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Risks factors associated with orthodontic temporary anchorage device failures

A systematic review

INAUGURAL-DISSERTATION
zur Erlangung der Doktorwürde der Zahnmedizin
der Medizinischen Fakultät
der Universität Zürich

vorgelegt von
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Zürich 2009

to my beloved mother

Inhaltsverzeichnis

1. Zusammenfassung:

Ziel: Das Ziel dieser Studie war, systematisch die Literatur nach Risikofaktoren zu untersuchen, die mit einem vorzeitigen Verlust von temporären skelettalen Verankerungen (TSV) (Gaumenimplantaten, Miniplatten, Onplants® und Minischrauben) assoziiert sind.

Material und Methoden: Zur Identifizierung der Risikofaktoren und der Wahrscheinlichkeit für den vorzeigtigen TSV Verlust wurden lediglich randomisierte klinische Studien und prospektive Kohortenstudien herangezogen. Mittels einer manuell ergänzten elektronischen Medline-Suche wurden Studien über Gaumenimplantate, Miniplatten, Onplants® und Minischrauben mit einer durchschnittlichen Beobachtungszeit von mindestens 12 Wochen und mindestens 10 Einheiten ausgewählt. Die Patienten mussten bei den Nachkontrollen auch klinisch untersucht worden sein.

Resultate: Die Suche lieferte 390 Titel und 71 Abstracts. Die Analyse des gesamten Textes erfolgte bei 34 Artikeln, von denen 10 Studien, die Einschlusskriterien erfüllten. Für Onplants® stellten das chirurgische Vorgehen und eine ungünstige anatomische Struktur des harten Gaumens die grössten Risikofaktoren für einen vorzeitigen Verlust dar. Folgende Faktoren zeigten für Minischrauben einen direkten Zusammenhang mit einer erhöhte Verlustrate: Schraubendurchmesser, Eindrehwiderstand bei Minischrauben-Insertion, die rechte Patientenseite, Entzündung aufgrund von ungenügender Mundhygiene, nicht-keratiniserte Mukosa und Schrauben-Beweglichkeit im Verlaufe der Behandlung. Bezüglich des Insertionsortes (Maxilla vs. Mandibula) konnten keine eindeutigen Schlussfolgerungen gezogen werden. Bei Gaumenimplantaten stellt die aufgrund des Implantat-Designs kritische Implantat-Insertion das grösste Risiko dar. Da Miniplatten mit mindestens 2 Minischrauben fixiert werden, haben diese ähnliche Risikofaktoren wie Minischrauben: Schleimhaut-Entzündung aufgrund von ungenügender Mundhygiene um die Platten oder nicht-keratiniserte Mukosa. Zusätzlich wurde über eine erhöhte Verlustrate bei wachsenden Patienten berichtet.

Schlussfolgerung: Die Verwendung von TSV erweitert das Spektrum an skelettalen und dentalen Abweichungen, in denen eine kieferorthopädische Behandlung erfolgreich sein kann. Die Kenntnis möglicher Risiko-Faktoren, die zu einem vorzeitigen Verlust von TSV führen können, ist entscheidend für die kieferorthopädische Behandlungsplanung. Die Verlust-Dynamik ist ein weiterer entscheidender Faktor, da bei einem allfälligen vorzeitigen Verlust, eine Änderung des Behandlungsplanes schwierig bis unmöglich ist. Es sind weitere prospektive Kohortenstudien mit klaren Selektionskriterien notwendig, um weitere Risiko-Indikatoren auf deren Relevanz prüfen zu können.

2. Introduction

Anchorage in orthodontics

In orthodontics, anchorage is a prerequisite for the application of therapeutic forces, and can limit their successful use. Its control is therefore essential. The term “orthodontic anchorage” denotes the nature and degree of resistance to displacement expected from an anatomic unit. Ideal orthodontic anchorage should thus result in a maximum of desired dental movement and a minimum of adverse effects. The term orthodontic anchorage was first introduced by Angle (1907) and later defined by Ottofy (1923). Orthodontic anchorage denoted the nature and degree of resistance to displacement of teeth offered by an anatomic unit when used for the purpose of tooth movement. The principle of orthodontic anchorage has been implicitly explained already in the Newton’s third law (1687) according to which an applied force can be divided into an *action* component and an equal and opposite *reaction* moment. In orthodontic treatment, reciprocal effects must be evaluated and controlled.

