Meredith et al, 1996). Indeed, a linear inverse relation could be established between the RF and the distance of the transducer from the embedding material. Due to this finding the technique seemed to have a great attractiveness in the detection and follow-up of early peri-implant bone losses. A second factor that turned out to influence RF, was the stiffness of the interface as indicated by repeated
measurements of implants placed in self curing resin (Meredith et al, 1996). RF revealed to be linearly related to the stiffness of the interface and therefore very promising in evaluating changes in stiffness at the bone implant interface due to haling processes or progressive loss of implant stability. When the rabbit tibia was used as a model to study implant stability, it was found that repeated measured during the healing period showed a significant increase in RF after 14 and 28 days from placement (Meredith et al, 1997a). This was most likely attributed to the bone healing process that improved the stability of the implants. It was also shown how the response of the transducer is directional and how the greatest variation in stability could be seen when its L-shaped element was perpendicular to the tibias. In addition a very good repeatability of the measurements was found in the above studies (better than 1%).

When considering the early clinical studies a good correspondence with the in-vitro work resulted. Meredith measured the stability of 56 maxillary implants in nine edentulous patients and their RF significantly increased from placement to the abutment connection (Meredith et al, 1997b). Such a time dependant increase was expected and related to the structural changes at the bone implant interface provoked by the healing events. Only two implants were classified as failure and accordingly their RF fell between the two measurements the technique was therefore claimed to be able to discriminate between successful implants and clinical failures. In addition, the stability of 52 osseointegrated maxillary implants was measured in the above mentioned study and a significant correlation was found between their exposed implant lengths (abutment length + bone loss) and the corresponding RF values. Further studies on resonance frequency of implants placed in mandibular and maxillary bone were carried out by Friberg. He evaluated the stability of one stage mandibular implants with repeated measures over a 15-week healing period (Friberg et al, 1999a). A slight decrease of stability in such a dense bone resulted as compared
to the values recorded at placement. Indeed, the contribution to implant stability of the healing process and new bone formation was considered negligible in dense bone. The reason for the decreased values was therefore attributed to a slight bone resorption occurred (-0.4 -0.7 mm) with a consequent increase of the distance of the transducer from the first bone contact. In addition, another very interesting observation made, was that a drop in RFA anticipated the loss of an implant in one patient, due to a flap dehiscence, nine weeks before the implant was clinically mobile. Another patient in the study showed a similar decrease in RFA for three implants six weeks after placement, immediate action was taken to relieve the implants from denture contact and the patient was asked to minimize the use of the denture. As a result RFA increased at the subsequent controls after 15 weeks when the final bridge was delivered and after 30 weeks the RF for the three implants was almost approaching the original levels.

When measuring the stability of maxillary implants at placement, abutment connection and one year of loading, a significant increase in resonance frequency resulted over time (Friberg et al, 1999b). In addition, when grouping the implant sites according to their bone quality as evaluated by the cutting torque analysis, it was evident that implants placed in softer bone had the lowest stability at placement as measurable with resonance frequency. However these implants significantly improved their stability over time with the greatest increase in resonance frequency. At the end of the follow-up, 20 months after placement all the implants had comparable stabilities, irrespective of the values at the installation and of the quality of the bone site. Resonance frequency was useful to recognize the importance of the new bone formation to the achievement of the final implant stability.

Given the results of the above-mentioned early studies made with the experimental apparatus for RF, the Osstell™ was commercially launched and
claimed to be an aid for the clinician when making decision during the implant therapy (Osstell™ Clinical Manual, Integration Diagnostic). In particular it could be useful to evaluate primary stability at placement in order to decide the feasibility of an immediate/early loading protocol or the length of the healing time (normal or prolonged). In addition, it could be useful to evaluate the stability after healing and before loading thus assuring that enough stability has been achieved to withstand functional loading. The clinician could also detect decreases of stability during loading to be interpreted as early warning of implant failure and taking avoiding action.

In addition it has been suggested that the Osstell™ could serve as a measure of primary outcome when evaluating the performances of dental implants in clinical studies and meta-analysis (Esposito et al, 2007).

After ten years since the first clinical studies and the commercialization of the equipment, it is interesting to evaluate if the Osstell™ is capable of providing diagnostic information specific and sensitive on the outcome of the implant treatment. In the following paragraphs the literature dealing with the clinical application of resonance frequency will be reviewed with the aim to analyse its utility in the practice.

I.2 What RF measures and what are the factors of influence on the measurements

The two main parameters related to RF are the distance of the transducer from the first bone contact and the stiffness of the interface. In particular RF is inversely related to the bone transducer distance as documented in early in vitro and in vivo studies (Meredith et al, 1996) (Meredith et al, 1997b). Although clinically the exposed length of an implant depends on the marginal bone level together with the abutment height, it is possible to set the Osstell™ to compensate for the latter so that the sensitivity of the instrument is aimed at the
evaluation of the marginal bone level. More recently the same relationship resulted from an animal study where RF was measured during the initiation and resolution of an experimental peri-implantitis (Sennerby et al, 2005). Given the high correlation resulting between RF and experimental bone level changes, the authors therefore supported the claim that the technique is sensitive and can detect even minor variation of the transducer-bone distance. In contrast when analysing data from recent clinical studies such a correlation between RF and bone level was not found (Balleri et al, 2002) (Bishof et al, 2004). Conversely, others could see a relation between RF and resorption occurred from placement to six months but not from six to 12 months (Turkyilmaz et al, 2006). Even though these results might seem controversial, it has to be clarified that such relation is supposed to be more evident when RF is repeated over time to detect marginal bone level changes than when a single RF measurement is put in correlation with the bone level. The linear correlation between bone stiffness and RF also resulted from the early studies (Meredith et al, 1996) (Meredith et al, 1997b). FEA studies confirmed that RF is highly sensitive to changes of the stiffness at the implant interface (Pattijn et al, 2006). Accordingly clinical studies showed that implants placed in the denser mandibular bone have higher RF than those placed in maxillas (Balleri et al, 2002) (Nedir et al, 2004) At placement the stiffness of the interface, namely the primary stability, was found to be dependant on the bone quality, the surgical technique and the implant shape (Östman et al, 2006). Therefore RF measured at placement seems to represent the degree of stiffness reached by the mechanical interlock created with the surgical procedure. Nevertheless Huwiler showed how RF at placement is not correlated with the bone density and trabecular connectivity of the bone core obtained during the surgical procedure and analysed with micro CT (Huwiler et al, 2007). Conversely, Miyamoto showed how RF significantly correlates with the amount
of cortical bone present at the implant site that is therefore judged more contributal to stability than the length of the implant itself (Miyamoto et al, 2005). The influence of implant shape on RF was showed by O’Sullivan in a cadaver study where tapered implants reached higher stabilities in soft bone than cylindrical implants (O’Sullivan et al, 2000). In another study the use of tapered implants permitted to reach high RF in the maxilla regardless of bone quality (Degidi et al, 2007). As far as surgical technique is concerned, in a larger RF study on 905 implants, it was found that an adapted placement procedure with reduced drill diameter allows for high primary stabilities regardless of the jawbone region, however it cannot fully compensate for bone quality and implant diameter/length (Östman et al, 2006).

After the healing period, bone formation and remodelling at the interface promote the osseointegration of the implant (Meredith 1998). Therefore the stiffness of the interface, namely secondary stability, is now dependant by the interlock of the implant surface with the newly formed bone. However the relation between RF and bone structure is not fully understood yet (Rasmusson et al, 1998). Degidi was able to demonstrate a significant correlation between RF and bone contact on implants retrieved from humans after a mean of six months from placement (Scarano et al, 2006). On the other hand Rocci was unable to relate RF of retrieved human implants with any histomorphometrical parameter (Rocci et al, 2003). It must be concluded that it is still unclear what biological parameter RF measures on integrated implants, although it can be speculated that it measures the stiffness of the interface in bending (Rasmusson et al, 1998).

An additional parameter that needs to be taken into account when measuring the RF using the Osstell™ is the orientation of the transducer. In rabbit tibias it was shown that the response of the transducer is directional and therefore variable with transducer orientation (Meredith et al, 1997a). It was also stated that the
perpendicular orientation would better detect changes at the bone implant interface. Accordingly, the manufacturer suggest to orient the transducer in a repeatable manner when measuring RF over time and the perpendicular orientation with the output cable on the buccal side is advised (Osstell™ clinical manual). The same conclusions on the directionality of the transducer response were made in a recent study in the guinea pig model (Pattijn et al, 2007). This study assessed the influence of the transducer orientation and of the boundary conditions, such as the bone size. However the authors recognized the need of a clinical study before extrapolating their finding to the clinical field.

Another parameter that was defined by Meredith to need further investigation if RF was to be used as a clinical diagnostic tool, is the shape of the wave (Meredith 1998). This shape is related to the damping that is the width of the frequency/amplitude plot obtained when exciting the Osstell™ transducer. Although the damping is not taken into account by the Osstell™ in the elaboration of the ISQ value, recently it was found that damping was related to chemically induced changes in the porosity and density of excised animal bone (Panteliou et al, 2004). In addition, Meredith (Meredith 1997) suggested that the damping of bone would be influenced by factors including the mineral content, the number of trabeculae, and the bone density. Consequently, the first part of this project aimed at verifying under clinical conditions the influence of different transducer orientations on RF and if any particular orientation would best relate with bone levels. Another purpose was to look for a correlation between the damping, as measurable with the Osstell™ equipment, and a radiographic parameter for bone architecture, namely the fractal dimension.
I.3 Clinical significance of resonance frequency

I.3.a Prognostic value at placement

Although the equipment was claimed to be useful in helping the clinicians when deciding for the loading protocol after implant placement, it was admitted that no normative values were available to distinguish if the primary stability was sufficient for an immediate or early loading or if it was rather the case to submerge the implant and wait for osseointegration (Osstell™ clinical manual). In addition, as emerged from subsequent studies, such values should be specific for each implant type and bone site encountered (Pattijn et al, 2006), unfortunately the majority of the clinical studies on RF has been carried out on the Brånemark and ITI systems, while there is a scarcity of data for the other systems. This limitation may be one of the factors why RF has not been well perceived by clinicians (Koka 2006).

When considering the Brånemark system, it was suggested that, according to preliminary experience, implants with a primary stability above 60-65 ISQ may be sufficient for successful immediate loading while implants below 40 could be more susceptible to failures (Sennerby and Meredith 2001). Many earlier studies did not use RF as a parameter for deciding early loading, but RF at placement was just reported as an adjunctive implant outcome parameter. In the majority of those studies a high primary stability >60 ISQ (most often expressed as a mean RF value at placement) was reassuringly associated with correspondent high implant success in the short term, while the failure reported were most often associated with early losses due to post-operative infections. Glauser immediately/early loaded 81 Brånemark implants placed in all the jaw regions, it was reported that a high primary stability was achieved for all the implants, nevertheless nine implants failed during the first year of loading. Except for two implants that failed during the first month, failures were anticipated by a marked continuous decrease in RF as compared to successful
implants (Glauser et al, 2004). However in a subsequent study the same research group placed 102 TiUnite implants in soft bone and subjected them to immediate loading (Glauser et al, 2005). The mean ISQ at placement was 68 and all the implants were successful after a four-year follow-up excluding three that early failed due to a post-operative infection. Calandriello immediately loaded 50 Brånemark TiUnite implants replacing mandibular single molars, he found that all the 24 implants that passed the one year follow-up were successful (Calandriello et al, 2003). The resonance frequency at placement was described as high (mean ISQ 76). Olsson early loaded 61 TiUnite implants in edentulous maxillae, the mean ISQ at placement was 60 and all the implants were successful after one year of loading, except four that were loss due to an infection (Ollsson et al, 2003). Sjöström reported the three-year outcome of 192 Brånemark implants placed in grafted edentulous maxillae (Sjöström et al, 2007). He found that the mean ISQ at placement was 61.9 and 20 implants were lost during the follow up (12 were early failures). Remarkably, it was also found that when comparing individual implants the mean RF for successful implants (62.6 ISQ) was significantly higher than the value registered at failed implants (54.9 ISQ).

More recently researchers, used RF as an inclusion criterion to decide for immediate/early loading. Östman directly loaded 123 TiUnite implants in edentulous maxillae using an adapted surgical technique and primary implant stability as criteria for inclusion (Östman et al, 2005). The implants were included if they were placed with a final torque of at least 30 Ncm and if RF was above 60 ISQ for the two posterior fixtures while the RF sum of the four anterior implants was above 200 (mean ISQ 50). After one year of loading the failure of only one implant was reported. Schincaglia immediately loaded 42 Brånemark implants in partially edentulous mandibles, 22 of those were TiUnite the remaining being machined (Schincaglia et al, 2007).
attribution of the immediate loading was a final torque >30 Ncm and an ISQ above 60. However, despite the inclusion criterion was met for all the implants, two implants failed in the machined group during the first year of loading. When considering ITI implants, Nedir measured at implant placement, after 1, 2, 4, 6, 8, 10 and 12 weeks the stability of 106 ITI implants placed in both jaws and subjected to conventional or early loading (Nedir et al, 2004). An ISQ ≥54 threshold value at placement was considered predictive for the osseointegration of ITI implants in an immediate loading protocol. In addition, it was suggested that implants with an ISQ ≥49 should be subjected to delayed loading. However no significant differences in stability resulted at early time points regardless of the loading protocol and the implant location. It was concluded that RF is not able to demonstrate the early healing events that happen at the implant interface but, rather, it measures the overall local stiffness of the interface. Huwiler, who studied RF in relation to bone quality in the phases following implant installation, drew similar conclusions (Huwiler et al, 2007). In maxillary and mandibular single edentulous areas he measured the RFA of 24 Straumann implants at placement and 1, 2, 3, 4, 5, 6, 8 and 12 weeks thereafter. A range of 59-69 ISQ was found during and although RF increased at the first week, decreased at weeks 3-4 and increased once again thereafter, none of such variations reached statistic significance. For this reason these changes were defined as a trend of variation within the range of RF measured. In addition, a correlation was attempted between the bone quality, as assessed by micro CT analysis of the parent bone into which implants were placed, and the RF values recorded during the early healing period but no relation could be established. Also to be taken into account is the fact the failure of an implant was not anticipated by a fall in its RF values that was only coincident with the event. For these reasons the clinical utility of RF in monitoring implant stability was seriously questioned. Conversely, Barewal performed a similar study on 27
implants placed in the posterior maxilla and mandible (Barewal et al, 2003). RF was measured at placement and 1, 2, 3, 4, 5, 6, 8 and 10 weeks thereafter and in addition the implants were grouped according to the bone quality (I-IV Lekholm and Zarb classification) of the site. For bone quality IV it was found that the stability of the implants decreased significantly from 0 to 3 weeks and then it was increased significantly at 6 weeks compared to the week 3, no further significant changes were seen thereafter. For bone qualities II and III RF decreased significantly from placement to the week 3 however a significant increase was only seen between week 3 and 10. Implants placed in bone of quality I did not show any significant change. The authors concluded that the study allowed the evaluation of the bone stability during the critical period of early healing.

Taken together these data show that a single RF measurement at placement could help the clinician in deciding if the implants can be subjected to immediate loading, however this indication has to be evaluated together with the surgeon’s perception of the bone quality and with the individual loading conditions of each patient. In fact high primary stabilities and corresponding high RF are almost guaranteed if an adapted surgical technique is used and this could hide the real bone quality that, nevertheless, remains of paramount importance for the prognosis of an implant especially if an immediate/early loading is applied (Esposito et al, 1998). Simply put, an adapted surgical technique can increase the primary stability of an implant in soft bone and RF will mirror this event with an high ISQ, however what remains unchanged are the biomechanical properties of that bone that might remain unsuitable to bear an immediate/early load. Therefore, in accordance with a recent literature review on the subject (Aparicio et al, 2006), when answering to the question if RF at placement could be a predictor of the implant outcome, the response based on the available literature seems to be no. Although RF could represent
an indication for the risk of failure of the implant, it is not an absolutely reliable prognostic parameter, however it has also to be recognized that these conclusions are based on few clinical studies and therefore cannot be regarded as conclusive.

I.3.b Prognostic value at second surgery

The second surgery is the phase of the implant treatment when loading is started. It has been showed how half of the implant failures are happening during the period from placement to second surgery (early failures) whereas the other half is distributed during the whole implant life under loading (late failures) (Esposito et al, 1998). Moreover, approximately half of the late failures are concentrated during the first year of loading that is therefore a critical period for the outcome of the treatment (Esposito et al, 1998). This is particularly true in the maxilla where failures have been reported to be three times more frequent due to the compromised bone support often found and overloading (Esposito et al, 1998). The edentulous maxilla has also been described as the condition where implant failures tend to cluster in few patients leading to a complete loss of the implant supported prosthesis (Jemt and Häger 2006). No clear motivation has been given for this phenomenon, although bone resorption and smoking have been reported to be a risk factor that needs to be discussed with patients prosthesis (Jemt and Häger 2006). Prolonged healing times together with adapted surgical techniques are regarded as the very important to increase implant success in soft bone (Friberg et al, 1999b). Therefore for the clinician it is of interest, when loading an implant, to appraise the degree of secondary stability achieved. There is no other way to evaluate this parameter other than RF as clearly explained by Meredith (Meredith 1998). The tapping test is subjective and non quantitative; radiography, although fundamental to evaluate bone levels, has revealed imprecise to estimate implant stability while the reverse torque method, advocated by some, might be
detrimental to the implant whilst being little informative with only an all-or-none end-result.

Studies that attempted to measure the RF of osseointegrated implants have been mainly carried out on the Brånemark system. Balleri reported a range of 57 to 82 ISQ with a mean of 69 ISQ for integrated implants placed in partially edentulous jaws after one year of loading (Balleri et al, 2002). Sjöström followed-up implants placed in grafted maxillas and reported that their stability after a three-year loading period was 61.8 ISQ (Sjöström et al, 2007). Hallman described the stability of integrated implants placed in grafted sinuses or in residual bone three years after placement, the mean ISQ was 65.6 ISQ and 67.4 ISQ respectively (Hallman et al, 2005). Turkyilmaz measured the stability of TiUnite implants placed in the anterior mandible to support overdentures and that were subjected to early or immediate loading (Turkyilmaz et al, 2006). The 12-month measurements showed 76.4 ISQ and 76.4 ISQ for immediately and early loaded implants respectively. Scarano measured the stability of 7 XIVE implants that were retrieved from humans and subjected to histomorphometry (Scarano et al, 2006). All the implants were judged as clinically stable and integrated and their RF before biopsy was above 60 ISQ for all the specimens. When considering ITI implants a mean value of 53.1 ISQ was reported by Zix for integrated implants loaded longer than 12 months (Zix et al, 2005). This somewhat lower value as compared to Brånemark implants can be explained taking into account that ITI implants have a supracrestal shoulder of 3 mm that reduces RF. The authors correctly remark how, if the mean value is corrected for this height, about 9 ISQ units are to be added to the measurements therefore leading to RF similar to those of the Brånemark system. To the knowledge of the present author, much less information is available on the RF of the Astra Tech system, with only one study that reported the RF of implants in grafted
maxillas at placement abutment connection and one year of loading (Thor et al, 2005).