Orthodontic anchorage is oriented to the quality of the biological anchorage of the teeth. Basically, each tooth has its own anchorage potential as well as a tendency to move when force is applied towards the tooth. This is influenced by a number of factors, such as:

- the size of the root surfaces available for periodontal attachment
- the height of the periodontal attachment
- the density and structure of the alveolar bone
- the turnover rate of the periodontal tissues
- the muscular activity
- the occlusal forces
- the craniofacial morphology

and the nature of the tooth movement planned for the intended correction (Diedrich 1993). When teeth are used as anchorage, the inappropriate movements of the anchoring units may result in a prolonged treatment time and unpredictable or less-than-ideal outcomes.

To maximize tooth-related anchorage, techniques such as differential torque (Burstone 1982), placing roots into the cortex of the bone (Ricketts 1976) and distal inclination of the molars (Begg & Kesling 1977, Tweed 1941) may be used. If the periodontal anchorage is inadequate with respect to the intended treatment goal, additional intraoral and/or extraoral anchorage may be needed to avoid adverse effects. While the teeth are the most frequent anatomic units used for anchorage in orthodontic therapy, other structures such as the palate, the lingual mandibular alveolar bone, the occiputal bone and the neck are also alternatives.

Additional anchorage such as extraoral and intraoral forces are visible and hence, compliance-dependent and are associated with the risk of undesirable effect such as tipping of the occlusal plane, protrusion of mandibular incisors and extrusion of teeth.

Compliance dependent Anchorage Strategies

- extraoral: Headgear, chin-cap, reversed headgear ...
- intermaxillary: Class II/III elastics, Herbst Appliance, Jasper, Eureka ...
- Gingiva, muscles, cortical bone: Plates, Nance-plate, lip bumper, transpalatal arch

The success of compliance dependent anchorage strategies relay on patient's cooperation. Based on a questionnaire of patients own reporting of headgear wear showed, that one third of the patients do not convey accurate information (Cole 2002). Monitoring the wearing time with a gauge with an electronic recorder did not significantly increase the compliance (56.7% to 62.7%) (Brandão et al. 2006). Since patient's cooperation is not always optimal (Nanda & Kierl 1992) temporary anchorage devices (TAD) (Daskalogiannakis 2000) have been introduced. TADs anchored in bone and subsequently removed. They are designed to overcome the limitations of conventional orthodontic anchorage devices. The anchorage by means of TADs permits independency in relation to patient compliance (Creekmore & Eklund 1983) either by supporting the teeth of the reactive unit or by obviating the need for the reactive unit altogether.

Since regular orthodontic patients have a full dentition or extraction sites to be closed, no edentulous alveolar bone sections are available for the insertion of any kind of TADs. As a consequence, they must be placed in other topographical regions for orthodontic anchorage purposes. New additional insertion sites were offered with the introduction of:

- Diameter reduced temporary orthodontic anchorage devices such as miniscrews (<2mm) in various lengths (Kanomi 1997, Costa et al. 1998);
- Titanium pins (Bousquet et al. 1996);

- L-shaped miniplates with the long arm exposed into the oral cavity (Umemori et al. 1999), and zygomatic anchors (De Clerck et al. 2002), both fixed by bone screws;
- Length-reduced orthodontic anchorage devices such as titanium flat screws (Triaca et al. 1992);
- Resorbable orthodontic implant anchors (Glatzmaier et al. 1996);
- Palatal implants such as T-shaped orthodontic implants (Wehrbein et al. 1996), (Orthosystem®, Straummann AG, Basel, Switzerland), the Graz implant- supported pendulum (Byloff et al. 2000) as well as the subperiostally placed Onplant®.

Having used these TADs for more than a decade, numerous case reports and scientific papers have been published documenting the clinical feasibility of the TADs mentioned. But in some cases, premature loss of the TADs occurs prior to orthodontic loading or achieving the intended orthodontic treatment goals. The dynamics of TAD loss (loss over time), however, are an important factor related to decision making in orthodontic treatment planning. Even though TADs have been used in orthodontic treatment for more than a decade, in contrast to prosthetic oral implants, the literature exploring the risk factors associated with early failures of orthodontic TADs has not been evaluated systematically. Early failures may make it difficult or impossible to change the treatment plan.