It is evident that, contrary to the immediate loading protocol, no studies tried to evaluate the prognostic value of RF at second surgery after conventional or shortened healing periods. Conversely, it would be remarkable to check if, after a healing period, when remodelling of the interface has taken place and the effect of surgical technique faded away, RF could better reflect the bone implant integration with more reliable long-term prognostic value. These data would be of special interest when treating edentulous maxillas where success rates are less favourable than other protocol of treatment. The bone of soft quality here present might take longer to heal completely after surgery and develop an interface able to bear loads at its full. Although, medium roughness surfaces show a stronger bone response than machined surfaces (Albrektsson and Wennerberg 2004), it has to be considered that woven bone might still be present at the interface even one year after implant installation (Zaffe et al, 1997) (Trisi et al, 1999). It would therefore be relevant for the clinician to have a range of ISQ defining a level of osseointegration that warrants a long-term outcome or, on the contrary, that requires additional attention and possibly interim loading conditions for the first year of loading. In fact, it has been reported that failing implants, those that despite being still integrated are progressively losing their anchorage, can be individuated by means of RF and possibly rescued by unloading (Friberg et al, 1999b). Of course this would be possible if the RF of failing implants could be evaluated against a range of value for successfully implants. Such a range should be system specific because it has been showed that different implants systems might result with different RF just because of the differences in dimensions and anchoring of the dedicated transducer (Pattijin et al, 2006). From the literature reviewed it is apparent how the majority of the clinical studies evaluating implant stability using RF focused
on the Brånemark or ITI systems. In addition, very few studies dealt with the RF of integrated implants in the edentulous maxilla the district where failures have higher occurrence. Therefore, a further step in this research project aimed at measuring the RF of osseointegrated Brånemark implants in edentulous jaws after one year of loading. After this period the implants might be regarded in a steady state and their RF considered like a baseline value for implants that will successfully bear functional load over time. From the literature review it also appears that little information is available on the RF of AstraTech implants despite being the third system per selling. Therefore, a further step in this research project aimed at measuring the stability of AstraTech implants placed in edentulous maxillas after six months of healing and to assess their outcome after 3 years of function in order to evaluate if these measurements are of any prognostic value. In addition a further aim of this project was to use RF to monitor, during the first year of loading, the stability of AstraTech implants with a 3.5mm diameter, placed in a non-optimal implant bed, namely the maxilla with knife-edge resorption. It would be interesting in this case, to see if the stability of such implants would differ from the stability of implants placed in more favourable bone quantities and what level of stability they show after the first year of loading that is regarded as the most critic period for implant survival.

1.3. c Comparison of the outcome of different implant designs
Given the increasing number of implant macro- and micro-design available on the market, it would be useful to compare their outcome in an objective manner. It has been advocated that RF could be an outcome measure when reporting the results of different types of dental implant in clinical trials (Esposito et al, 2007). Unfortunately this is not often possible in fact a prerequisite for comparing the RF of different implant systems is that the distance of the transducer from the bone contact are equal. The stiffness measured by RF is not
only the stiffness of the bone implant interface but also the stiffness of the whole system (bone – implant – transducer) (Pattijin et al, 2006). Even though the latter are assumed to be constant, different implant connections might gave rise to different ISQ and therefore comparison of different implant systems in the clinical practice is not feasible (Pattijin et al, 2006). On the contrary the change in RF over time of different implants could be subject to comparison. Therefore, although attempted in past studies (O’Sullivan et al, 2000), the direct comparison of different systems has to be confined to experimental settings where it could be possible to standardize the distance of the transducer from the bone and the type of attachment. One field where such a direct comparison seemed feasible is the evaluation of the primary stability of orthodontic mini screws. These devices for temporary anchorage rely for their function on their primary stability, as they are not intended to osseointegrate (Melsen 2005). Nevertheless, despite their wide diffusion, their outcome in bone of soft quality has been reported to be unsatisfactory (Melsen 2005). The last part of this project aimed at evaluating the soft bone primary stability of three different mini screws after a modification that allowed their connection with an Osstell™ transducer.
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Chapter II: Importance of the transducer orientation and the shape of the ISQ graph.

II.1 Influence of transducer orientation on Osstell™ stability measurements of osseointegrated implants.

Mario Veltri, Piero Balleri, Marco Ferrari.

Introduction

Resonance frequency is a non-invasive, objective method to evaluate implant stability and it has been validated through in vitro and in vivo studies (Meredith et al, 1996) (Meredith et al, 1997a) (Meredith et al, 1997b). The technique is based on the measurement of the resonance frequency of a small piezoelectric transducer screwed to an implant or abutment (Meredith et al, 1996). The accordance between the clinical outcome of implants placed in different bone qualities (Friberg et al, 1999a) (Friberg et al, 1999b) (Bishof et al, 2004), cutting torque at surgery qualities (Friberg et al, 1999a) (Friberg et al, 1999b), Finite Element Model (Huang et al, 2002) and resonance frequency analysis suggest that this technique is a valuable help in the evaluation of implant stability qualities (Friberg et al, 1999a) (Friberg et al, 1999b) (Bishof et al, 2004) (Huang et al, 2002). The access to the technique has increased greatly since it is commercially available as the Osstell™ equipment (Integration Diagnostics AB, Gothenburg, Sweden). The Osstell™ converts the resonance frequency values into Implant Stability Quotients (ISQ) which can be directly compared.

ISQ values are increasingly taken into account when evaluating the clinical performance of dental implants. Interestingly, in an extensive review assessing
different types of dental implants (Esposito et al, 2005), Osstell™ values were regarded as a possible measure of the primary outcome of dental implants. Due to the possible increasing use of the technique, it would seem important to evaluate all the factors that might influence measurements. It was demonstrated that the distance of the transducer from bone (Meredith et al, 1996) (Meredith et al, 1997a) (Meredith et al, 1997b) and the implant stability (Meredith et al, 1996) (Meredith et al, 1997a) (Meredith et al, 1997b) (Friberg et al, 1999a) (Friberg et al, 1999b) influence resonance frequency, also the repeatability of the technique was demonstrated (Meredith et al, 1996) (Nedir et al, 2004). Furthermore, it was found that, above a modest threshold, variations in the tightening torque of the transducer do not affect the measurements significantly (Meredith et al, 1996) (Cawley et al, 1998). On the other hand, less information have been reported regarding the influence of the transducer position with respect to bony anatomy. According to Meredith and colleagues, the response of the transducer is directional (Meredith et al, 1997a) and, therefore, it could be anticipated that, due to bone anatomy, different ISQ are to be obtained in different directions. In a rabbit model it was found that more sensible measures of bone quality changes at the implant interface were obtained if the transducer was placed perpendicular to the rabbit tibia (Meredith et al, 1997a). Accordingly, the Osstell™ manufacturer recommends that the transducer is positioned perpendicular to the jaw with the cable in a buccal direction. However, no studies evaluated the influence of the transducer orientation when measuring the ISQ in human edentulous jaws using the Osstell™ apparatus. Aim of this study was to evaluate to what extent different orientation of the transducer would influence the ISQ of Brånemark System® implants (Nobel Biocare AB, Gothenburg, Sweden) placed in fully edentulous maxillae and that reached the steady-state. A second aim was to find out if ISQ obtained with any particular transducer position would best relate with bone levels.
Materials and methods

Patients

Nine patients, 7 females and 2 males (mean age 63 years, range 46-68), edentulous in the upper jaw were included in the study. They had received a total of 55 implants (Brånemark System®) supporting fixed cantilevered bridges. The patients had their prostheses in function for 3 years before the present study.

Implant stability measurement

All the bridgeworks were removed and implants checked manually for mobility. Resonance frequency was then measured using the Osstell™ equipment. Transducers were hand-screwed to the abutments and care was taken to avoid soft tissue contact. Abutments lengths were inserted in the Osstell™ which automatically compensate for these. Whenever the graph associated with the ISQ measure showed flat or double peaks, screw tightening was checked and the measure repeated. For each implant four measurements were made, each one with a different transducer position as shown in figure1. The first measure (B) was taken with the transducer perpendicular to the bone crest and the cantilever beam placed buccally. The second measure (D) was taken with the transducer parallel to the bone crest and the cantilever in a distal position. The third (P) was taken with the transducer perpendicular to the crest and the cantilever placed palatally. The fourth (M) was taken with the transducer parallel to the crest and the cantilever oriented mesially. All the ISQ values were then transferred to an electronic spreadsheet.
Radiographic examination
Intra-oral radiographs were taken using a parallel technique with the bridgework in place. Radiographs were thereafter digitized and analyzed using ImageJ a freeware software (NIH, USA http://rsb.info.nih.gov/ij/). Bone levels were obtained by measuring the vertical distance of the implant/abutment connection from the bone contact. Measurements, taken to the closest 0.5 mm, were made on the distal and mesial side of each implant and then a mean value was calculated.

Statistical analysis
Non-parametric Kruskal-Wallis test and post hoc Tukey test were used to identify statistically significant differences between the ISQ values obtained with different transducer positions (B, D, P, M). In addition a correlation between bone levels and the different ISQ (B, D, P, M) was evaluated using a Spearman’s test. Statistical significance was set at .05.
Results

All the implants were clinically stable and free from symptoms. Mean ISQ values for the four different transducer orientations are reported on figure 2. A significant difference (H=85.9, P<0.05) resulted and paired comparisons revealed significant differences between the measurements made perpendicular to the bony crest (B, P) and the parallel ones (M, D). The mean bone level was 1.5 mm (S.D. 0.6 mm) from the reference point. The frequency distribution of the bone levels measured is illustrated in figure 3. A slightly negative correlation was found when plotting bone levels and the ISQ values measured along the different directions, however for none of the positions this correlation was statistically significant (P>0.05).

Fig. 2: Mean ISQ values for the different transducer orientations (n=55 H=83.9 P<0.05). Paired comparison:

- M versus B (Q=13.4) P<0.05
- M versus P (Q=10.4) P<0.05
- M versus D (Q=0.65) P>0.05
- D versus B (Q=12.8) P<0.05
- D versus P (Q=9.8) P<0.05
- P versus B (Q=3) P>0.05
Discussion

The present results, as expected and in accordance with previous observations (Meredith et al, 1997a), show that the resonance frequency, measured using the Osstell™ equipment, is influenced by transducer position. Significant differences resulted when the transducer cantilever was oriented perpendicular or parallel to the bony crest. Conversely, no difference was seen when rotating the cantilever along the same axis, in fact no significance resulted between the bucco-palatal positions and between the mesio-distal ones. According to the present results, when measuring the resonance frequency perpendicular to the bony crest ISQ values may be up to 8 to 10 units lower compared to parallel orientations. Nevertheless, irrespective of transducer orientation, the mean stability values for each group were consistent with the range of ISQ levels already presented as descriptive of osseointegrated implants (Balleri et al,
However in order to monitoring the stability of an implant over time correctly, it seems important that the same transducer orientation is kept during the different measurements. A second implication of present data is that a standardized transducer orientation is advisable whenever the Osstell™ is used to report the outcome of different implant systems.

A second finding of the study was the lack of correlation between ISQ values and bone levels. According to previous in vitro and in vivo studies, a strong negative correlation exists between ISQ and bone levels (Meredith et al, 1997a) (Meredith et al, 1997b), in fact greater distances of the transducer from the bone significantly lower the ISQ values. This was not the case in the present study and similarly, Balleri and colleagues (Balleri et al, 2002) reported of no significant correlation when measuring the ISQ values of maxillary and mandibular implants after one year of loading. In the same way, Bischof and colleagues (Bishof et al, 2004) did not find any difference when comparing the ISQ of ITI implants placed 1 mm deeper into bone due to aesthetic considerations and implants placed in normal relation to the bony crest. Interestingly, for implants placed in gypsum blocks, Huang and colleagues (Huang et al, 2002) reported the same lack of correlation between resonance frequencies and boundary heights when the height of the gypsum was less than 3 mm from the neck of the implant. In contrast, a strong correlation was found if boundary height was more the 3 mm, it was therefore concluded that resonance frequency becomes more sensible to bone losses when those exceed 3 mm. However, it has to be pointed out that in Huang’s study (Huang et al, 2002) resonance frequency was measured using a transient method which is slightly different from the static method applied in the Osstell™. When considering previous in vivo data by Meredith and colleagues regarding the static method (Meredith et al, 1997a), a correlation resulted between resonance frequency and bone levels, however the exposed implant lengths were higher
than in the present study. In fact the experimental equipment for resonance frequency analysis could not compensate for abutment length and, as a consequence, the resonance frequency values were plotted versus exposed implant lengths that included abutment heights. In another in vitro study by Meredith and colleagues (Meredith et al., 1996), the resonance frequency of implants embedded in metallic blocks and luted with resin was measured. Implants were exposed for 5, 4, 3, 2, 1 mm or were completely embedded and, although some scatter of the data was noted for 0 and 1 mm levels, a strong correlation resulted between resonance frequency and exposed implant length. Even though these results seem controversial, a possible explanation for the lack of correlation resulted between resonance frequency and bone levels of the present study could be due to the fact that the distance of the first bone contact from the transducer was minimal. This explanation seems to be supported by the present data where the majority of the implants had similar bone levels (in the range of 1.5 or 2 mm below the implant\abutment connection) and no great variation in bone levels resulted. In fact, it has to be considered the possibility that a high stiffness of the bone implant interface could overshadow the influences of small bone losses eventually occurred at implants. On the other hand Sennerby and colleagues (Sennerby et al., 2005) showed in an animal model that resonance frequency was sensitive to detect changes in stability due to the initiation and resolution of an experimental peri-implantitis. In that study resonance frequency values appeared to be linearly related to continuous bone resorption as measured radiographically. Contrary to Sennerby’s investigation (Sennerby et al., 2005), in the present study resonance frequency was measured only once, therefore it is likely that repeated measurements would have been significantly related to the bone losses eventually occurred. In conclusion, when measuring the resonance frequency of dental implants using the Osstell™ it has to be taken into account that the transducer orientation
influences the measure. It seems therefore advisable to standardize the orientation. Also to be considered is that, according to the present data, there is no transducer orientation that gives ISQ values that best relate with minimal bone resorptions.
References


II.2 Damping factor for monitoring the bone interface at dental implants.

Veltri M, Balleri P, Ferrari M. Clinical Oral Implants Research 18, 2007; 738–742

Introduction

Vibration analysis has been applied for non invasive evaluation of the bone interface at osseointegrated dental implants (Meredith 1998). This kind of test is based on the analysis of two parameters: Resonance Frequency (RF) and Damping. Even though several methods, which are slightly different from a technical and theoretical point of view, have been used for the vibration analysis of dental implants (Meredith 1998), the most common one is a steady state method proposed by Meredith (Meredith et al, 1996). This method of analysis is commercially available as the Osstell™ equipment.

The functioning of the machine is based on the excitation of the implant over a range of frequency of interest and at the same time, the amplitude of the response is recorded. The whole operation is executed by piezoelectric transducers screwed to the implant. At the end of the excitation a frequency/response plot is obtained. Resonance frequency is then identified as the frequency where the maximum amplitude of the response is registered (Dimarogonas 1996). The Osstell™ transforms automatically the RF into Implant Stability Quotients (ISQ) which range from 1 to 100 with higher values indicating better implant stability. The clinical meaning of the RF was extensively studied and it was found to be related to the stiffness of the bone implant interface and to the distance of the transducer from the first bone contact (Meredith et al, 1996). On the other hand, Damping, which is related to the width of the frequency/amplitude plot, was not considered in the previous studies regarding RF of dental implants and is not taken into account by the Osstell™ in the elaboration of the ISQ value. However, recently it was found
that damping was related to chemically induced changes in the porosity and density of excised animal bone (Panteliou et al, 2004). In addition, Meredith (Meredith 1997) suggested that the damping of bone would be influenced by factors including the mineral content, the number of trabeculae, and the bone density. Damping would therefore be a more precise measure of the quality of the bone implant interface and it could in theory be applied in clinical settings to estimate the biomechanical competence of bone (Panteliou et al, 2004).

Aim of the study is therefore to investigate if the damping of osseointegrated implants, as measured with the Osstell™, would relate with the fractal dimension of peri-implant bone. Fractal analysis, which appears to be in some measure insensitive to variations in film exposure and orientation (Shrout et al, 1997), has been previously used as a simple descriptor of the complex architecture of the cancellous bone (Geraets & van der Stelt 2000) and therefore it is supposed that the damping would relate to the architecture of the implant interface as measured by the fractal dimension.

Materials and methods

Patients

Nine patients, 7 females and 2 males (mean age 63 years, range 46-68), edentulous in the upper jaw were included in the study. They had received a total of 55 implants (Brånemark System® Nobel Biocare AB, Gothenburg, Sweden) supporting fixed cantilevered bridges. The patients had their prostheses in function for 3 years before the present study.

Damping measurement

All the bridgeworks were removed and implants checked manually for mobility. Resonance Frequency was then measured using the Osstell™ equipment (Integration Diagnostic, Savedalen, Sweden). Transducers were hand-screwed to the abutments and care was taken to avoid soft tissue contact.
Abutments lengths were inserted in the Osstell™ which automatically compensate for these. Whenever the graph associated with the ISQ showed flat or double peaks, screw tightening was checked and the measure repeated. Because it was found that the transducer response is directional (Meredith et al., 1997) for each implant two measurements were made. The first measure was taken with the transducer perpendicular to the bone crest and the cantilever beam placed buccally. The second was taken with the transducer parallel to the bone crest and the cantilever in a distal position. All the ISQ values were then transferred to a computer equipped with the Osstell™ Data Manager (version 3) (Integration Diagnostic, Savedalen, Sweden). Using this software measurements were converted to a spreadsheet containing all excitation frequency values and the associated amplitude responses. The half-power bandwidth method (fig. 1) was applied to calculate the damping for all the measurements. This method is based on the measurement of the width of the amplitude response around the resonance peak (Dimarogonas 1996) and, accordingly the damping can be defined as the bandwidth divided by the resonance frequency:

\[ D = \frac{(f_2 - f_1)}{2f_r} \]

where the bandwidth is the difference between the frequencies \( f_1 \) and \( f_2 \) at which the amplitude is 0.707 times the amplitude at the resonance frequency \( f_r \).

Unfortunately, for many measurements it was not possible to locate one of the two half-power points because of the limited resolution of the amplitude response. In order to overcome the problem encountered, it was decided to take the frequencies \( f_1 \) and \( f_2 \) where the amplitude response was 0.85 of the amplitude at resonance frequency.
Fractal analysis

Intra-oral radiographs (Ultra-Speed, Kodak, Rochester, NY) were taken using a parallel technique with the bridgework in place. The machine (096 Belray, Takara Belmont, Osaka, Japan) settings were 70 kVp and 10mA. Radiographs were processed using ImageJ a freeware software (ImageJ, USA http://rsb.info.nih.gov/ij/) and according to a method, here only briefly described, presented by White & Rudolph (White and Rudolph 1999). First of all radiographs were scanned at 600dpi (Nikon Coolscan, Tokyo, Japan) (fig. 2a) and two regions of interest (ROI) were selected mesially and distally to each implant. ROI were positioned in close contact with the implant threads and were 47x47 pixels large (fig. 2b). The bottom side of the ROI was placed so that it contacted the cortical border. Whenever the dimension of the ROI exceeded the available space near the implant, that site was excluded from the analysis. In order to remove large brightness variations from the image a
filtering procedure was applied. First a Gaussian filter was applied (sigma=35 pixels, kernel size=33x33) (Semmlow 2004) so that fine and medium structures were eliminated and only large variation in density remained (low pass filtering) (fig. 2c). The resulting blurred image was then subtracted from the original and 128 was added to the resulting image at each pixel location (fig. 2d). The image was then transformed in a binary one so that the segmented object approximated the bone trabecular pattern. After that, erosion and dilation of the image were performed once to reduce noise. The last step was to invert and then skeletonize the image so that only the central line of pixel remained (fig. 2e).

Fractal dimension calculation

The fractal dimension of the processed ROI was calculated using the Box Counting algorithm featured in ImageJ. In essence, several grids of decreasing caliber (box size) are placed over an image and the number of boxes that contain pixels is counted for each grid. Data are gathered for each box of every grid. The fractal dimension is the slope of the regression line for the log-log plot of box size and the number of grid boxes that contained pixels. Because for each of the two implant side (mesial and distal) a fractal dimension resulted, a mean value was calculated. In cases where only the ROI of one implant side was available, its fractal dimension was calculated and the result was assumed as the mean value.

Statistical analysis

Using a non parametric Spearman test a correlation was searched between fractal dimensions and damping values obtained along both axes. Significance was set to .05.
Fig 2. A: digitized image. B: region of interest of peri-implant bone (ROI). C: blurring of ROI. D: Result of subtracting Fig c from the square ROI showed in b. E: skeletonized image of the trabecular pattern obtained from d, on this image Fractal dimension was calculated. F: Superimposition of image e on the ROI to visually demonstrate the good correspondence between the original trabeculae and the skeletonized image.
Results

All the implants were clinically stable and free from symptoms. The mean ISQ was 63 for the palatal orientation and 71 for the distal orientation. 3 implants were excluded from the study because it was not possible to position the ROI due to a reduced inter-implant distance. Another 4 implants were excluded because it was still not possible to locate both the half-power points even at 0.85 of the peak amplitude. Therefore it was possible to include in the study 48 implants only. The mean fractal dimension was 1.47 SD 0.1, the mean damping value for palatal orientation was 12.3% SD 5.4 while for the distal orientation was 8.2% SD 5.9. No significant correlation resulted (figs. 4 and 5).

Fig 3: Mean fractal dimensions plotted against Damping values obtained with the transducer positioned palatally (P>0.05).

Fig 4: Mean fractal dimensions plotted against Damping values obtained with the transducer positioned distally (P>0.05).
Discussion
In the present study damping values, measured at peri-implant bone, were found not to be related with a radiographic parameter of trabecular bone pattern like the fractal dimension. In addition, without the presence of an outlying point in the data (figs. 3 and 4) an even smaller correlation would have resulted. This finding was somewhat unexpected and contrary to what supposed. Infact, although to the authors knowledge damping was never investigated as an indicator of the quality of the interface at dental implants, it has shown to be a promising method to evaluate bone quality and changes related to osteoporosis, at least in an in vitro setting. Moreover, considering that the response of the transducer is directional and changes with transducer orientation (Meredith et al, 1996) (Pattijn et al, 2006a), it was expected to find a correlation between the damping obtained with the transducer oriented parallel to the crest and the fractal dimension of the peri-implant bone. In fact, under these conditions, the analyzed x-rays depict the trabecular pattern that lies on the same plane of the direction of vibration of the transducer. Conversely, the lack of correlation here observed could be due to the fact that the dampening effect of soft tissues affects the measurement significantly, infact ideally soft tissues should be removed to correctly measure the damping (Panteliou et al, 2004), obviously this was not done in the present study for ethical reasons. Also to be considered to explain the lack of correlation is the fact that the measurements here obtained had a limited resolution in the amplitude response and this fact precluded the application of the half power bandwidth to calculate the damping. Indeed it is obvious that the damping here measured was approximated because of the change in the calculating method, nevertheless some kind of estimation of it was obtained. In effect, as the calculating protocol was kept standardized for all the measurements, the above seemed not to limit the general validity of the final results. A further consideration explicating the absence of association resulted,
is that damping values are more difficult to measure accurately than the RF (Meredith 1997) and it might be the case that the equipment is not accurate enough and that extraneous damping is introduced. Interestingly, the ISQ value, unit of measurement of the Osstellt™ system, is only based on the RF value while the damping is not taken into account. The clinical implication of the present study would be that the shape of the frequency/amplitude plot, shown on the Osstellt™ screen along with the ISQ value, seems not to be related with the trabecular pattern of the peri-implant bone. Different authors showed dissimilar results regarding the shape of the plot, according to some (Meredith 1998) (Rasmusson et al, 1999) a single sharp peak indicated stable implants, conversely others found that sharp peaks were exhibited by mobile implants as well (Nedir et al, 2004). However it has to be considered that, according to the manufacturer, when measuring on clinically mobile implants a measurement can result in a distinct peak but the ISQ can not be considered reliable. The evaluation of the sharpness of the peak allows a subjective determination of the level of damping: the more rounded the shape the more damping is present in the structure. Because it was shown experimentally that the amount of damping increases with decreasing bone quality and greater porosity (Panteliou et al, 2004), it would seem correct to state that stable implants exhibit sharp peaks. Yet, on the basis of the more quantitative data here presented, it seems that graphs displaying distinct or more rounded peaks might both indicate a stable implant as long as the associated ISQ values are in a range of satisfactory values proposed in previous publications (Glauser et al, 2004) (Balleri et al, 2002). Noticeably, when considering the lack of correlation found it has to be pointed out that others factors like bone resorptions, thickness and density of the marginal cortex have not been taken into account in the present investigation. As a result it cannot be excluded that these factors may be of influence on the damping as measurable using the Osstellt™.
One last consideration has to be spent regarding the radiographic technique of analysis chosen to evaluate the trabecular appearance of peri-implant bone and its possible drawbacks for the present study aim. It is important to consider that, due to difficulty to visualize the whole implant length on intraoral x-rays, the chosen size of the ROIs does not represent the entire length of the bone implant interface whereas RFA more likely does, nevertheless this seems to be only a minor limitation. In fact it was previously demonstrated in laboratory and Finite Element Analysis studies (Meredith et al, 1996) (Pattijn et al, 2006B), that, given a good fixation of an implant, as the osseointegrated implants here investigated may supposed to show, an increase of the implant length embedded in the bone does not affects RF significantly. In other words, given a stiff interface, it seems that resonance frequency is not affected by the implant length inside bone, as a consequence it could be supposed that also a shorter ROI would well correlate with the vibration response. Fractal analysis has been used to measure bone morphology both in maxillofacial and general radiology (Geraets & van der Stelt 2000). Several methods have been used for fractal calculation and although it has been reported that they might not be directly comparable, nevertheless they are suitable for trabecular pattern quantification (Geraets & van der Stelt 2000). For sure this technique is particularly attractive because no dedicated equipment is required. In only one previous investigation fractal analysis was used to study bone changes at mandibular implant (Wilding et al, 1995). In that study fractal dimension was found to increase with trabecular remodelling occurring up to two years after implantation and slightly different fractal dimension resulted compared to the present data. This difference is probably explained because this investigation included only maxillary implants that are surrounded by a looser trabecular pattern. In the present study, using digital elaboration and fractal analysis it was possible to visualize and measure the trabecular pattern at dental implants, we therefore
suggest that fractal analysis could be useful in the evaluation of the peri-implant bone conditions. In addition, it would be interesting to investigate if during the implant treatment planning fractal analysis would be useful to describe bone quality on preoperative x rays better than the naked eye of the operator.

In conclusion, as elsewhere already pointed out, it seems that the Osstell™ measures the general stiffness of the bone implant interface rather than its complex anatomy (Nedir et al, 2004) and even if the technique has proven to be useful in the clinical monitoring of dental implants (Rasmusson et al, 1999) (Nedir et al, 2004) (Glauser et al, 2004) (Balleri et al, 2002) (Meredith et al, 1997) (Friberg et al, 1999a) (Friberg et al, 1999b), more studies are necessary to develop a non invasive method able to assess the biomechanical competence of the bone at the implant surface.
References


Chapter III: Clinical significance of resonance frequency in the rehabilitation of completely edentulous maxillas

III.1 Resonance frequency measurements of osseointegrated implants in fully edentulous patients after one year of loading.
Veltri M, Cagidiaco MC, Ferrari M, Balleri P.
International Dentistry South Africa. 2006; 8: 30-35.

Introduction
The long-term success rate of implant supported fixed prostheses has been documented by a number of studies (Adell et al, 1990) (Brånemark et al, 1997) (Zarb et al, 1990) (Ekelund et al, 2003). On the other hand, failures still occur in a percentage that has been estimated to be 7.7% for machined Brånemark implants which have the most extensive amount of epidemiologic data. According to Esposito (Esposito et al, 1998), late implant failures are mainly due to reduced bone volume, deficient bone quality and overload. This seems crucial for distal implants that have to bear heavy loads and have in general reduced length due to insufficient quantity of available bone and presence of anatomical landmarks. Biomechanical investigations warned of higher compressive load and bending moments born by the implants adjacent to the cantilever extension (Dujck et al, 2000). Accordingly a high failure rate was historically described for short implants (Moy et al, 1992) especially when placed in maxillary bone where Jemt reported a high failure rate for 7 mm implants after 5 years (Jemt and Lekholm 1995). However, with improvements in surgical protocols and the possibility of optimizing stability also in bone of reduced volume and soft quality, the use of shorter implants increased in predictability. Many studies (Friberg et al, 2000) (Fugazzotto et al, 2004)
(Renouard and Nisand 2005) suggested that the placement of short implants might be as predictable as that of longer ones thus avoiding, in most cases, the need of advanced surgical techniques. Together with improved surgical techniques, clinicians have the possibility to monitor the stability of implants that are placed in bone of reduced quality and quantity or in situations suspected to be at higher risk of failure due to inappropriate loading. In fact, while in the past it was difficult to detect early loss of osseointegration, the advent of Resonance Frequency Analysis and the Osstell™ equipment may help clinicians to assess implant stability in a more reliable manner (Meredith et al, 1997). Using this technique, Friberg, by successively measuring resonance frequency of mandibular implants, described the possibility to detect implant loss of stability before any clinical evidence of failure (Friberg et al, 1999a). He also reported the possibility to avoid failure of implants that during the healing phase carried uncontrolled loading from a removable denture (Friberg et al, 1999a). After unloading, those implants showed an increase of stability so that it was possible to deliver a fixed prosthesis to the patient. Monitoring implant stability during the first year of loading might help the clinician to evaluate if the implant has reached and maintains a safe fixation into bone by comparison with either measurements of the same implant taken at previous follow-up or normal stability values from the literature. The primary aim of the this retrospective study was to measure the stability of implants supporting fixed prostheses in edentulous jaws after one year of loading and evaluate differences with stability values already presented for implants in partially edentulous jaws (Balleri et al, 2002). A second aim of the study was to investigate differences in implant stability between those adjacent to cantilever distal fixtures and their medial counterparts. Correlations between
bone loss around threads and implant stability, and between implant stability and implant length, were also sought.

**Materials and methods**

**Patients**

This study included 12 consecutive edentulous patients (3 men and 9 women, mean age 66.2, ranging from 56 to 74) fully edentulous in one dental arch. All the patients were in good general health and four of them were smokers of less than 8 cigarettes a day. A total of 69 implants (Brånemark System, Nobel Biocare AB, Gothenburg, Sweden) had been placed. Length, diameter and position of the implants are summarized in Table 1.

All the surgery was performed by one surgeon (P.B.) in accordance with a standard two stage surgical technique (Lekholm 1985). All maxillary posterior osteotomies were adapted to the soft bone density by reducing the final diameter of the site compared to the diameter of the implant, this technique is reported to allow a maximization of implant stability even in soft bone (Friberg et al, 2002). According to the case records the surgeon reported a good primary stability for all the implants, although no ISQ values were recorded. Abutment connection was performed after a minimum of 3 month 6 month respectively for mandibles and maxillas, and then fixed metal-acrylic resin Brånemark-type prosthesis were delivered. The mean length of the cantilever distal to the last implant was 10,8 mm.

**Implant stability measurement**

After one year of loading prostheses were removed to gain access to the implants and to measure resonance frequencies using the Osstell™ (Integration Diagnostic, Savedalen, Sweden). Transducers were positioned perpendicular to
the bony crest so that the output cable was in a buccal direction. Data were collected in a PC using a dedicated software (Osstell™ Data Manager, Integration Diagnostic). Due to the difference in bone density two separate groups were made for implants placed in the maxillary and mandibular arches. Implants were then further divided into three groups according to their position: distal, medial and mesial (Tab.2). In case of a bridge supported by six implants, distal implants were adjacent to cantilevers, mesial implants the most anterior and medial implants in between the two other groups. If an odd number of fixtures was present, implants were divided so that the odd one was included in the mesial group (Fig.1). A mean ISQ value was calculated for each group.

**Radiographic examination**

Using a paralleling technique intraoral radiographs, were taken at abutment connection to check the fit of the framework, and then at the time of resonance frequency measurement one year later. Radiographs were digitized and analyzed using ImageJ, a freeware software (NIH, USA http://rsb.info.nih.gov/ij/). Crestal bone levels were measured as the vertical distance of the implant/abutment connection from the bone contact. Measurements were made at the distal and mesial side of each implant and a mean value per implant was then calculated.

**Statistical analysis**

A Mann-Whitney test was used to evaluate differences in the ISQ values of fixtures in the upper and lower jaw. A Kruskal-Wallis test was used to identify significant differences in stability between the distal, mesial and medial groups due to implant position.

Correlations between implant length versus their stability and between implant stability versus crestal bone loss were ascertained using a Spearman’s rank test was used for correlation analyses.
<table>
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<th>Implant Length</th>
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<th>Mandible</th>
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<td>Patient</td>
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<td>6 7 8 9 10 11 12</td>
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Table 1: Length (mm) of placed implants. All the implants had a 4mm diameter unless differently specified.

<table>
<thead>
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<th>Length</th>
<th>Maxilla</th>
<th>Mandible</th>
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<tbody>
<tr>
<td></td>
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<td>Medial</td>
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<tr>
<td>7</td>
<td>6 6 3</td>
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<tr>
<td>8.5</td>
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<tr>
<td>18</td>
<td>4 4</td>
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</tbody>
</table>

Table 2: Lengths (mm) and positions of placed implants.
FIG 1: Implant grouping according to their position: ● distal implants, * medial implants, ○ mesial implants.

Results

All the implants were clinically stable and asymptomatic. The mean ISQ value after one year of loading was 72.84 ISQ SD 8.28 (range 53 to 94). A statistical difference was found between mean maxillary and mandibular ISQ values (respectively 67.6 ±7.9 and 76.6 ±6.1; Zt= 4.8 P=0) (Figs.2 and 3).

When dividing maxillary implants according to their position the resulting mean ISQ values for each group are shown in figure 4. No statistical differences resulted between distal fixtures adjacent to the cantilevers and their medial counterparts (H=0.019, P=0.977). Mandibular mean values of the three groups are shown in figure 5, no statistical significant differences were found (H=0.111, P=0.987).

No correlation resulted between the length of the implants and their stability (r_s= -0.17, P=0.150) (Fig.6).

A mean bone loss of 0.3 ±0.5mm (range 0 to 1.5mm) resulted from the x-rays taken at abutment connection and resonance frequency measurement but no correlations resulted between bone loss and implant stability (r_s=-0.140 P=0.231) (Fig.7).
FIG. 2 Mean ISQ for mandibular and maxillary implants, mandibular implants were the most stable (P<0.05).

FIG. 3 ISQ levels after one year of loading for each of the implants studied.

FIG. 4 Mean ISQ of maxillary implants placed in the different positions, no significant differences were seen.
FIG. 5 Mean ISQ of mandibular implants placed in the different positions, no significant differences were seen.

FIG. 6 ISQ values plotted against implant lengths, no significant correlation resulted.

FIG. 7 ISQ values plotted against marginal bone loss, no significant correlation resulted.
Discussion

Mean mandibular and maxillary ISQ values found in this study are similar to those of osseointegrated machined implants in partially edentulous jaws published in a previous study (Balleri et al, 2002) where the stability of successfully integrated Brånemark machined implants ranged from 57 to 82 ISQ with a mean of 69 ISQ. The present data showed greater stability of implants in the mandible than in the maxilla, probably because of differences in bone density. This finding is in accordance with previous studies regarding partial edentoulisms where mandibular implants reached higher stability values (Balleri et al, 2002) (Bishof et al, 2004).

The possibility of monitoring implant stability using Resonance Frequency was applied in the present study to verify if heavy loads carried by implants adjacent to cantilevers would cause harmful effects detectable by the Osstell™. Biomechanical investigation demonstrates that distal implants connected to fixed full prostheses take large compressive loads and bending moments that might reach twice the applied load due to the cantilever effect (Dujek et al, 2000), in addition epidemiological data seem to suggest that overloads might be a possible cause of implant late failures (Esposito el al, 1998). However, no clear evidences of the stresses that cause bone change, either resorption or remodelling, are present in the literature and consequently the precise mechanism for loss of integration is still unclear. As shown in figures 4 and 5, no differences in ISQ values were found between distal implants and the most anterior ones. ISQ values of all the implants adjacent to cantilevers were similar to their medial counterparts, therefore demonstrating that the increased load they bear might not be a clinical disadvantage. However, when considering the present data, it has to be taken into account that ISQ values at implant placement were not recorded, since Osstell™ was not yet available at the time. Therefore it is possible that variations in implant stability due to loading have
not been detected. Nevertheless, the positive outcome of the implants closer to cantilevers was not unexpected considering well documented reports on fixed full arch rehabilitations supported by only four implants in the maxilla and three in the mandible, that show high implant survival rates despite the reduced support (Brånemark et al, 1995) (Brånemark et al, 1999). A full understanding of the biomechanical capacity of these rehabilitations has not yet been developed because of the difficulty in quantifying bone healing, mineralization and turnover at the implant interface (Brunski et al, 2000) (Skalak 1985). However, despite this lack of biomechanical data, the clinical effectiveness of implant supported cantilevered prostheses cannot be minimized.

Also to be considered is the absence of any correlation between implant length and stability. This finding agrees with other studies that suggested the effectiveness of short implants in supporting fixed prostheses when small bone volumes are present and anatomic landmarks are to be avoided (Friberg et al, 2000) (Fugazzotto et al, 2004) (Renouard and Nisand 2005). Short implants might be regarded as a viable alternative to more complicated grafting techniques that, although well accepted, increase morbidity, cost and duration of the implant treatment. On the other hand, it also must be considered that advanced surgeries might restore lost bone volumes and be advantageous in terms of superior appearance and function of the final prosthetic result.

Further speculations on the present results could be made on the basis of table 2 where it is shown that many 10mm implants were placed in maxillary posterior soft bone areas, yet they all reached ISQ values over 60. This phenomenon was well explained by Friberg who showed that, when using an adapted surgical technique and prolonged healing time, implants placed in soft bone achieve the same stability as those placed in denser bone. Bone density changes due to healing and loading are likely to be the reason for this increase in stability (Friberg et al, 1999a) (Friberg et al, 1999b).
The last observation regards the clinical insignificance of minor bone losses on implant stability. Unfortunately, because ISQ values at the time of surgery where not recorded in the present study it is not possible to say if the stability of the implants studied was eventually influenced by minor bone losses resulted.

Finally, it has to be clearly pointed out that although prognostic rates of various ISQ intervals were reported for machined Brånemark and ITI-SLA implants (Glauser et al, 2004) (Nedir et al, 2004), the ISQ value measures the rigidity of the implant bone interface at the moment of the registration. Unfortunately, to date, it is still not possible to give a reliable prognostic long term judgement of the osseointegration reached based on ISQ values. In fact formation of new bone and its remodelling might continue over the whole first year of implant function and therefore changes in the stiffness of the bone implant interface do occur during this period (Friberg et al, 1999a) (Friberg et al, 1999b). Nevertheless, monitoring implant stability during the first year of loading might be useful to assess the maintenance of implant stability during peri-implant bone remodelling and appraise how the implant performs under loading. Availability of base line measurements, although of no prognostic value, might help the clinician to evaluate if the implant has reached and maintains a safe stability.

In conclusion, a clinical trend of an ISQ of more than 69 with a range of 57 to 82, as probably descriptive of osseointegrated implants, was observed in this study. In addition, this study seems to suggest that, in fully edentulous jaws, the stability of distal implants is not affected by the higher compressive loads they bear in comparison to their anterior counterparts, at least as detectable using resonance frequency. Further investigation is needed to establish the ISQ threshold each implant has to reach in a given bone site to successfully bear functional load.
References


III.2 Stability values of titanium dioxide-blasted dental implants in edentulous maxillas: a three-year pilot-study.