Therefore, the aim of the present systematic review was to determine the risk factors associated palatal implants, mini screws, miniplates and onplants failures within the context of being used as orthodontic TADs.

3. Material and Methods

Retrospective studies cannot establish causal or temporal relationships, but may point to factors influencing the failure of TADs, and may be considered "risk indicators". However, the determination of true risk factors requires prospective longitudinal studies. A true risk factor is a component which, is known to be associated with failure related conditions on the basis of epidemiological evidence. Such an attribute may be associated with an increased probability of occurrence of a particular event (failure of a TAD) without necessarily being a causal factor. A risk factor may also be modified by interventions thereby reducing the likelihood for the development of a particular disease or failure (Beck 1994).

Based on the results of a systematic review on the survival and failure rates of orthodontic temporary anchorage devices (Schätzle et al. 2009) covering the period from 1966 up to and including January 2009, it was obvious that there were no randomized controlled clinical trials (RCTs) available comparing all the different types of TADs. However, there were 2 RCTs comparing TADs (Onplants® and palatal implants) to compliance dependent anchorage devices (COADs) (Sandler et al. 2008, Feldmann & Bondemark 2008) and one RCT comparing two different miniscrew types (Wiechmann et al. 2007).

Inclusion criteria

In the absence of RCTs comparing all different types of TADs to each other, this systematic review was based only on the available limited randomized clinical trials and all prospective cohort studies. The additional inclusion criteria for study selection were:

- Mean TAD loading time of at least 12 weeks or 3 months
- Publications reported in English
- Included patients had been examined clinically at the follow-up visit, i.e. publications based on patient records only, on questionnaires or interviews were excluded.
- Reported details on the screw types used.
- Reported details on risk factors

Data extraction

Information on the risk factors and odds ratios was retrieved of the included 10 prospective studies/RCTs included in the reported systematic review (Schätzle et al. 2009) (Table 1, 2, 3). From the included studies the risk factors and odds rations for early TAD failures were abstracted.

4. Results

Onplants®

There was only one article fulfilling the inclusion criteria concerning Onplants® reporting a failure rate 17.2% failed (Table 1) (Feldmann & Bondemark, 2008). One of 29 Onplants failed to osseointegrate during the healing period and was removed before the orthodontic treatment. Furthermore, due to narrow and high palates, another 2 Onplants became tilted during osseointegration and could therefore not be to use in a bar system and thus removed. Two other failures were due to loss of anchorage (>1mm) and poor oral hygiene. The Onplant® system therefore appeared to be sensitive for anatomic restrictions. However, once osseointegrated, they remained stable during treatment.

Microscrews/Microimplants and Miniscrews/Miniimplants

Only four studies provided prospective data on factors associated with an increased risk for early miniscrew failures (Table 2). In the randomized clinical trial included in this study the survival and failure rates of two different screw diameters were assessed (Wiechmann et al. 2007). The cumulative survival of the 1.6mm diameter micro-implants was significantly higher than for the 1.1mm diameter, identifying screw diameter as a risk factor (odds ratio (o.r.) 2.9 (95% C.I.: 1.2-7.4)). Additionally, the failure rates differed significantly depending on the insertion site independent of the screw diameter. The cumulative survival of both micro-implants systems was significantly higher in the maxilla than those in the mandible. Miniscrews placed in the mandible had a more than 5-times increased risk for failure (o.r. 5.1 (95% C.I.: 2.2-12.1)). The failure rate of implants inserted lingually of the mandible was significantly higher than in all other localizations (o.r. 13.5 (95% C.I.: 3.9-46.6)).

These results are corresponding to findings from a cohort study comparing various lengths of different miniscrews of the same diameter (Park et al. 2006). For the local host factor, the screw implants placed in the mandible showed a significantly higher failure rate than those placed in the maxilla (o.r. 5.3 (C.I. 95%: 1.7 – 16.7)). But this factor could not be confirmed in two other prospective studies (Motoyoshi et al. 2007, Garfinkle et al. 2008). The right patient side had significantly higher failure than the left side (o.r. 6 (C.I. 95%: 1.6 – 21.7).

For procedure management factors, the screw heads covered by overlying soft tissue showed higher success than screw heads exposed in the oral mucosa, although this difference was not found to be statistically significant. The screw implants in the upper palatal alveolar bone between the first and second molars showed higher success rates than those in other locations, although there was no statistical significance again. There was no significant correlation in success rate according to the method of force application or placement angle.