Veltri M, Ferrari M, Balleri P.

Accepted for publication in the International Journal of Oral and Maxillofacial Surgery

Introduction

Resonance frequency has been introduced as a quantitative measure of implant stability (Meredith et al, 1996) and extensively adopted in clinical research (Aparicio et al, 2006). The technique has been reported to be useful at implant placement to quantify the degree of primary stability reached (Östman et al, 2005). Moreover, during the implant functioning life, a decrease in resonance frequency might indicate to the clinician implants that are losing their integration and in need of some rescue procedure to avoid their failure (Friberg et al, 1999a).

However, in a recent literature review, the current clinical utility of resonance frequency at placement was doubted (Aparicio et al, 2006). In fact, although some authors suggested a normative implant stability quotient (ISQ) threshold that would allow sufficient primary stability for successful immediate loading (Sennerby and Meredith 2001), its validation has not been presented yet. For instance, some studies showed failures of immediately loaded Brânemark implants despite the high primary stability reached at placement (Glauser et al, 2004) (Schincaglia et al, 2007). Conversely, other investigators could distinguish (Nedir et al, 2004) a threshold value at placement considered predictive for the osseointegration of ITI implants. However, it has to be considered that the different results of the above studies and the consequent scarce prognostic value attributed to the ISQ at placement (Aparicio et al, 2006), might be partly due to the possibility of modulating primary stability. In
fact, Östman and coworkers were able to achieve a high primary stability in all the jaw bone regions by using an adapted surgical technique (Östman et al, 2005). The placement technique could therefore overshadow the measurable contribution to primary stability given by bone quality, which is nonetheless of paramount importance for implant prognosis (Esposito et al, 1998). It can be speculated that at second surgery, when remodeling of the interface has taken place, RF could better reflect the bone implant integration with more reliable long-term prognostic value. Unfortunately, few studies described implant stability in the long-term using resonance frequency. Sjöström et al were the only to use resonance frequency for a three-year follow-up on Brånemark implants in grafted maxillae (Sjöström et al, 2007). Despite successful and failing implants had significantly different ISQ at placement, it was recognized that the possibility to identify a failing implant from its placement ISQ value is limited. Additionally, so far, the majority of the clinical studies evaluating implant stability employing resonance frequency focused on the Brånemark system (Balleri et al, 2002) (Friberg et al, 1999a) (Friberg et al, 1999b) (Glauser et al, 2004) (Hallman et al, 2005) (Meredith et al, 1996) (Östman et al, 2005) (Schincaglia et al, 2007) (Sjöström et al, 2005) (Sjöström et al, 2007) or ITI implants (Huwiler et al, 2007) (Nedir et al, 2004). Unfortunately, such information should not be extrapolated to other systems because of differences in implant design and anchoring of the transducers which may affect resonance frequency (Pattijn et al, 2006).

Also questioned was the utility of resonance frequency to individuate failing implants before any evident clinical sign (Aparicio et al, 2006). Glauser et al. evaluated the development of implant stability of 81 immediately loaded Brånemark implants (Glauser et al, 2004). Nine implants failed in that study but a drop in resonance frequency before a clinically evident failure was only shown for 7 of the failed implants. In addition, when measuring the stability of
ITI implants in the early phases of healing Huwiler et al. observed how the clinical failure of an implant was coincident with a decrease of the ISQ values (Huwiler et al, 2007), but not anticipated.

The purpose of the present follow-up study was to measure the resonance frequency of Astra Tech implants during the late healing phase and up to three years of loading. A second purpose was then to investigate if resonance frequency at second surgery could discriminate between successful implants and implants that will fail over a three-year loading period. The investigated implants were placed in edentulous maxillas which is the district where failures have been described to be more frequent due to reduced bone volumes and low bone quality often found (Esposito et al, 1998).

**Materials and methods**

*Patients and surgery:* Eight consecutive patients, 5 females and 3 males, (mean age 56 years, range 46 - 64) participated to the present study. The patients were edentulous in their upper jaws and were scheduled for fixed implant supported restorations. Two patients, who were completely edentulous, had a fixed implant supported restoration in the lower jaw, the remaining patients had partially dentate mandibles. All the treatments were carried out in the period January - December 2003. Preoperative x-rays showed a class II or III of Cawood & Howell (Cawood & Howell 1988) for all the patients. A total of 51 TiO₂ blasted implants were placed (MicroThread, Astra Tech, Mölndal, Sweden) according to a two stage protocol. Six implants had a 3.5mm diameter while the remaining 45 had a 4mm diameter. Each patient received the longest implants possible according to the available space. Site preparation was adapted aiming at the best possible primary stability. All the operations were executed by one surgeon. Sutures were removed 15 days after surgery and healing was uneventful for all the patients.
Prosthetic procedures: Existing patient dentures were relined with a soft material (Viscogel, Dentsply, York, PA) during the healing period. After 6 months of healing all the patients had second surgery performed and abutment connected (UniAbutment 20°, Astra Tech, Mölndal, Sweden). All the patients were rehabilitated with fixed metal acrylic prostheses using conventional prosthetic procedures.

Follow-up: The patients were followed-up for three years after loading and no drop outs occurred. Follow-up visits were scheduled for all the patients at one and three years of loading intervals. On these occasions prostheses were removed to individually verify implant stability.

Implant stability measurement: Resonance frequency of the implants was measured at abutment surgery. The Osstell™ equipment (Integration Diagnostic, Savedalen, Sweden) was used with transducers (type F5L5) screwed at the fixture level. At follow-up visits resonance frequency analysis was carried out with transducers (type A5L5) screwed at the abutment level. Transducers were always positioned perpendicular to the bony crest so that the output cable was in a buccal direction. Data were collected in a PC using a dedicated software (Osstell™ Data Manager, Integration Diagnostic).

Radiographic examination: Using a paralleling technique intraoral radiographs, were taken at second surgery (baseline), and then at the one- and three-year follow-up visits. Radiographs were digitized to 600 dpi and analyzed using ImageJ, a freeware software (NIH, USA http://rsb.info.nih.gov/ij/). Crestal bone levels were measured as the vertical distance of a fixture reference point from the bone level. Such a reference point was the most coronal point of the vertical part of the fixture (Åstrand et al, 1999). Measurements were made at the distal and mesial side of each implant and a mean value per implant was then calculated. Whenever the bone level was visible only at one side of an implant that value was adopted as the mean one. Bone loss during the studied period
was obtained by subtracting the baseline bone level from the one- and three-year level.

Statistical evaluation: All the statistical evaluations on resonance frequency and bone level changes were made with the patient as a unit, if not otherwise specified. Cumulative implant success rate was calculated using a life table analysis based on all the implants placed. Differences in resonance frequency at the measured time points were evaluated not only for the implants as a whole but also by dividing implants according to their position. Anterior implants were placed anteriorly to positions 12 and 22 while posterior ones were behind those positions. Differences in resonance frequency at the measured time points were evaluated using the Wilcoxon signed rank test. Implants were also split in four groups to evaluate the changes in resonance frequency in relation to the stability registered at the second surgery. For this evaluation implants were considered as a unit and the Kruskal-Wallis test was used for the statistical computation. Regarding bone resorption during the studied period, the Wilcoxon signed rank test was applied to evaluate the differences at the 1- and 3-year intervals.

A difference was considered statistically significant if P < 0.05.

Results
One implant was removed at the abutment surgery because of an early failure. All the other implants were clinically stable and asymptomatic through the whole study period. The cumulative success rate is shown in table 1. The mean resonance frequency recorded was: 65±4.8 ISQ (range 50-78 ISQ) at second surgery; 66±3.4 ISQ (range 53-76 ISQ) after one year of loading; 64±3.8 ISQ (range 53-77 ISQ) after three years of loading. No significant differences in resonance frequency resulted between these three time points.
<table>
<thead>
<tr>
<th>Observation period</th>
<th>N of implants</th>
<th>Failed</th>
<th>Dropouts</th>
<th>CSR% in the group</th>
<th>CSR%</th>
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<tr>
<td>Placement - second surgery</td>
<td>51</td>
<td>1</td>
<td>0</td>
<td>98%</td>
<td>98%</td>
</tr>
<tr>
<td>II surgery – 1 year of loading</td>
<td>50</td>
<td>0</td>
<td>0</td>
<td>100%</td>
<td>98%</td>
</tr>
<tr>
<td>1 year – 3 years of loading</td>
<td>50</td>
<td>0</td>
<td>0</td>
<td>100%</td>
<td>98%</td>
</tr>
</tbody>
</table>

Table 1: Life table analysis for all the placed implants (n = 51) in 8 patients.

When considering changes for implants with different levels of resonance frequency at second surgery, implants with lower values showed an increase during the observation period, the opposite happened for the implants with higher ISQ values (table 2).

<table>
<thead>
<tr>
<th>ISQ at II surgery</th>
<th>N of implants</th>
<th>% of implants</th>
<th>Mean change after 1 Yr</th>
<th>Mean change after 3 Yrs</th>
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<td>4 ±5</td>
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<td>3 ±3</td>
<td>5 ±5</td>
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<tr>
<td>61-65</td>
<td>8</td>
<td>16</td>
<td>2 ±3</td>
<td>2 ±7</td>
</tr>
<tr>
<td>&gt;65</td>
<td>23</td>
<td>46</td>
<td>-1 ±4</td>
<td>-2 ±4</td>
</tr>
</tbody>
</table>

Table 2: Implant distribution according to the ISQ measured at the second surgery. The variation in resonance frequency for each group during the follow-up is also showed.
However, this difference represented only a tendency because it did not reach statistical significance. Also no differences resulted when considering the stability of anterior and posterior placed implants at the three time intervals considered (figure 1). Lastly, there were no significant changes in the bone resorption measured at the first and the third year of loading (table 3).

![Comparison between implant stability quotient values for anteriorly and posteriorly placed implants. No significant differences resulted.](image)

<table>
<thead>
<tr>
<th></th>
<th>Mean bone loss (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline/1 Yr of loading</td>
<td>-0.4±0.66</td>
</tr>
<tr>
<td>Baseline/3 Yrs of loading</td>
<td>-0.6±0.4</td>
</tr>
</tbody>
</table>

Table 3: Changes in marginal bone level between baseline registration (second surgery) and the 1- and 3-year follow-ups.
Discussion

In this study the attention was drawn on the ISQ recorded for Astra Tech implants in edentulous maxillas at the second surgery and during a three-year follow-up. The first reason for that is the little information available on resonance frequency of Astra Tech implants. In fact, previous studies were mainly carried out in-vitro (Rasmusson et al., 2001) or on cadaver bone (O’Sullivan et al., 2000). Only one paper dealt with resonance frequency of Astra Tech implants placed in grafted maxillas (Thor et al., 2005). In the present study 50 implants placed into edentulous maxillas exhibited a range of 53-76 ISQ with a mean value of 66 ISQ after one year of loading. All the implants were asymptomatic and functionally stable during the three-year follow-up period without significant changes in resonance frequency. It can therefore be concluded that, within the conditions of the present study, the above-mentioned represents the range of stability for integrated Astra Tech implants. The present results are consistent with the resonance frequency data for Astra Tech implants after one year of loading in grafted maxillas (Thor et al., 2005). However, because of the different surgical techniques, might be of limited comparability. When considering Brånemark implants placed in grafted maxillas, the mean resonance frequency was slightly lower at both second surgery and after three years of loading compared to the present data (Sjöström et al., 2005) (Sjöström et al., 2007). Again, the difference could be explained by the different surgical techniques used. It has also important to consider that any correspondence between the present and the literature data might be coincidental. In fact different implant systems might result with different ISQ due to differences in dimension and type of anchoring with the transducer (Pattijin et al., 2006). This consideration gave rise to the recommendation not to compare the stability of different implants in an absolute sense (Pattijin et al., 2006) and consequently to the rationale for the present study.
When considering the ISQ variation for implants with different levels of resonance frequency at the second surgery, implants with lower values tended to an ISQ increase during the observation period, the opposite tendency was showed for implants with higher ISQ values at second surgery. A significant variation of ISQ between placement and second surgery was well established in previous publications (Friberg et al, 1999b) (Sjöström et al, 2005) (Sjöström et al, 2007). Implants showing lower ISQ “caught up” implants with higher stability at placement while implants with the highest ISQ decreased in their stability. Conversely, this so called “catch up” did not reach statistical significance in the present study. A probable reason is that ISQs at placement were not measured, while the most evident change in resonance frequency is likely to happen between placement and second surgery. Also to be mentioned is the lack of difference in resonance frequency resulted between anterior and posterior implants at none of the intervals considered. The similar stability achieved by integrated implants regardless of their position is in agreement with previous results by Balleri and coworkers (Balleri et al, 2002) on integrated Brånemark implants.

With regard to the prognostic value of resonance frequency, no clear information comes from the literature although the technique was introduced a decade ago (Aparicio et al, 2006). One of the earlier publications showed that a progressive ISQ decrease would detect a failing implant before any evident clinical sign and it was also possible to take an avoiding action to prevent the complete failure (Friberg et al, 1999a). In more recent clinical studies the attention was drawn on resonance frequency at implant placement (Glauser et al, 2004) (Huwiler et al, 2007) (Nedir et al, 2004) (Östman et al, 2005) and during the early healing phases (Glauser et al, 2004) (Huwiler et al, 2007) (Nedir et al, 2004) and on the prognostic value of these measurements (Glauser et al, 2004) (Huwiler et al, 2007) (Nedir et al, 2004). It resulted that a single
resonance frequency measurements at placement or during early healing phases was not able to distinguish between implants that would maintain their integration and those destined to fail (Huwiler et al, 2007) but, rather, low ISQ values after 1 or 2 months might indicate an increased failure risk (Glauser et al, 2004). On the contrary, in another study, implants that would fail over a three-year period showed significantly lower ISQ values at placement (Sjöström et al, 2007). In the same way, a cut-off ISQ guarantying osseointegration could be established for ITI implants at placement (Nedir et al, 2004). On the other hand, a progressive decrease of resonance frequency was not able to reliably predict an implant failure (Huwiler et al, 2007). These somewhat controversial results are another reason why in the present study the attention was focused on the ISQ at second surgery in maxillary implants. The stability of an implant at placement is dependent on the implant design and the surgical technique together with the bone quality (Östman et al, 2005). It is possible that the first two factors are able to overshadow the measurable contribution to primary stability given by bone quality, which is nonetheless of paramount importance for implant prognosis (Esposito et al, 1998). As a matter of fact, Östman et coworkers were able to achieve an high primary stability in all the jaw bone regions by using an adapted surgical technique (Östman et al, 2005). In addition, the influence of implant shape on primary stability was shown by O’Sullivan in a cadaver study where tapered implants reached higher stabilities in soft bone than cylindrical implants (O’Sullivan et al, 2000). If it is speculated that after six months of healing the influence of these two factors might fade away due to remodeling of the interface, resonance frequency could then better mirror the bone implant integration. At this regard, Scarano and coworkers were able to demonstrate in human biopsies, a significant correlation between resonance frequency and bone contact at implants that were left to heal for a six-month period before removal (Scarano et al, 2006). On the other hand,
Huwiler et al. did not find correlation between bone density and trabecular connectivity and resonance frequency analysis recorded at placement and during the early healing phases (Huwiler et al, 2007).

The information gathered in the present study on resonance frequency at second surgery could be relevant for the clinician treating edentulous maxilllas. Indeed, while the experienced operator, when placing an implant, gets a perception of bone quality and stability, no feedback on implant integration comes from the second surgery. Still, implant failures in the edentulous maxilla have been reported as more frequent compared to edentulous mandibles and partially edentulous situations (Esposito et al, 1998). Also a tendency to cluster in few patients (Esposito et al, 1998) (Jemt and Häger 2006) with increasing losses during the first three years after placement (Jemt and Häger 2006) was observed. An instrumental way to measure implant secondary stability could therefore be an aid for clinicians dealing with this treatment.

When considering that no significant differences resulted in the ISQ measured at the second surgery and after 1 and 3 years of loading, it could be inferred that the stability of Astra Tech implants reaches an homeostasis after a six-month healing period before loading. Although possible differences in the bone remodeling dynamics, this result is in agreement with what described by Thor in grafted maxilllas loading (Thor et al, 2005). They found no difference in stability between the second surgery and the one-year follow-up for Astra Tech implants. Equally important, the cumulative implant success rate and the bone resorption at the one- and three-year intervals of this study is similar to what previously reported by Åstrand (Åstrand et al, 1999) and Rasmusson (Rasmusson et al, 2005) in their long term follow-ups for the Astra system. The above-mentioned studies showed how equilibrium, with little or no failures or bone changes, was reached after the first year of loading. Taken together these success rate, bone changes and resonance frequency analysis data could support
the hypothesis that the range of 53-76 ISQ, here obtained after one year of loading, is representative of implants that will be stable over time after the first year of function.

On the contrary, the prognostic value of resonance frequency at second surgery still needs better validation with more studies including a larger number of implants. According to the data gathered in this study, Astra Tech implants showing an ISQ ≥50 at the second surgery after six months of healing are supposed to maintain their integration over a three-year period. However, it has to be considered that most of the late failures concentrate in the first year of loading (Esposito et al, 1998), therefore more evidence is needed to elucidate if the range of 50-78 ISQ, emerged in this study, is representative of integrated Astra Tech implants that will keep their stability in the long term after the second surgery.

One limitation of the present follow-up study is that no late failures were encountered. Therefore it was not possible to establish a cut-off ISQ value for implants that would maintain their osseointegration or would rather fail over a three-year period.

In conclusion, in edentulous maxillas, osseointegrated Astra Tech implants show a range of 53-76 and a mean ISQ 65 after one year of loading. Within the limitations of this study, an ISQ >50 at second surgery seems to indicate implants that will keep their stability over a three-year period.
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Thor A, Wannfors K, Sennerby L, Rasmusson L. Reconstruction of the severely resorbed maxilla with autogenous bone, platelet-rich plasma, and implants: 1-
III.3 One-year outcome of narrow diameter blasted implants for rehabilitation of maxillas with knife-edge resorption.

Veltri M, Bertelli E, Ferrari M, Balleri P.
In Press Clinical Oral Implants Research 2008

Introduction
The rehabilitation of edentulous maxillas with implant-supported prostheses is an effective procedure with 15 years of documented follow-up (Jemt and Johansson 2006). For the good prognosis of an implant treatment it was suggested that at least 1 mm of supporting bone should be present around each implant (Lekholm et al, 1986). However, a long-standing maxillary edentouolism might cause severe bone resorption thus preventing the achievement of this condition around implants of standard diameter and length. In these cases grafting of the maxilla has been proposed to allow implant placement in optimal bone volumes. Onlay bone grafts (Breine and Brånemark 1980) (Kahnberg et al, 1989) (Lundgren et al, 1997) and maxillary sinus lifting (Boyne and James 1980) (Lundgren et al, 1997) (Jensen et al, 1998) are well-documented procedures to restore lost bone volumes. However, it is obvious that grafting procedures are more demanding both for the patient and the clinician. In fact, they have an increased morbidity and a prolonged treatment time with the necessity of a graft-healing period when dentures cannot be worn. Also to be considered is the slightly increased failure rate reported for machined implants placed in grafted bone compared to conventional treatments (Esposito et al, 1998). As an alternative, a modification of traditional implant placement has been advocated for the restoration of severely resorbed maxillas. Narrower and shorter implants can be placed also in knife-edge crests if exposure of some implant threads is accepted as a compromise. At this regard, it was observed by Lekholm (Lekholm et al, 1996) that the exposure of some threads at insertion
does not lead to increased bone loss after 5 years of loading, therefore it was suggested that bone grafting procedures might be unnecessary in those cases. The five-year results of severely resorbed maxillas treated with machined implants with and without bone grafts were reported in two studies (Widmark et al, 2001) (Becktor et al, 2004). The failure rate was lower in the group treated with narrow implants without grafts than in the grafted group. Even if in the short term only, a similar outcome was also described by Hallman (Hallman 2001) for narrow non-submerged titanium plasma-sprayed implants in resorbed maxillas. Although limited, these reports suggest that placement of narrow implants has to be considered when planning the treatment of patients with resorbed maxillas. In addition, the use of implants with medium roughness surfaces might further improve the prognosis of this treatment, as compared to earlier reports. In fact, these surfaces are claimed to stimulate bone response in marginal situation where implants are placed in reduced bone volumes. Evidence in animal experiments suggests that the implant design and surface has an effect on bone regeneration at implants with dehiscence (Rasmusson et al, 2001). Indeed at sites with exposed threads, micro-threaded blasted implants had better results in terms of bone regeneration and increase of resonance frequency than their machined controls. The present study was then aimed at assessing the clinical outcome of 3.5mm diameter blasted implants in the treatment of patients with edentulous maxillas of adequate bone height but inadequate width (Class IV) (Cawood and Howell 1988).

Materials and methods
Patients: 12 consecutive patients (8 women and 4 men) with edentulous maxillas seeking a fixed prosthesis were included in the study, their mean age was 58 years (range 42-74). Three of the patients had fixed prostheses in the opposite arch while the others their own teeth. Criterion for inclusion was a
maxillary knife-edge resorption with a bone width not greater than 4 mm. This condition has been defined by Cawood and Howell as class IV maxillary atrophy with insufficient bone for placement of conventional diameter implants (Cawood and Howell 1988). Bone volumes were measured on preoperative tomograms and revealed a width insufficient for placement of 4mm diameter implants in the planned sites, conversely bone height were estimated to be sufficient for implant placement (Figure 1). The preoperative lateral projection cephalographic x-rays showed a tendency to intermaxillary relations of class III for all the patients. Exclusion criteria were: a compromised health status contraindicating any surgical intervention and smoking of more than 10 cigarettes a day.

Surgical procedures: All the implants used in the study were 3.5 mm TiO₂ blasted implants (Micro-Thread, Astra Tech, Mölndal, Sweden) and were placed according to a two stage protocol (Figure 1). All the operations were executed by one surgeon. Site preparation was adapted aiming at the best possible primary stability. 73 implants were inserted and flaps were carefully sutured. Each patient received the longest implants possible according to the available bone (table 1). In 36 sites, implants showed marginal bone defects like dehiscence or vestibular fenestrations. These defects were covered with autologous bone chips collected during drilling or taken at adjacent sites. Amoxicillin was administered 1 hour prior to surgery without further administrations thereafter. Sutures were removed 15 days after surgery and healing was uneventful for all the patients.
Figure 1: Preoperative radiographs of one patient. Clinical images show the atrophic crest, exposed threads were covered with autologous bone chips.

<table>
<thead>
<tr>
<th>Length</th>
<th>Placed</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td>13</td>
<td>32</td>
</tr>
<tr>
<td>15</td>
<td>28</td>
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<tr>
<td>17</td>
<td>7</td>
</tr>
<tr>
<td>total</td>
<td>73</td>
</tr>
</tbody>
</table>

Table 1: Length distribution of the placed implants.
Prosthetic procedures: Existing patient dentures were relined with a soft material (Viscogel, Dentsply, York, PA) during the healing period. After 6 months of healing all the patients had the second surgery performed and abutments connected (UniAbutment 20°, Astra Tech, Mölndal, Sweden). All the patients were rehabilitated with fixed metal acrylic prostheses using conventional prosthetic procedures.

Follow-up: At the one-year follow-up the following clinical variables were recorded: absence of pain, discomfort or infection associated with the implants. The clinical immobility of each implant was also checked after bridge removal. A surviving implant was defined as an implant that was stable, in function and symptom free. In addition, at prostheses delivery and one year thereafter, the intelligibility of the dental phonemes, as perceptible by the restoring dentist, was checked and the patients were asked if they were satisfied with the phonetic outcome.

Implant stability measurement: Resonance frequency of the implants was measured at implant surgery and repeated at abutment surgery. The Osstell™ equipment (Integration Diagnostic, Savedalen, Sweden) was used for measuring, transducers (type F5L5) were screwed at the fixture level. After one year of loading, resonance frequency analysis was repeated with transducers (type A5L5) screwed at abutment level. Transducers were always positioned perpendicular to the bony crest so that the output cable was in a buccal direction. Data were collected in a PC using a dedicated software (Osstell™ Data Manager, Integration Diagnostic).

Radiographic examination: Using a paralleling technique, intraoral radiographs were taken at the abutment connection, and then one year later (Figure 2). Radiographs were digitized to 600 dpi and analyzed using ImageJ, a freeware software (NIH, USA http://rsb.info.nih.gov/ij/). Crestal bone levels were measured as the vertical distance of a fixture reference point from the bone.
level. Such a reference point was the most coronal point of the vertical part of the fixture (Åstrand et al, 2004). Measurements were made at the distal and mesial side of each implant and a mean value per implant was then calculated. Whenever the bone level was visible only at one side of an implant that value was adopted as the mean one. Bone loss during the study period was obtained by subtracting, for each implant, the bone level registered at the abutment connection from the level registered a year later.

![Figure 2: Radiographic examination at abutment connection and 1 year of loading.](image)

*Statistical analysis:* Having checked that the data distribution was normal (Kolmogorov-Smirnov test, p>0.05) and group variances were homogeneous (Levene test, p>0.05), a paired t-test was used to evaluate differences in resonance frequency at the measured intervals. Statistical significance was set at $\alpha = 0.05$. 
Results
All the patients could be restored with the planned fixed prostheses. All the implants were followed-up to one year of loading and no dropouts occurred. When checked individually, all the implants were clinically immobile and symptom-free. The implant survival rate was 100%. Bone loss for all the implants after one year of loading was (mean ± SD) 0.30 ± 0.13 mm. The distribution of bone changes, calculated with patients and implants as a unit, is shown in Table 2. Stability values were (mean ± SD) 63 ± 5.8 ISQ at placement, 60 ± 4.7 ISQ at the abutment connection and 61 ± 5 ISQ after one year of loading. A significant difference resulted between placement and abutment connection values (p=0.03). 4 patients had a defective pronunciation of the dental phonemes as judged by the restoring dentist. However, only 2 of them were aware of the defect that additionally did not meliorated after one year of function. In the other two patients, the defect did not influence their satisfaction with the overall treatment result and it tended to disappear after one year of loading. One patient reported a fracture of the resin veneer that was easily repaired.

<table>
<thead>
<tr>
<th>Bone loss (mm)</th>
<th>Number of patients</th>
<th>Number of implants</th>
</tr>
</thead>
<tbody>
<tr>
<td>+0.5 to -0.5</td>
<td>9</td>
<td>53</td>
</tr>
<tr>
<td>-0.6 to 1</td>
<td>3</td>
<td>14</td>
</tr>
<tr>
<td>1 to 2</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>2 to 3</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 2: Bone level changes between abutment connection and one year of follow-up. Changes were evaluated both as a mean per patient and at each single implant.
Discussion

Human edentulous maxillas go through resorption processes that might prevent restoration with implant-supported prostheses. Grafting procedures can restore bone volumes available for implant placement. As an alternative to these invasive reconstruction techniques, placement of narrow implants might be possible in residual native bone volumes. In the present prospective follow-up investigation, 12 patients with class IV maxillary atrophy have been successfully restored with fixed prostheses supported by 3.5mm diameter blasted implants. The positive results are consistent with two previous reports of machined implants placed in resorbed maxillas with and without previous bone grafting (Widmark et al, 2001) (Becktor et al, 2004), in both these studies the best 5-year results were obtained in the graftless group. However, those study designs were not randomized and therefore definitive conclusions cannot be drawn. Satisfactory one-year results were also described for reduced diameter titanium plasma-spray implants in atrophic maxillas otherwise candidates to grafting procedures (Hallman 2001). As a consequence, the effectiveness of adaptation of the implants to the residual bone anatomy was emphasized. In addition, it has to be considered that, in a review of the literature, it was clearly pointed out that both inlay and onlay grafting procedures of atrophic maxillas seem to greatly increase the implant failure rate as compared to standard procedures (Esposito et al, 1998). Hence the use of narrow diameter implant in Cawood & Howell Class IV maxillary atrophies could be regarded as a very reliable alternative to bone grafting procedures. With regard to the dehiscence present at many implants sites after placement, they were managed with autologous bone chip coverage without affecting the outcome of the treatment after one year of loading. This was done in accordance with clinical recommendation by Lekholm (Lekholm et al, 1986) who observed that incomplete bone coverage at implant placement does not
influence the 5-year outcome of the implants. Incomplete bone coverage of some threads is therefore an acceptable situation that does not require previous grafting to improve the bone support. Further experimental evidence pointed out at the fact that at sites with dehiscence, the use of blasted implants allows for higher level of bone regeneration and bone implant contact than machined implants (Rasmusson et al, 2001). This ability might have contributed to the positive results reported in the present investigation. Bone resorption, measured after the first year of loading, was similar to those previously reported for narrow diameter blasted implants placed in maxillas with more favourable bone volumes (Åstrand et al, 2004). It could be therefore inferred that, during the first year of loading, the procedure of placement adopted in the present study does not seem to lead to bone resorption greater than that reported for implants placed in less resorbed maxillas.

One limitation of the present technique is the impossibility to correct intermaxillary discrepancies due to atrophy. In fact the rehabilitation of edentulous maxillas involves not only functional exigencies but also aesthetical and phonetic ones, the latter two might be difficult to satisfy when severe maxillary atrophies are present. As a result, four of the patients included in the present study had a disrupted articulation of the dental phonemes. Two of them had an initial minor defect but a satisfactory self-assessment of their own speaking ability. Conversely, other two patients had a disturbance that persisted during the first year of function. It has been shown that the patient speaking ability greatly influences his satisfaction with an implant prosthesis (Awad and Feine 1998). However, loss of supportive hard and soft tissues might create gaps between the fixed prosthesis and the tissues that are likely to disturb the speaking ability (Lundqvist et al, 1992). These gaps are impossible to close without reconstructive procedures or recourse to overdenture prosthesis. Therefore, when patients seek fixed implant supported prostheses, phonetic and
aesthetic aspects have to be preoperatively evaluated and weighed against the increased morbidity associated with major bone reconstruction techniques. In the present study, preoperative discussion of possible pronunciation problems following the implant supported oral rehabilitation increased the acceptance of the defect for the two patients who incurred in it.

Regarding resonance frequency a decrease in implant stability resulted between placement and abutment connection measurements. This could be due to the fact that an adapted drilling technique was chosen to maximize primary stability. As a consequence, resonance frequency values were correspondingly high despite the bone defects resulting at many implant sites. Similar findings were presented in an animal study where no differences in primary stability, as measured with resonance frequency, resulted when comparing test implants with marginal bone defects and control implants with complete bone coverage (Rasmusson et al, 2001). An explanation for this could be found in the anchorage reached in the residual cortical bone circumferentially to the implant. The stabilizing potential of cortical bone when placing an implant was showed by Miyamoto who demonstrated how resonance frequency is linearly related to the cortical bone thickness, regardless of implant dimension (Miyamoto et al, 2005). The decreased stability values at abutment connection could be attributable to bone remodelling and releasing of tensions developed at placement due to the adapted surgical technique as already observed for implants placed in maxillary grafted bone (Sjöström et al, 2005). However, after the first year of function, when the risk of failure is generally higher (Esposito et al, 1998), the stability of all the implants remained in the range reported for integrated implants in more favourable bone volumes (Balleri et al, 2002).

In conclusion according to the clinical, radiographical and resonance frequency outcome, narrow implants may be successfully used to restore edentulous
maxillas with class IV Cawood & Howell atrophies. This possibility has to be considered in the treatment planning of maxillas with such resorption pattern as an alternative to more demanding grafting techniques.
References


Chapter IV
Comparison of the stability of bone anchoring devices for orthodontic purposes

IV.1 Soft bone primary stability of three different mini screws for orthodontic anchorage: a resonance frequency investigation.
Veltri M, Balleri B, Goracci C, Giorgetti R, Balleri P, Ferrari M.
Accepted for publication in the American Journal of Orthodontics and Dentofacial Orthopedics.

Introduction
Since its discovery, the ability of titanium to integrate in bone has been successfully applied in prosthodontics (Williams 2001). Soon after, fields of application have expanded to orthopaedics and audiology while, in the latest years, titanium biocompatibility has been increasingly applied for orthodontic anchorage (Melsen 2005). The known clinical advantages of skeletal anchorage over dental and extraoral anchorage are absolute stability and independence from patient compliance (Park et al., 2006). To provide skeletal anchorage mini-screws have recently been developed by several manufacturers. They have smaller size than regular dental implants and are claimed to allow for immediate loading and easy removal at the end of their use (Melsen 2005).

Similarly to dental implants, for their response to immediate loading orthodontic mini screws rely on primary stability, i.e. the mechanical stability achieved immediately after insertion (Melsen and Costa 2000). Primary stability is influenced by bone quality and quantity, surgical technique and screw geometry (O’Sullivan et al., 2004). While clinicians have little control on bone quantity available for screw placement due to resorption processes triggered by extractions and the presence of roots and anatomical landmarks,
the remaining parameters have to be carefully considered for the success of the procedure.

Bone of soft quality with less than 0.5 mm cortical thickness has been suggested to increase the risk of failure (Melsen 2005). In addition, the possibility of screw displacement under loading has been reported in dependence of healing time, screw design and bone quality (Liou et al, 2004). In a finite elements model, it was showed that the cortical layer determines the load transfer from the mini screw to the bone, and that bone quality might affect mini-screw stability (Melsen and Verna 2005). Under orthodontic forces, bone stress at the mini screw interface does not cause bone damage in medium or high density trabecular bone (Melsen and Verna 2005). Conversely, when the cortical layer is less than 0.5 mm and the trabecular portion has low density, strains may exceed the bearing threshold and begin a pathological overload that might ultimately lead to the mini screw loss (Melsen and Verna 2005). These bone conditions might be present in posterior edentulous areas of the human jaws (Ulm et al, 1997) (Ulm et al, 1999).

With the intention to maximize primary stability in soft bone, orthodontic screws, which have machined surfaces, have been designed to be either self-drilling or self-tapping. Histological analysis of self drilling and self tapping mini screws placed in animal bone showed that a grater bone contact is found for self drilling screws after healing (Heidemann et al, 2001) and orthodontic loading (Kim et al, 2005).

Screw geometry is another relevant parameter for primary stability. Particularly, previous clinical studies have suggested that screw diameter is influential for clinical success, and the inadequacy of a diameter of 1 mm or less has been documented (Miyawaki et al, 2003). Conversely, screw length and design appeared to be less critical factors (Miyawaki et al, 2003) (Cheng et al, 2004). However, the outcome of these mentioned investigations may have been
influenced by a defective standardization of the assessed geometrical variables. As a matter of fact, in a better controlled animal study measuring removal torque as a parameter of primary stability, significant differences were reported between conical screws (Dual Top) and cylindrical pins (Tomas) (Wilmes et al, 2006).

Although numerous differently designed screws are becoming available on the market for orthodontic anchorage, still accurate and repeatable measurements of their primary stabilities are not being provided. Such information may actually be of help to orient clinicians decision, especially when dealing with soft bone of less favourable quality.

The purpose of this study was then to use the Osstell™ equipment for Resonance Frequency Analysis, an instrument of documented reliability in quantifying the bone-implant interface stiffness (Meredith et al, 1996) (Meredith et al, 1997), to measure the primary stability of mini-screws for orthodontic anchorage. Rabbit femoral condyles were used for testing as an experimental model of soft quality bone.

**Materials and methods**

*Mini screws.*

The following screw systems were tested: Aarhus Mini-implant (Aarhus Mini-implant, Charlottenlund, Denmark), Spider Screw (HDC, Sarcedo, Italy), and Micerium Anchorage System (Micerium, Avegno, Italy). The Aarhus Mini-implants on trial had a diameter of 1.5 mm, a 9 mm long threaded portion, and a 1.5 mm smooth neck. The tested Spider screws featured a 1.5 mm diameter and a 8 mm long threaded portion (short neck version). The selected Micerium screws presented a 1.5 mm diameter and a threaded portion of 9 mm in length. None of these system had available transducers for resonance frequency analysis with the Osstell™ equipment (Integration Diagnostic, Sävedalen,
Sweden). All the screws were therefore modified by cutting the bracket-like head and by laser soldering (ModelXXX, Orotig, Castelnuovo del Garda, Italy) on this site an Astra Tech 0.0 mm 20° Uniabutment (Astra Tech, Mölndal, Sweden) (Figure 1). Since resonance frequency is influenced not only by bone interface stiffness, but also by the exposed screw length, *i.e.* the distance of the transducer from the first bone contact (Meredith *et al*., 1996), on soldering care was taken that all the screws ended up having similar heights above the bone level. After laser welding 10 screws per system, the four in each group that presented with the most similar exposed lengths were selected for testing.

Fig 1. The mini screw with the soldered abutment and the screwed transducer are represented in the design. The Osstell™ equipment is also shown on the right.
Bone segments and placement procedure

Sixty femoral condyles excised from rabbit knee joints were used for this study. The animals (New Zealand white rabbits) were sacrificed the day before the test and their excised femurs kept refrigerated until use. The unrelated study from which the rabbits were obtained had preliminarily been approved from the Review Board for animal studies of the University of Siena. The mini screws were placed through the cartilage and subchondral bone in the femoral articular surface of the femoral patellar joint (Figure 2). This implantation site has been considered as an experimental model of soft bone, as it exhibits cancellous bone with a practically absent cortical layer (Sennerby et al, 1992).

Fig 2. Clinical and radiographic view of an inserted mini screw. Absence of the cortical layer and soft quality of the bone are evident in the x-ray.
According to manufacturers indications for soft bone placement, Micerium and Spider screws were placed after preparing a hole only through the cartilage layer, using respectively 1.0 mm and 1.2 mm diameter dedicated drills. Water cooling was maintained during low speed drilling at 200 Rpm. Conversely, the Aarhus mini implant, being self-drilling, was placed without performing any preliminary site preparation.

All the screws were mounted on an Astra Tech abutment adapter to allow for placement. All the screws were carefully inserted into the bone up to a predefined reference point (shown by the white line in Figure 3). This allowed for similar exposed screw lengths in the three tested groups.

Fig 3. From the left Micerium, Aarhus, and Spider screws after abutment laser soldering. The white lines show the point that was used as a sinking reference during placement to obtain similar exposed screw lengths. It also shows that the distance of the top of the abutment from the reference point was similar in the three groups.
To check for similarity of the exposed screw portions the distance of the abutment top from the bone level was measured radiographically. Post-placement x-rays were scanned at 600dpi (Nikon Coolscan, Tokyo, Japan) and then analyzed using a freeware software (ImageJ, USA http://rsb.info.nih.gov/ij/). The exposed screw length was measured at the mesial and distal side of each screw and a mean value was calculated. The exposed lengths were (mean ± standard deviation) 8.7 ± 0.8 mm for Spider screws, 8.6 ± 0.5 mm for Aarhus mini implants and 8.9 ± 0.7 for Micerium screws. The one-way analysis of variance demonstrated that there was no significant difference in exposed lengths among the three investigated groups (p>0.05).

Each of the 12 modified mini screws was inserted and removed from 5 different femoral condyles. Therefore, in each of the 60 condyles one mini screw was placed and a resonance frequency measurement was carried out.

*Resonance Frequency Analysis.*

Resonance frequency analysis is a bending test where a small bending force is applied to an implant through a transducer which is screwed directly to the implant or to the abutment. Resonance frequency is directly proportional to screw stability and inversely proportional to the distance of the transducer from the first bone contact.

The Osstell™ instrument (Integration Diagnostic, Sävedalen, Sweden), a commercially available equipment for resonance frequency analysis, was used in the study. The measurement technique involves the use of a transducer and a response analyser device. The L-shaped transducer includes two piezoelectric elements. The first element is excited to a range of approximately 5-15 kHz, while the second one records the amplitude of the microscopic displacement of the bone-implant interface induced by the vibration. The transducer (type A5L5, Integration Diagnostic, Sävedalen, Sweden) has to be finger tight...
screwed on the abutment, and oriented with its cantilever beam perpendicular to the bone.

Resonance frequency is the peak of the amplitude-frequency plot received from the transducer, and can be conveniently read on the display of the equipment. The Osstell™ transforms resonance frequencies into Implant Stability Quotients which range from 0 to 100, with higher values indicating higher stabilities. However, this index is only validated for transducers calibrated for a specific implant type in human jaws. Therefore, in this study, resonance frequency values in Hertz (Hz) were considered. Collection of these raw data was accomplished with the Osstell™ Data Manager (v.3) software (Integration Diagnostic, Sävedalen, Sweden).

Statistical analysis.

Having checked that the data distribution was normal (Kolmogorov-Smirnov test, p>0.05) and group variances were homogeneous (Levene test, p>0.05), the Analysis of Variance for repeated measures was applied to assess whether significant differences in resonance frequency existed among the tested systems (between subject factor), as well as to rule out the chance that a significant decline in stability occurred due to a possible loss of tapping ability from the five time repeated insertion and removal of each screw in the experiment (within subject factor). Statistical significance was set at $\alpha = 0.05$.

Results

No screws fractured during the repeated insertion and removal procedures. All the screws were stable right after insertion, as judged by the manual perception of the operator. Recorded frequency values in Hz are shown in Table 1. Mean and standard deviation in Hz for the three groups were: Micerium screws 6236.1±192.1, Spider screws 6270.1±99.7; Aarhus Mini-implants 6193.1±142.4. Differences in resonance frequency among the three systems
were not statistically significant (between subject factor p>0.05). As also the within subject factor was found to be non significant (p>0.05), repeated insertion and removal did not significantly affect the screws primary stability.

<table>
<thead>
<tr>
<th>System</th>
<th>Screw</th>
<th>Resonance Frequency (Hz)</th>
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</thead>
<tbody>
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<td>Aarhus Mini Implant</td>
<td>1</td>
<td>6176 5950 6063 6232 6007</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>6118 6436 6401 6270 6164</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>6289 6176 6439 6157 6007</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>6186 6206 6268 6306 6010</td>
</tr>
<tr>
<td>Micerium Anchorage System</td>
<td>1</td>
<td>6289 6345 6214 6063 6176</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>6027 6031 6101 6200 6253</td>
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<tr>
<td></td>
<td>3</td>
<td>6725 6477 6289 6044 6552</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>5948 6381 6173 6186 6247</td>
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<tr>
<td>Mini Spider Screws</td>
<td>1</td>
<td>6195 6044 6270 6308 6138</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>6281 6146 6279 6308 6152</td>
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<tr>
<td></td>
<td>3</td>
<td>6326 6439 6326 6421 6383</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>6321 6293 6317 6264 6190</td>
</tr>
</tbody>
</table>

Table 1: Resonance frequencies recorded for each mini screw inserted in the five different condyles. No between subject nor within subject differences were found (p>0.05).
**Discussion**

The introduction of screws for orthodontic anchorage has greatly extended orthodontic treatment options. Despite their temporary clinical service, failure rate of orthodontic mini-screws has been reported to be higher than that of machined dental implants (Cheng *et al*, 2004) (Chen *et al*, 2006) (Motoyoshi *et al*, 2006) (Esposito *et al*, 1998). One possible explanation is that mini screws are most often immediately loaded. Conversely, dental implants placement usually involves the wait for a healing period, followed by the achievement of a secondary stability, *i.e.* the additional bone implant contact due to the osseointegration process. Therefore, the success of mini screws is completely dependent upon their mechanical stability at insertion. The use of self-tapping or self-drilling mini screws is expected to effect the best possible contact between recipient bone and screw surface. Such condition may be difficult to obtain in a soft bone where cortical thickness is less than 0.5 mm and the trabecular pattern is loose. As such sites have been suggested as failure risk factors (Melsen 2005) (Melsen and Verna 2005), it would be relevant to know if a particular screw design allows for higher primary stability in soft bone where cortical thickness might be insufficient to withstand functional loading without overloading. This information may also be relevant since, in consideration of the reported mini screw slight displacement under orthodontic forces, clinicians may wish to select the screw that assures the best stability in soft bone (Liou *et al*, 2004). Femoral condyles were chosen for this study because they present the soft bone features reported to be critical for screw stability such as cortical thickness inferior to 0.5 mm and low trabecular connectivity (Sennerby *et al*, 1992).

In this resonance frequency analysis no difference was found in soft bone primary stability of three different mini screws for orthodontic anchorage. This finding is in contrast with previous studies that evaluated self-drilling and
In the present study, no difference in primary stability resulted between three different mini screws investigated. This might be considered controversial because two of them were self-tapping (Spider Screw and Micerium Anchorage System) and one self-drilling (Aarhus Mini-implant). However, this finding can be accounted for by the difference in screw placement technique between our and the previous studies. In the latter ones (Heidemann et al, 2001) (Kim et al, 2005), pilot drilling was deepened to the entire screw length, most likely reducing the initial bone contact. On the contrary, in the present study the bone preparation for self-tapping mini screws was limited to the cartilaginous layer. Notwithstanding this adapted preparation, the screws could still be completely seated in the bone of soft trabecular quality. This insertion technique resulted in our study in similar primary stabilities in a soft bone model, regardless of whether the screw was self-tapping or self-drilling. Moreover, the followed placement technique complies with the

self-tapping screws. Heidmann (Heidemann et al, 2001) compared self-drilling and self tapping orthodontic screws placed in the anterior wall of the frontal sinus of mini pigs. After six months of healing, self-drilling screws obtained the best bone contact percentage, in addition no signs of bone damage resulted at the bone interface, in spite of the high pressure that can be generated in bone upon their insertion (Phillips et al, 1989). The use of self-drilling screws in the human midface was hence recommended for bone fixation purposes. Similar conclusions were drawn by Kim (Kim et al, 2005), who used Periotest in combination with histological analysis to test orthodontic mini screws in beagle jaws. After eleven weeks of orthodontic load, greater bone to metal contact and higher Periotest values were observed for self-drilling screws. This result was attributed to a less traumatic insertion technique for self-drilling screws thus resulting in a better tissue integration and subsequent improved resistance to orthodontic load.

Conversely, in the present study no difference in primary stability resulted between three different mini screws investigated. This might be considered controversial because two of them were self-tapping (Spider Screw and Micerium Anchorage System) and one self-drilling (Aarhus Mini-implant). However, this finding can be accounted for by the difference in screw placement technique between our and the previous studies. In the latter ones (Heidemann et al, 2001) (Kim et al, 2005), pilot drilling was deepened to the entire screw length, most likely reducing the initial bone contact. On the contrary, in the present study the bone preparation for self-tapping mini screws was limited to the cartilaginous layer. Notwithstanding this adapted preparation, the screws could still be completely seated in the bone of soft trabecular quality. This insertion technique resulted in our study in similar primary stabilities in a soft bone model, regardless of whether the screw was self-tapping or self-drilling. Moreover, the followed placement technique complies with the
recommendation to adapt site preparation to bone quality when placing dental implants. This recommendation was given with the aim to maximize thread engagement within bone (Friberg et al, 2002). The achievement of high implant primary stability regardless of bone quality was demonstrated if using this approach (Östman et al, 2006). Based on the findings of our resonance frequency analysis, this strategy seems to be effective also with orthodontic mini screws.

Another technique that has been applied to non invasively evaluate primary stability of mini screws is the PeriotestTM (Gulden-Medizintechnik, Bensheim an der Bergstraße, Germany) (Kim et al, 2005). This device was designed to measure tooth mobility but it was also used to evaluate implant mobility. The instrument measures the contact time of a small metal slug which is accelerated toward the tooth/implant. The contact duration is then converted to a Periotest value (PTV). The use of Periotest on mini screws is straightforward since no screw modification is required. However, one limitation of Periotest, which is a hand held instrument, is the susceptibility to the striking position (Meredith et al, 1998), which is an operator related variable. In addition, when Periotest is applied to an implant, only a narrow range of PTVs is obtained ensuing a limited sensitivity in the measurement of the implant stability (Meredith et al, 1998) (Olive and Aparicio 1990). Conversely, the Osstell™ transducers are screw tightened and therefore only screw tightening (Meredith et al, 1996) and transducer orientation (Veltri et al, 2007) are operator dependent variables. The precision of resonance frequency analysis has been previously tested and a good repeatability was reported (Meredith et al, 1996). Additionally, the technique has proved sensitive in measuring implant stability (Meredith et al, 1996) (Meredith et al, 1997) and was successfully used with to compare the primary stability of implants with different designs placed in human cadaver bone (O’Sullivan et al, 2000).
In order to carry out the resonance frequency analysis with the Osstel instrument, a modification of the mini screws with an implant platform was needed. This modification was believed not to affect the measurements accuracy based on the following considerations. The resonance frequency of dental implants is influenced by the orientation of the transducer (Veltri et al, 2007), the bone transducer-distance (Meredith et al, 1996) (Meredith et al, 1997) and the overall stiffness of the system, including the transducer-implant and bone-implant interfaces (Meredith et al, 1996) (Meredith et al, 1997). Under the conditions of this study, the transducer had a standardized orientation and was screwed finger tight to the abutment according to manufacturer’s indication. The abutment soldering altered the bone-transducer distance, however care was taken to obtain similar exposed screw lengths in the tested groups. Finally, a stiff welding connected the abutment with the mini screw. Thereby, the only parameter with a possible influence on the resonance frequency measurements remained the stiffness of the bone-screw interface.

With regard to absolute values, it is worth mentioning that resonance frequency data recorded in this study did not exceed the 6480 Hz indicated as the threshold of primary stability requested for immediate/early loading of machined dental implants (Glauser et al, 2004). A possible explanation for this finding resides in the modification introduced by soldering the abutment on top of the screw, consequently increasing the exposed screw length, which is inversely proportional to resonance frequency. Having been reported that an increase in exposed implant length lowers resonance frequency by 413 Hz per mm (Sennerby et al, 2005), we can infer that the resonance frequency measurements taken in this investigation somewhat underestimated the primary stability actually achieved. In any case, the data collected in the present study are not to be directly compared with those of dental implant literature, that have been obtained with transducers dedicated to each implant system and easily
calibrated for different abutment heights. All the three screw systems tested in this experiment feature machined surfaces according to the manufacturers. As far as shape is concerned, Aarhus and Micerium screws are cylindrical, while Spider screw is slightly tapered with a diameter that decreases from 1.5 mm at the neck to 1.3 mm at the tip. With regard to length, Spider screws were 1 mm shorter than the other two tested types, as the manufacturer does not provide 9 mm long screws. However, this small difference in lengths was not expected to be influential, based on the finding of previous clinical studies that mini screws success rates was not significantly correlated with screw length (Miyawaki et al, 2003) (Cheng et al, 2004).

Regarding the resistance of the screws, caveats against tip breakage at insertion or removal can be found in the literature (Melsen 2005) (Park et al, 2006). Although mini screws are intended for single use, in this study no fractures were recorded over five-time repeated insertion and removal of each. Therefore, no relevant fatigue phenomena manifested, and the tapping ability, as quantifiable by resonance frequency, did not significantly decrease. Thus, the chance of screw fracture upon placement in soft bone appears very unlikely based on our data.

The unavailability of transducers adaptable to orthodontic mini screws, besides complicating the experiment by requiring precise soldering, currently precludes the application of resonance frequency analysis in the orthodontic clinic. Nevertheless, this technical problem, apparently not unsolvable by manufacturers, seems to be the only limitation to the applicability of the resonance frequency analysis for testing primary stability of orthodontic mini screws.

In conclusion, the use of the resonance frequency analysis technology deserves attention for its potential to conservatively provide repeatable and comparable
measurements of orthodontic screws retention. In this experiment the method was applied to compare the primary stability of three marketed systems that performed similarly in an experimental model of soft bone. The applicability of the method to screen the retentive potential of differently sized and designed screws or different implantation sites, as well as to assess the impact on stability of clinically relevant loads is yet to be largely explored. It would then be of interest to verify, still through resonance frequency measurements, whether and to what extent screws stability in soft bone is affected by immediate loading with clinically relevant orthodontic forces.
References


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Chapter V
V.1 Summary, conclusions and future directions.

Osseointegrated implants have been a major breakthrough in dentistry. They show a percentage of success that is amongst the highest in the whole medicine (Esposito et al, 1998). The stability of an implant is the key factor for the long-term outcome (Meredith 1998). Primary mechanical stability has to be achieved at placement to allow for undisturbed healing. Secondary stability is the result of osseointegration at the implant interface and allows the distribution of the functional load to the bone. Once achieved with the healing process, secondary stability has to be maintained during the implant functional life that should be regarded as life-long. While implant stability is a concept of well-established importance, the possibility of its quantification in the clinical practice is not as well-established. Resonance Frequency has been proposed like an objective parameter to measure the stability of an implant (Meredith et al, 1996) and its technology has been included in a commercially available apparatus, the Osstell™ equipment. Approximately ten years since its introduction, numerous studies have been carried out with this technique that has gradually been favoured by researchers and clinicians as the standard instrumental parameter for non-invasive stability evaluation.

In the first chapter of this thesis a review of the literature has been provided to evaluate if the method provides diagnostic information on the implant outcome. In addition, the rationale of the study has been presented aiming at demonstrating limits and possibilities of resonance frequency when evaluating implant stability. The review showed how among the factors of influence of the resonance frequency, traditionally described as the stiffness of the interface and the bone-transducer distance (Meredith et al, 1996), there are some that were not adequately taken into account. In particular, the orientation of the transducer
and the shape of the curve associated with the ISQ could affect the specificity and sensitivity of the stability measurements therefore deserving further investigation.

When considering the ability of resonance frequency to prognosticate the outcome of an implant it was distinguished between measurements taken at placement or after a healing period. It is well showed that resonance frequency at placement cannot be used to discriminate if an implant has reached a degree of primary stability sufficient to withstand immediate loading (Aparicio et al, 2006). Rather, it could be used to evaluate the risk of failure of when placing an implant (Glauser et al, 2004) (Sjöström et al, 2007), however it is recognized that repeated measures are more likely to individuate an implant that is losing its stability (Sjöström et al, 2007). Also to be mentioned is the fact that a surgical technique aiming at optimizing cortical anchorage and implant stability could overshadow the quality of the bone that nevertheless remains crucial not only for the possibility to attribute an immediate early loading but also for the whole treatment outcome. As a consequence, the clinical utility of the technique have been questioned in a recent literature review (Aparicio et al, 2006) and although the studies considered were few, it seems clear that the Osstell™ equipment has not been well received when it comes to helping clinicians to decide for early or delayed loading protocols after placement of an implant (Koka 2006). On the other hand, when considering the prognostic value at second surgery it is evident that much less studies have been carried out. In fact, at placement the surgeon has a tactile perception of implant stability while no feedback is obtained at the second surgery. Therefore, in our opinion resonance frequency can be best valuable at second surgery and the studies in the second part of the thesis tried to reveling this utility with a special attention to the edentulous maxilla, the situation when implant losses seems to be higher.
In the second chapter it has been shown how transducer orientation influences resonance frequency in human jaws. In particular the perpendicular orientation results in lower ISQ values. This seems clinically relevant because repeated measurements need to have standardized orientations to detect stability changes. A standardized transducer orientation seems therefore equally important when resonance frequency is used as an outcome measure to compare different types of dental implants (Esposito et al, 2007). In addition, for integrated implants, no correlation was found between the shape of the ISQ curve that is an expression of the damping of the system and a radiographic parameter for the peri-implant trabecular pattern. Therefore no correlation to the implant outcome seems to be attributable to the shape of the wave, with sharp and more rounded plots to be regarded as acceptable.

A focus on the clinical significance of resonance frequency in the rehabilitation of completely edentulous maxillas has been put in chapter 3. The baseline stability for clinically integrated Brånemark implants placed in edentulous maxillas has been given and compared to that of mandibular implants. Implants appeared to be integrated with ISQ values above 53, however this study was descriptive and not prospective, therefore its result can only be used as a reference for integrated implants in edentulous maxillas, but without correlation to a long-term outcome. In the successive study presented in chapter 3, resonance frequency was measured at the second surgery for Astra Tech implants and their outcome was followed up to three years of loading. Data on resonance frequency of the Astra Tech system are lacking in the literature. From our results it appeared that Astra Tech implants with ISQ above 50 ISQ at second surgery would maintain their stability over a three-year period. In addition after the first year of loading the stability of these implants ranges between 53 and 76 ISQ. The last study in chapter 3 measured the stability of Astra Tech implants with a diameter of 3.5 mm placed in maxillas with a knife-
edge resorption (class IV of Cawood and Howell), a non-optimal bone bed. In accordance with previous studies that showed how a high primary stability is achievable in all jawbone regions if an adapted surgical technique is used (Östman et al, 2006), a mean ISQ of 63 was obtained at placement despite dehiscence present at some sites. The mean ISQ at abutment connection and after one year of loading was respectively of 60 and 61 ISQ. Remarkably, regardless of suboptimal bone conditions and reduced diameter, all the implants maintained their stability during the first year of loading, the most critical period for implant failures (Esposito et al, 1998). It has to be highlighted how, for implants with a mean ISQ of 60 at second surgery, resonance frequency seemed to be able to correctly predict stability maintenance during the first year of loading in spite of suboptimal conditions. However, it is recognized that more studies on larger implant samples are needed to confirm these observations on the prognostic value of resonance frequency at second surgery for Astra Tech implants.

In chapter 4 a comparison was presented between three different mini screws for orthodontic anchorage placed in bone of soft quality. Mini screws have no dedicated transducers and therefore they were modified by soldering an abutment on their top. This also allowed for equal exposed implant lengths and type of connection that are essential for result comparability (Pattijn et al, 2006). It was showed how the stability of the three mini screws in soft bone is equivalent if their placement technique is changed to self-drilling.

Future directions
Resonance frequency is the only objective clinical instrument available for non-destructive stability testing. Even though its prognostic value at placement has been questioned, the ability of resonance frequency to monitor the stability of an implant during its function has been showed. It is possible that future studies
will further clarify the correlation between bone boundary conditions and resonance frequency therefore nourishing the perception of the utility of the technique that today is maybe still incompletely understood.

In the future it would be advantageous if improvements in radiographic imaging could be combined with the use of resonance frequency for an optimized planning of the treatment outcome. More studies should evaluate what is the prognostic value of measurements taken at different healing stages of an implant. In addition, loading conditions should be related to resonance frequency to verify if the ISQ indicates an estimate of the biomechanical bearing capacity of the bone, shall this be the case, it could be possible to couple the design of the prosthesis with the specific biomechanical competence of an implant interface.
Gli impianti osteointegrati hanno costituito un’importante innovazione in odontoiatria. Essi mostrano una percentuale di successo che è tra le più elevate dell’intera medicina (Esposito et al, 1998). Il fattore chiave per il successo a lungo termine di un impianto è la sua stabilità (Meredith 1998). Una stabilità meccanica, detta primaria, deve essere ottenuta al momento dell’inserimento dell’impianto per permettere un periodo di guarigione indisturbata. La stabilità secondaria è il risultato dell’osteointegrazione a livello dell’interfaccia implantare e consente di trasmettere all’osso i carichi funzionali. Una volta raggiunta, a seguito del periodo di guarigione, la stabilità secondaria deve essere mantenuta per il periodo funzionale dell’impianto che dovrebbe corrispondere alla vita intera. La stabilità implantare è un concetto di consolidata importanza mentre la possibilità di una sua quantificazione nella pratica clinica non è ancora così ben definita. La frequenza di risonanza è stata proposta come un parametro oggettivo per misurare la stabilità di un impianto (Meredith et al, 1996) e questa tecnologia è stata inclusa in un’apparecchiatura disponibile commercialmente, l’Osstell. Circa dieci anni dopo la sua introduzione, numerosi studi sono stati fatti utilizzando questa tecnica che ha gradualmente raccolto il favore di clinici e ricercatori come standard strumentale per la valutazione non invasiva della stabilità di un impianto.

Nel primo capitolo di questa tesi è stata compiuta una revisione della letteratura per valutare se la metodica fornisca effettivamente indicazioni diagnostiche sul risultato di un impianto. È stato inoltre presentato il razionale di questa tesi volta a dimostrare limiti e possibilità dell’analisi della frequenza di risonanza nella valutazione della stabilità implantare. La revisione ha mostrato come tra i fattori di influenza della frequenza di risonanza, tradizionalmente descritti come la rigidità dell’interfaccia e la distanza del trasduttore dall’osso (Meredith et al,
1996), ve ne siano alcuni altri non presi adeguatamente in considerazione. In particolare, l’orientamento del trasduttore e la forma della curva associata con l’ISQ potrebbero influenzare la specificità e sensibilità delle misurazioni meritando perciò ulteriore studio.

Considerando invece la capacità della frequenza di risonanza di prognosticare il risultato di un impianto, c’è da distinguere tra misurazioni effettuate all’inserimento dell’impianto e dopo un periodo di guarigione. È stato ben dimostrato come la singola misurazione della frequenza di risonanza all’inserimento non sia in grado di riconoscere se un impianto abbia raggiunto un grado di stabilità sufficiente a sostenere un carico immediato (Aparicio et al., 2006). Piuttosto essa potrebbe essere usata per valutare il rischio di fallimento di un impianto appena inserito (Glauser et al., 2004) (Sjöström et al., 2007), anche se è riconosciuto come misure ripetute nel tempo abbiano più probabilità di individuare un impianto che stia perdendo la sua stabilità. Deve essere anche ricordato come una tecnica chirurgica che miri ad ottimizzare l’ancoraggio corticale e la stabilità implantare potrebbe nascondere alla misurazione strumentale l’apporto della qualità ossea. Nondimeno questa rimane di cruciale importanza, non solo per la possibilità di attribuire un carico precoce, ma anche per il risultato complessivo del trattamento. Di conseguenza, l’utilità clinica è stata messa in discussione in una recente revisione della letteratura (Aparicio et al., 2006) e, sebbene gli studi considerati fossero pochi, sembra chiaro come l’Osstell non sia percepito in maniera utile quando si tratti di aiutare il clinico a decidere per un protocollo di carico immediato o precoce dopo l’inserimento di un impianto (Koka 2006). Per contro, è evidente come molti meno studi siano stati focalizzati sul valore prognostico alla seconda chirurgia. Infatti, mentre all’inserimento dell’impianto il chirurgo ha una percezione tattile della stabilità implantare, al momento della seconda chirurgia non si ottiene alcun feedback su questo parametro. Perciò è nostra opinione che la frequenza di risonanza possa
essere di maggior aiuto al momento della seconda chirurgia e gli studi nella seconda parte di questa tesi hanno cercato di rivelare questa utilità con una particolare attenzione alla mascella edentula, la situazione in cui i fallimenti implantari sembrano essere maggiori.

Nel secondo capitolo è stato dimostrato come l’orientamento del trasduttore influenzi la frequenza di risonanza nei mascellari umani. In particolare l’orientamento perpendicolare alla cresta ossea dà luogo a valori di ISQ più bassi. Questo sembra di rilevanza clinica perché misure ripetute devono avere un orientamento standardizzato del trasduttore per individuare cambiamenti di stabilità. Un orientamento standardizzato sembra ugualmente importante se la frequenza di risonanza è utilizzata per paragonare differenti tipi di impianti (Esposito et al, 2007). Inoltre, per impianti integrati, non è stata trovata correlazione tra la forma della curva dell’ISQ che è espressione del damping del sistema e la trabecolatura ossea peri-implantare misurata grazie ad un parametro radiografico. Perciò non sembra attribuibile alla forma dell’onda associata all’ISQ alcuna correlazione con il risultato dell’impianto, con grafici arrotondati o più appuntiti da considerare entrambi come accettabili.

Nel capitolo 3 di questa tesi l’attenzione è stata focalizzata sul significato clinico della riabilitazione della mascella completamente edentula. La stabilità baseline per impianti Branemark inseriti in mascelle edentule e clinicamente integrati è stata ricercata e paragonata a quella di impianti in mandibole edentule. Un valore di ISQ superiore a 53 è apparso descrivere la stabilità degli impianti mascellari integrati. Essendo però questo studio descrittivo e non prospettico, i suoi risultati possono solo essere utilizzati come riferimento per definire impianti integrati nella mascella edentula ma senza correlazione a risultati a lungo termine. Nello studio successivo presentato nel capitolo 3, la frequenza di risonanza è stata misurata alla seconda chirurgia per gli impianti Astra Tech ed il loro risultato monitorizzato per tre anni di carico. Dati sulla
frequenza di risonanza degli impianti Astra Tech sono assenti in letteratura. Dai nostri risultati è apparso che gli impianti con un ISQ superiore a 50 alla seconda chirurgia mantengono la loro stabilità durante un periodo di tre anni. Inoltre dopo il primo anno di carico la stabilità di questi impianti risulta in un range di valori tra 53 e 76 ISQ. L’ultimo studio di questo capitolo ha misurato la stabilità di impianti Astra Tech di diametro 3.5 mm inseriti in mascellari con un riassorbimento crestale a lama di coltello, un letto osseo non ottimale. In accordo a studi precedenti che hanno mostrato come una buona stabilità sia raggiungibile in tutte le aree dei mascellari se viene utilizzata una tecnica chirurgica adattata (Östman et al, 2006), un valore medio di 63 ISQ è stato ottenuto all’inserimento nonostante le deiscenze presenti in alcuni siti. Il valore medio di ISQ alla connessione dei pilastri protesici e dopo un anno di carico era rispettivamente di 60 e 61 ISQ. È interessante notare come gli impianti di questo studio, sebbene in volumi d’osso non ottimali e di diametro ridotto, abbiano mantenuto la loro stabilità durante il primo anno di carico, il periodo in cui i fallimenti sono più frequenti. Quindi, nonostante le condizioni non ottimali, sembra che la frequenza di risonanza sia in grado di predire in maniera corretta il mantenimento della stabilità durante il primo anno di carico, per impianti con un ISQ medio maggiore di 60 alla seconda chirurgia. Comunque, maggiori studi su campioni più numerosi di impianti sono necessari per confermare queste osservazioni sul valore prognostico dell’analisi della frequenza di risonanza alla seconda chirurgia per gli impianti Astra Tech.

Nel capitolo 4 è stato presentato uno studio comparativo fra tre differenti tipi di mini viti per ancoraggio ortodontico inserite in osso di qualità soffice. Le mini viti non hanno trasduttori dedicati perciò sono state modificate saldandovi in cima un pilastro protesico compatibile con i trasduttori Osstell. Questo ha anche consentito di ottenere equivalenti lunghezze della parte esposta sopraossea e lo stesso tipo di connessione per tutte e tre le mini viti. È stato dimostrato come la
stabilità delle tre mini viti testate è equivalente se viene impiegata una tecnica di inserimento auto fresante.

Direzioni future
La frequenza di risonanza è il solo strumento clinico oggettivo disponibile per l’analisi non distruttiva della stabilità di un impianto. Sebbene il suo valore prognostico all’inserimento sia stato messo in discussione, la capacità della tecnica di monitorare la stabilità di un impianto durante la sua funzione è stata dimostrata. È possibile che in studi futuri chiarificheranno ulteriormente la correlazione tra le condizioni dell’osso peri-implantare e la frequenza di risonanza in modo da alimentare la percezione dell’utilità della tecnica che oggi ancora non è forse completamente capita.
Sarebbe molto vantaggioso se in futuro se miglioramenti nelle tecniche di immagine radiografica potranno essere combinati con l’utilizzo della frequenza di risonanza per una pianificazione ottimizzata dei risultati del trattamento. Ulteriori studi dovranno valutare quale sia il valore prognostico di misurazioni fatte in differenti momenti del periodo di guarigione. Inoltre, le condizioni di carico dovrebbero essere correlate alla frequenza di risonanza per verificare se l’ISQ fornisca una stima delle capacità biomeccaniche dell’osso, sarebbe possibile in questo caso personalizzare il disegno della protesi con la specifica competenza biomeccanica di una specifica interfaccia osso-impianto.
V.3 Resumen, conclusiones y direcciones futuras

La introducción de los implantes osseointegrados en el tramo de la Odontología ha dado inicio a una nueva era. A partir de sus primeros utilizos clínicos, los implantes osseointegrados reportaron un porcentaje de éxito que es uno de lo más alto en todas las ramas de la Medicina (Esposito et al., 1998). La estabilidad de un implante es la propiedad llave para lograr un buen pronóstico a largo plazo (Meredith 1998). De hecho, la estabilidad mecánica primaria tiene que ser alcanzada al momento del posicionamiento del implante para favorecer una completa cicatrización. Mientras que la estabilidad secundaria es la que deriva de la osseoitegración a nivel de la interfase del implante permitiendo así una distribución adecuada de las cargas funcionales a nivel óseo. Una vez acabado el proceso de cicatrización, la estabilidad secundaria tiene que ser mantenida durante toda la vida funcional del implante. Aunque si la importancia de la estabilidad de un implante ha sido ya bien interpretada, aún no se ha solucionado la posibilidad de cuantificarla en la práctica clínica. El análisis de frecuencia de resonancia ha sido propuesta como parámetro útil para medir la estabilidad del implante dental (Meredith et al., 1996) y últimamente en el mercado dental son disponibles dispositivos como por ejemplo lo de Osstell™. Después de diez años desde su primer utilizo, han sido desarrollados varios estudios sobre este aparado y con el tiempo ha sido muy agradecido desde investigadores y clínicos que lo han explotado para valoraciones no invasoras de la estabilidad del implante dental.

En el Capítulo 1 de esta tesis doctoral, se presentó una revisión de la literatura para analizar si la metodología sobrescrita ofrezca adecuadas informaciones diagnosticas cerca de los resultados a largo plazo de los implantes dentales. Además, el objetivo del estudio fue lo de presentar limites y posibilidades del análisis de frecuencia de resonancia al momento de evaluar la estabilidad del
implante. La revisión enseñó como entre los varios factores influyentes, tradicionalmente descritos como compactez a nivel de la interfase implantar y distancia hueso-transductor (Meredith et al., 1996), existan algunos de aquellos que nunca fueron efectivamente considerados. En particular, la orientación y la forma de la curva asociada a ISQ que puede influenciar la especificidad y sensibilidad de las medidas de la estabilidad.

Para pronosticar el éxito de un implante a través de esta análisis tenemos que distinguir entre las medidas sacadas al momento de posicionar el implante o después al periodo de cuarición. Hasta hoy no se reconoce la capacidad del análisis de frecuencia de resonancia de entregarse si un implante haya alcanzado el grado de estabilidad primaria suficiente como para soportar una carga inmediata (Aparicio et al., 2006). Más bien, el análisis puede ser utilizada para prever el riesgo de fracaso al momento de colocar el implante (Glauser et al., 2004) (Sjöström et al., 2007). De toda forma, está bien valorado como medidas repetidas pueden ayudarnos en individuar la falta de estabilidad del implante (Sjöström et al., 2007). No tenemos que olvidar que una técnica quirúrgica que mejore el ancoraje cortical y estabilidad del implante tiene que superar la calidad ósea que de su parte es muy importante no solamente en termino de consentir el colocamiento de una eventual carga inmediata si no también para todo el éxito final del tratamiento. La eficacia clínica de estas técnicas han sido analizadas en una reciente revisión de la literatura (Aparicio et al., 2006) y aunque si las investigaciones hasta ahora no sean demasiadas, parece que aún no se haya definido en que momento Osstell pueda dirigir los clínicos en elegir una carga inmediata o posdergada de los implantes (Koka, 2006). De otra parte, al considerar el pronóstico en la segunda cita quirúrgica, se hace hincapié aún más de como hasta ahora el asunto no ha sido tratado adecuadamente. En efecto, en la primera cirugía, coincidente con el colocamiento del implante, el cirujano percibe táctilmente la presencia de
estabilidad implantar, la misma que pero a veces ya falta en la segunda cita. El autor de esta tesis doctoral está convencido que el análisis de frecuencia de resonancia representa un válido soporte durante la segunda cirugía, por lo tanto las investigaciones presentadas en el Capítulo 2 entretuvieron de comprobar la eficacia del análisis, concentrando particularmente la atención a las maxilas completamente edéntulas, donde hay mayor porcentaje de fracaso.

El Capítulo 2 relató cómo la orientación del transductor pueda influenciar la frecuencia de resonancia en la mandíbula humana. Particularmente, la dirección perpendicular del transductor resultó en valores menores de ISQ. Este asunto parece clínicamente relevante ya que medidas repetidas tienen que tener orientaciones estandarizadas para poder notificar alteraciones en la estabilidad del implante. Medidas estándar parecen igualmente importantes si se utiliza el análisis para confrontar diferentes tipos de implantes (Esposito et al., 2007).

Con respecto a los implantes osseointegrados, no se encontró ninguna correlación entre la forma de la curva de ISQ (representante la expresión de la preservación del implante) y el parámetro radiográfico del implante dental. Pero aún no hay relación segura de estos resultado y la forma de la curva, más bien son aceptadas como válidas las áreas mas redondas y nitidas.

El Capítulo 3 focalizó sobre el uso clínico de frecuencia de resonancia para rehabilitar maxilas completamente edéntulas. Clínicamente se estableció una estabilidad de base para los implantes Branemark puestos en maxilas edéntulas y luego estuvieron confrontada con las medidas sacadas en los implantes mandibulares. Los implantes en cuestión parecieron integrarse con lo valores de ISQ sobre 53, aunque si este estudio se formuló más de una forma descriptiva y no perspectiva; desde un punto de vista, estos resultados pueden servir al cirujano como indicación clínica para el tratamiento implantar de maxilas edéntulas, desde luego sin relacionarlos con resultados a largo plazo. En la segunda investigación del Capítulo 3, se midió la frecuencia de resonancia de
implantes Astra Tech durante la segunda cirugía y por los tres años siguientes. En la literatura dental no se encuentran datos cerca la frecuencia de resonancia de implantes Astra Tech. El estudio evidenció que los implantes Astra Tech con valores de ISQ sobre 50 mantuvieron sus estabilidades durante todos los tres años. Al fin del primer año de carga, la estabilidad implantar varió entre 53 y 76 ISQ. En el último estudio del Capítulo 3 se midió la estabilidad de implantes Astra Tech con diametro de 3.5 mm colocados en maxilas que presentaban una reabsorción a ángulo de cuchilla (clase IV de Cawood y Howell), entonces en una situación poco óptimal. Según cuanto reportado en investigaciones recién hechas, se puede obtener una aceptable estabilidad primaria en todos los huesos maxilares cuando y solo se utilice una técnica quirúrgica idónea (Ostman et al., 2006), y en estos casos pueden lograrse valores ISQ de 63 ya al momento de poner el implante, aunque si se trabaja en áreas que presentan deiscencias. Los promedios resultantes al momento de la coneción del abutment y después de un año fueron respectivamente 60 y 61 ISQ. Con respecto a la calidad y diametro óseo, todos los implantes empleados en el estudio mantuvieron sus estabilidad durante el primer año, que es el periodo mas crítico para la vida del implante (Esposito et al., 1998). Tenemos que evidenciar como, en caso de implantes con promedio de 60 ISQ obtenido durante la segunda cirugía, la frecuencia de resonancia puede ser útil para predicir el mantenimiento de la estabilidad implantar durante el primer año, aunque si son colocados en condiciones óseas suboptimal. De toda manera, se necesitan de ulteriores investigaciones, specialmente para los implantes con diametro mayores así que los resultados logrados en este enfoque puedan ser igualmente convalidados.

En el Capítulo 4 se compararon varios tipos de mini screw utilizadas para el anclaje ortodontico en presencia de tejido óseo de buena calidad. Ya que no hay transductor, las mini screws fueron modificadas ponendo un abutment en cima de ellas. Esto permitió también de exponer una igual cantidad de implantes y
connector, permitiendo así una confrontación (Pattjin et al., 2006). Resultó que la estabilidad de las tres mini screws en el tejido óseo esponjoso fue equivalente a cuando se posicionaron en modalidad auto-drilling.

Direcciones futuras
El análisis de frecuencia de resonancia es la sola que nos permita medidas de la estabilidad de un implante dental de una manera no destructiva. Aunque si el valor prónostico de esta metodología ha sido muy cuestionado, este estudio enseñó la capacidad del análisis de frecuencia de resonancia de monitorar la estabilidad del implante durante su trabajo. Puede ser que investigaciones futuras puedan fornir clarificaciones sobre la relación entre la calidad ósea y frecuencia de resonancia, ya que al día de hoy esta situación no ha sido bien entendida.

Podría ser vantajoso mejorar las imágenes radiográficas y combinarlas con el análisis de frecuencia de resonancia para ayudar el clínico en el presumir los resultados del tratamiento. Los estudios deberían focalizarse sobre el valor pronóstico de las medidas sacadas en diferentes estadios de cicatrización del implante. Además, las condiciones de cargas funcionales del implante deberían ser relacionadas a la frecuencia de resonancia para verificar si el ISQ pueda darnos una indicación de la capacidad biomecánica del hueso, porqué en este caso sería posible practicar una unión entre el dibujo de la prótesis y la competencia biomecánica de la interfase del implante dental.

Im ersten Kapitel dieser Dissertation wurde eine Literaturübersicht erstellt, um zu beurteilen, ob die oben vorgeschlagene Methode diagnostische Informationen über den Erfolg des Implantates geben kann. Außerdem wurde das Grundprinzip der Studie dargestellt, und die Grenzen sowie die Möglichkeiten der Resonanzfrequenz für die Bewertung der Stabilität eines Implantates einzusetzen. Die Literaturübersicht hat gezeigt, dass zwischen den
Faktoren, die die Resonanzfrequenz beeinflussen, traditionell beschrieben als die Festigkeit der Zwischenzone und die Distanz zwischen Knochen und Signalumwandler (Meredith et al., 1996), es welche gibt, die nicht angemessen angerechnet wurden. Die Ausrichtung des Signalumwandlers und die Form der Kurve, die mit dem ISQ im Zusammenhang gebracht wird, können die Spezifizität und die Empfindlichkeit der Messungen der Stabilität besonders beeinflussen. Daher sollten zu diesem Thema weitere Untersuchungen durchgeführt werden. Wenn die Fähigkeit der Resonanzfrequenz in Betracht gezogen wird, um den Erfolg eines Implantates vorauszusagen, gibt es einen Unterschied zwischen Messungen beim Einsetzen des Implantates und Messungen nach der Heilung. Es wurde bereits beschrieben, dass die Resonanzfrequenz beim Einsetzen des Implantates nicht verwendet werden kann, um zu bestimmen, ob das Implantat genügend primäre Stabilität erreicht hat, um den sofortigen Lastdruck auszuhalten (Aparicio et al., 2006). Im Gegenteil kann sie verwendet werden, um das Risiko von Misserfolg beim Einsetzen des Implantates zu bewerten (Glauser et al., 2004) (Sjöström et al., 2007). Es ist jedoch wohlbekannt, dass mit wiederholten Messungen eines Implantates, der Verlust der Stabilität besser erkannt werden kann (Sjöström et al., 2007). Erwähnenswert ist auch, dass eine chirurgische Technik, die auf die Optimierung der kortikalen Befestigung und der Stabilität des Implantates ausgerichtet ist, die Qualität des Knochens überschatten kann. Diese ist jedoch, entscheidend, nicht nur um einen sofortigen Lastdruck aufzubringen, sondern auch für den Erfolg der gesamten Behandlung. Daher, wurde die klinische Anwendung dieser Technik in einer neuen Literaturübersicht in Frage gestellt (Aparicio et al., 2006). Auch wenn nur wenige Studien in Betracht gezogen wurden, es scheint klar zu sein, dass das Osstell™ Gerät nicht ausreichend anerkannt wurde, um den Zahnärzten in die Entscheidung zwischen einem sofortigen oder verschobenen Lastdruck nach

suboptimalen Bedingungen des Knochens. Dennoch, werden weitere Untersuchungen mit mehreren Implantaten gebraucht, um diese Ergebnisse über die prognostische Wirkung der Resonanzfrequenz bei der zweiten Chirurgie für Astra Tech-Implantate zu bestätigen.


Zukünftige Richtungen

Die Resonanzfrequenz ist das einzige objektive klinische Gerät für die nicht destruktive Bewertung der Stabilität des Implantates. Auch wenn ihre prognostische Wirkung beim Einsetzen des Implantates in Frage gestellt wurde, wurde die Fähigkeit der Resonanzfrequenz, die Stabilität eines Implantates während der Funktion zu kontrollieren, bewiesen. Es ist möglich, dass zukünftige Untersuchungen die Korrelation zwischen den Bedingungen des perimplantären Knochens und der Resonanzfrequenz weiter erklären werden, so dass die Wahrnehmung der Tauglichkeit der Technik erhöht wird, die heutzutage vielleicht noch nicht völlig verstanden wird.

Es wäre günstig, wenn in der Zukunft die Verbesserungen der röntgenographischen Aufnahme-Technik in Zusammenstellung mit der Verwendung der Resonanzfrequenz gebracht würden, um die Ergebnisse der Behandlung optimal zu planen. Weitere Untersuchungen sollen die
Implantes osseointegrados têm sido um dos avanços mais importantes em Odontologia. Eles mostram um percentual de sucesso que está dentre os mais altos de toda a Medicina (Esposito et al, 1998). A estabilidade de um implante é a chave para o sucesso a longo prazo (Meredith 1998). Estabilidade mecânica primária é registrada no tempo cirúrgico da sua colocação. Já a estabilidade secundária é o resultado da osseointegração na interface do implante, permitindo a distribuição de cargas funcionais ao osso. Uma vez atingida, a estabilidade secundária tem que ser mantida durante a vida funcional do implante, que é chamada de vida-útil. Enquanto a estabilidade de um implante é um conceito de importância bem estabelecido, a possibilidade da sua quantificação em termos práticos clínicos ainda não foi bem estabelecida. Freqüência de Ressonância tem sido proposta como um parâmetro objetivo para mensurar a estabilidade de um implante (Meredith et al, 1996) e sua tecnologia tem sido incluída em dispositivos comerciais disponíveis no mercado, o equipamento Osstell™. Desde sua introdução há 10 anos, diversos estudos têm sido aceitos com essa técnica, que vem gradualmente privilegiando pesquisadores e clínicos como um parâmetro padrão ativo para a quantificação não invasiva da estabilidade.

No primeiro capítulo dessa tese foi feita uma revisão de literatura para avaliar se esse método oferece informações de diagnóstico do resultado de um implante. Além disso, a razão do estudo foi obter metas para demonstrar os limites e as possibilidades da freqüência de ressonância em avaliar a estabilidade de um implante. A revisão mostrou que dentre os fatores que influenciam a freqüência de ressonância, tradicionalmente descrita como a rigidez da interface e a distância do osso à sonda (Meredith et al, 1996), alguns não são adequadamente levados em consideração. Em particular, a orientação
da sonda e a forma da curvatura associada a ISQ podem afetar a especificidade e a compreensão das medidas de estabilidade e, assim, merecem novas investigações.

Quando se considera a habilidade da frequência de ressonância em prognosticar o sucesso de um implante, tem que se distinguir entre as medidas tomadas na colocação ou após o período de cicatrização. Já se relatou que a frequência de ressonância não pode ser usada para discriminar se um implante alcançou estabilidade primária suficiente para suportar cargas imediatas (Aparicio et al, 2006). De certo modo pode ser utilizada para avaliar os riscos de fratura durante a colocação de um implante (Glauser et al, 2004) (Sjöström et al, 2007), no entanto, é reconhecido que medidas repetidas são provavelmente mais para individualizar um implante do que para verificar a estabilidade (Sjöström et al, 2007). Deve ser mencionado também que uma técnica cirúrgica que objetiva o aprimoramento da ancoragem cervical e a estabilidade do implante pode exceder a qualidade do osso, o que por outro lado, é crucial não só para a possibilidade de atribuir uma carga imediata, mas também para o sucesso de todo o tratamento. Como conseqüência, a utilidade clínica dessa técnica foi questionada recentemente em uma revisão de literatura (Aparicio et al, 2006) e, apesar de pouco estudos terem sido considerados, parece claro que o equipamento Osstell™ não agradou quando este deveria ajudar os clínicos a decidir entre carga imediata ou tardia após a colocação do implante (Koka 2006). Por outro lado, quando se considera o prognóstico em uma segunda cirurgia é evidente que muito menos estudos foram desenvolvidos. De fato, durante a colocação o cirurgião tem a percepção tátil da estabilidade do implante, enquanto em uma segunda cirurgia não há esse “feedback”. Assim, em nossa opinião a frequência de ressonância pode ter uma ótima legitimidade na segunda cirurgia e o estuda na segunda parte dessa tese tenta revelar essa
utilidade com atenção especial à maxilas edêntulas, situação em que perdas de implantes são bem mais frequentes.

No segundo capítulo foi mostrado quanto a orientação da sonda influencia na frequência de ressonância em mandíbulas de humanos. Em particular a orientação perpendicular resulta em valores de ISQ menores. Isso parece ser clinicamente relevante já que as mensurações repetidas devem ter orientações padronizadas para detectar mudanças na estabilidade. Uma orientação padronizada da sonda parece, no entanto, ter igual importância quando a frequência de ressonância é usada para medidas conclusivas para se comparar diferentes tipos de implantes dentais (Esposito et al., 2007). Além disso, para implantes integrados, não foram encontradas correlações entre as formas de curvatura ISQ, o que pode ser uma expressão da falha do sistema e um parâmetro radiográfico para os padrões do trabeculado peri-implante. No entanto, a não correlação com os resultados do implante parece ser atribuída à forma da onda, com design mais pontiagudo e arredondado do que se considera aceitável. Uma especial atenção na significância clínica da frequência de ressonância na reabilitação de maxilas edêntulas foi dada no capítulo 3. A estabilidade primária para implantes clinicamente integrados de Brånemark colocados em maxilas edêntulas tem sido mensurada e comparada com a de implantes mandibulares. Implantes aparecem como integrados com valores de ISQ acima de 53, no entanto, esse estudo foi descritivo e não prospectivo. Assim, esses resultados podem apenas ser usados como uma referência para implantes integrados em maxilas edêntulas, sem correlação com conclusões a longo prazo. No estudo sucessivo apresentado no capítulo 3, frequência de ressonância foi usada para mensurar na segunda cirurgia para implantes Astra Tech e seus resultados foram acompanhados por 3 anos de carregamento. Dados de frequência de ressonância do sistema Astra Tech estão faltando na literatura. Pelos nossos resultados parece que implantes Astra Tech com valores
de ISQ acima de 50 na segunda cirurgia seriam suficientes para manter a estabilidade por 3 anos. Além disso, após o primeiro ano de carregamento a estabilidade desses implantes variou entre 53 e 76 ISQ. O último estudo do capítulo 3 mediu a estabilidade de implantes Astra Tech com diâmetro de 3,5 mm colocados em maxilas com reabsorção de ponta de faca (classe IV de Cawood e Howell), leito ósseo não ideal. De acordo com estudos prévios que demonstraram como uma alta estabilidade primária é alcançada em todas as regiões da mandíbulas se uma técnica cirúrgica adaptada é usada (Östman et al, 2006), uma média de ISQ de 63 foi obtida durante a colocação independente da presença de deiscência em alguns pontos. Os valores médios de ISQ nas conexões do abutment e após 1 ano de carregamento foram respectivamente 60 e 61 ISQ. Admiravelmente, apesar das condições sub-ótimas do osso e o diâmetro reduzido, todos os implantes mantiveram suas estabilidades durante o primeiro ano de carregamento, período mais critico para as falhas em implantes (Esposito et al, 1998). Deve ser enfatizado como, para implantes com valores médios de ISQ de 60 em uma segunda cirurgia, a frequência de ressonância parece ser capaz de predizer corretamente a manutenção da estabilidade durante o primeiro ano de carregamento, mesmo em condições sub-ótimas. No entanto, deve se reconhecer que mais estudos em amostras maiores são necessários para confirmar essas observações no prognóstico dos valores da frequência de ressonância em uma segunda cirurgia para implantes Astra Tech.

No capítulo 4 uma comparação entre três diferentes mini parafusos para ancoragem ortodôntica em osso esponjoso foi apresentada. Mini parafusos não têm sondas específcas e portanto, eles foram modificados pela solda de um abutment no topo. Isso permite uma exposição por igual no comprimento do implante e o tipo de conexão que é essencial para a comparação dos resultados (Pattijn et al, 2006). Foi demonstrado como a estabilidade de 3 min implantes
em osso esponjoso é equivalente quando a técnica cirúrgica de colocação é alterada para auto-aparafusada.

Direções futuras
Freqüência de ressonância é o único instrumento clínico disponível para testes não destrutivos. Apesar dos valores no prognóstico durante a colocação terem sido questionados, a habilidade da freqüência de ressonância em monitorar a estabilidade de um implante durante sua função foi demonstrada. É possível que novos estudos clarifiquem a correlação entre as condições ósseas limites e a freqüência de ressonância, consequentemente beneficiando a percepção da utilização dessa técnica, que hoje em dia é ainda parcialmente não entendida.
No futuro poderia ser vantajoso se melhorias nas imagens radiográficas pudessem ser combinadas com o uso da freqüência de ressonância para otimizar o planejamento dos resultados do tratamento. Mais estudos deveriam avaliar o que é o valor do prognóstico medido em diferentes fases do tratamento de um implante. Além disso, condições de carregamento deveriam estar relacionadas com a freqüência de ressonância para verificar se ISQ indica uma estimativa da capacidade biomecânica do osso, e se for o caso, seria possível unir o design de uma prótese com a capacidade biomecânica específica da interface de um implante.
V.6 Résumé, conclusions et directions futures

Les implants osteointegrat ont constitué une importante innovation en odontologie. Le succès clinique est un des plus élevés de la médecine (Esposito et al, 1998). La chose la plus important pour un succès durable de l’implant est sa stabilité (Meredith 1998). Une stabilité mécanique, qu’on appelle primaire, doit être obtenue au moment de l’insertion de l’implant pour permettre la guérison en paix. La stabilité secondaire est le résultat de l’ostéointegration au niveau de l’interface de l’implant et permet d’transmettre à l’os les charges fonctionnels. Une fois obtenue, après la période de guérison, la stabilité secondaire doit être maintenue tout le long la période fonctionnel qui devrait correspondre à la vie entière. La stabilité de l’implant est un concept très important tandis que la possibilité de sa quantification dans la pratique clinique n’est pas encore bien définie. La fréquence de résonance a été proposé comme paramètre objective au fin de mesurer la stabilité d’un implant (Meredith et al, 1996) et cette technologie a été incluse dans une appareil disponible dans le commerce, l’Osstell. A peu près dix ans après son introduction de nombreux études ont été faits en employant cette technique qui a graduellement recueillis la faveur des opérateurs et des chercheurs comme le standard instrumentale pour l’évaluation non invasive de la stabilité de l’implant.

Dans le premier chapitre de cette thèse a été accomplie une révision de la littérature pour évaluer si la méthode fournit en effet des indications diagnostiques sur les résultats de l’implant. On a aussi présenté le but de cette thèse qui veut démontrer les limites et le possibilités de l’analyse de la fréquence de résonance dans l’évaluation de la stabilité de l’implant. La révision a montré que parmi les facteurs importants de la fréquence de résonance, qui traditionnellement étaient la rigidité de l’interface et la distance du transducteur de l’os (Meredith et al, 1996), il y en a aussi d’autres qui n’étaient pas encore considérés d’une manière adéquate. En particulier,
l’orientation du transducteur et la forme de la courbe associé à l’ISQ pourraient influencer la spécificité et la sensibilité des mesures qui méritent par conséquent une étude ultérieure.

Au contraire si l’on considère la capacité de la fréquence de résonance de prévoir le résultat de l’implant, il faut distinguer entre les mesures effectuées à l’insertion de l’implant et après la période de guérison. On a bien démontrés que la single mesure de la fréquence de résonance à l’insertion n’est pas capable de démontrer si un implant a rejoint un degré de stabilité suffisant à soutenir une charge immédiate (Aparicio et al, 2006). On pourrait plutôt l’employer pour évaluer le risque de faillite d’un implant qu’on vient d’insérer (Glauser et al, 2004) (Sjöström et al, 2007), même si l’on reconnaît que des mesurassions répété dans le temps ont une plus grande possibilité de prévoir un implant qui va perdre sa stabilité. On doit aussi rappeler que une technique chirurgical qui tend à optimiser l’ancrage corticale et la stabilité de l’implant pourrait cacher à la mesure instrumentale l’apport de la qualité de l’os. même si elle reste d’importance cruciale, pas seulement pour la possibilité de faire une charge précoce, mais aussi pour le résultat totale du traitement. En effet, l’utilité clinique a été mise en discussion dans une récent révision de la littérature (Aparicio et al, 2006). même si les études considérées, étaient peux, il est évident que l’Ostell n’est pas considérer d’une façon utile quand il s’agit d’aider l’opérateur à décider pour le charge précoce après l’insertion d’un implant (Koka 2006). Par contre il est évident que peux études ont été directionnées à la valeur pronostique à la deuxième chirurgie. En effet, tandis que à l’insertion de l’implant opérateur peut évaluer tactilement la stabilité de l’implant, au moment de la deuxième chirurgie on n’obtient aucun renseignement sur cette paramètre. Pour cela on pense que la fréquence de résonance peut aider au moment de la deuxième chirurgie et les études dans la deuxième partie de cette thèse ont cherché à relever cette utilité avec une
particulière attention à la mâchoire ou les faillites implantaires sont nombreuses.
Dans le deuxième chapitre on a démontré que l’orientation du transducteur influence la fréquence de résonance dans la mâchoire. En particulier, l’orientation perpendiculaire à la crête de l’os montre des mesure de ISQ plus bas. Cela est cliniquement relevant parce que des mesurassions répétés doivent avoir une orientation standardizés du transducteur pur voir des changes de stabilité. Une orientation standardizés semble également importante si la fréquence de résonance est employées pour mettre en comparaison des types différent d’implants (Esposito et al, 2007). De plus, au regard des implant intégrés on n’a pas trouvé des corrélations entre la forme de courbe de l’ISQ qui exprime le damping du système et la qualité de l’os autour de l’implant mesuré avec un paramètre radiographique. Pour cela on ne peut pas attribuer à la forme de l’onde associé à l’ISQ aucun corrélation avec le résultat de l’implant.
Dans le troisième chapitre de cette thèse on considère en particulier la signification clinique de la réhabilitation de la mâchoire totalement sans dents. La stabilité baseline pour des implants Branemark insérés dans des mâchoires sans dents et cliniquement intégrés a été recherché et comparé à la stabilité des implant insérés dans des mandibules. Une valeur de ISQ supérieure à 53 semble décrire la stabilité des implants dans la mâchoire intégrés. Cette étude est descriptive et pas perspective ses résultats peuvent être employés seulement pour définir des implant intégrés dans la mâchoire sans dents mais sans corrélation à des résultats à long terme. Dans l’étude successive la fréquence de résonance a été mesuré à la deuxième chirurgie pour les implants Astra Tech et le résultat a été contrôlé pendant trois ans de charges. On n’a pas des résultat sur la fréquence de résonance des implants Astra Tech. Après nos études on a vus que des implants avec une ISQ supérieure à 50 a la deuxième chirurgie conservent leur stabilité pendant une période de trois ans. De plus, après la
première année de charge la stabilité de ces implants résultent dans une range de valeur entre 53 et 76 ISQ. La dernière part de ce chapitre a mesuré la stabilité d’implants Astra Tech de diamètre 3.5 mm insérés dans des mâchoires bien réabsorbés, une zone ‘insertion pas optimale. Des études précédents montrent que l’on peut rejoindre une stabilité optimale dans toutes zones de la mâchoire si l’on emploie une procédure chirurgical adapté (Östman et al, 2006), une valeur moyenne de 63 ISQ a été obtenu à l’insertion même si l’os n’été pas optimale. La valeur moyenne de ISQ au moment de la connection des piliers protesiques et après un an de charge étaient respectivement de 60 e 61 ISQ. Il est intéressant de relever que les implants de cette étude, même si dans des volumes d’os réduite ont maintenue leur stabilité pendant la première année de charge, la période dans laquelle les faillites sont les plus fréquentes. Par conséquent, même si les conditions n’étaient pas les meilleurs il semble que la fréquence de résonance est en gré de prévoir le maintien de la stabilité pendant la première année de charge s’il s’agit d’implant avec un ISQ moyen supérieure de 60 ö la deuxième chirurgie. De toute façon, d’autres études sur des echantillion plus nombreux d’implant sont nécessaire pur confirmer ces observations sur la valeur prognostique de l’analyse de la fréquence de résonance à la deuxième chirurgie pour des implants Astra Tech. 

Dans le quatrième chapitre on a présenté une étude comparative parmi trois différent type de mini-vis pour l’ancrage orthodontique insérées dans un os de qualité souffle. Les mini-vis n’ont pas de transducteur dédiés, pour cela on a modifié l’original. De cette façon on a pu obtenir des équivalent longueurs de la partie exposé et le même types de connections pour les trois mini-vis. On a démontrés que al stabilité est équivalent si l’on emploie une particulière technique d’insertion.
Directions futures
La fréquence de résonance est le seul instrument clinique objective disponible pour l’analyse pas destructive de la stabilité d’un implant. même si la valeur prognostique à l’insertion à été mise en discussion, la capacité de la technique de contrôler la stabilité d’un implant pendant sa fonction a été démontrée. Il est possible que dans des études future on pourra clarifier ultérieurement la corrélation entre les condition de l’os autour de l’implant et la fréquence de résonance de manière à alimenter la perception de l’utilité de la technique que peut être aujourd’hui on ne comprend pas complètement. opérateur pourrait être aider si en future les améliorations dans les technique d’image radiographique pourraient seront combinés avec l’utilisation de la fréquence de résonance pour une planification optimale des résultats de traitement. Avec d’ultérieures études on doit évaluer qu’elle est la valeur pronostiques des mesurassions faites dans des moments différent de la période de guérison. De plus, on devrait corréler les conditions de charge à la fréquence de résonance pour contrôler si L’ISQ fournit une estime de la capacité bio-mécanique de l’os. Dans ce cas on pourrait personnaliser le dessin de la prothèse avec la compétence biomécanique d’une spécifique interface entre l’os et l’implant.
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International Publications


**National Publications**


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