For environmental management factors, screw implants with inflammation showed significantly lower success rates (o.r. 4.8 (95% C.I.: 1.7-13.9)). Screw implants with mobility during treatment showed significantly lower success than those without mobility (o.r. 24.4 (C.I. 95%: 4.8 – 125)).

In a study assessing risk factors associated with minicrews of 1.6mm diameter and 8mm length, in contrast, it was not possible to show a significant failure difference between maxillary and mandiblular placement (Motoyoshi et al. 2007). In this cohort study, however, implant placement torque (IPT) was identified as a risk factor for early screw failure. The success rate for implants with an IPT between 5Ncm and 10Ncm was significantly higher than implants with IPT below 5Ncm or above 10Ncm in the maxilla, and the total sum of the maxilla and mandible. In the mandible alone, however, only IPT above 10Ncm were statistically significantly associated with an increase failure rate. The common odds ratio (risk factor) for failure of the mini-implant anchor was 11.7 (95% C.I.: 3.1-44.4) when the IPT below 5Ncm or above 10Ncm.

Palatal implants

Five prospective studies provided data fulfilling the inclusion criteria for palatal implants (Table 3). Two out of these were RCTs comparing palatal implants to conventional compliance-dependent orthodontic anchorage (CDOA) (Sandler et al. 2008) only or to CDOA and Onplants® (Feldmann & Bondemark 2008).

All but two of the palatal implants failures were due surgical failures during the healing phase leading to an early loss prior loading (Crismani et al. 2006, Männchen & Schätzle 2008, Sandler et al. 2008, Feldmann & Bondemark 2008, Jung et al. 2009). One palatal implant was judged as a failure, even though it remained stable during the whole treatment, as the supraconstruction did not provide sufficient anchorage (anchorage loss more than 1mm) (Feldmann & Bondemark 2008). Only one implant did not remain stable after successful osseointegration attributed to a unilateral heavy and excessive orthodontic loading (Männchen & Schätzle 2008).

Miniplates

Only one prospective cohort study out of the ten included reports provided data on risk factors associated with increased failure rates of miniplates (Table 3). In this report 15 bone plates were prematurely removed (Cornelis et al. 2008). Most (73.3%) failures occurred in growing patients. Increased mobility was more frequently reported in the mandible than the maxilla, possibly related to the flap design. The initial mandibular surgical protocol was therefore modified during the study and the releasing incision was placed in the attached gingiva instead of the sulcus. The odds ratios were not assessed in details.

Table 1: Study and patient characteristics of the reviewed study of Onplants®

Author	Kind of Study	Type of TAD	Manufacturer	Number of TADs	Number of Failures	% of Failures	Risk Factors	estimated relative risk
Feldmann & Bondemark 2008	RCT	Onplant®	Nobel Biocare®	29	5	17.2%	Surgical failure (1) sensitive for anatomic restrictions (2) Poor oral hygiene (1) Loss of anchorage (1)	Not assessed

Table 2: Study and patient characteristics of the reviewed studies of Mini-/ Microscrews

Author	Kind of Study	Type of TAD	Manufacturer	Diameter	Length	Number of TADs	Number of Failures	% of Failures	Risk factors	estimated relative risk
Park et al. 2006	Prospective	Miniscrew	Stryker Leibinger	1.2mm	5mm	19	3	15.8%	Mandible > Maxilla	5.3 (95% C.I.: 1.7-16.7)
Park et al. 2006	Prospective	Miniscrew	Ostomed	1.2mm	6 to 10mm	157	10	6.4%	Inflammation	4.8 (95% C.I.: 1.7-13.9)
									Mobility within 8 month of loading	24.4 (95% C.I.: 4.8-125)
Park et al. 2006	Prospective	Miniscrew	AbsoAnchor	1.2mm	4, 6, 7, 8 or 10mm	46	5	10.9%	Right site > left site	6.0 (95% C.I.: 1.6-21.7)
Wiechmann et al. 2007	RCT	Miniscrew	AbsoAnchor	1.1mm	5, 6, 7, 8 or 10mm	79	24	30.4%	Diamter (1.1mm > 1.6mm)	2.9 (95% C.I.: 1.2-7.4)
									Mandible > Maxilla	5.1 (95% C.I.: 2.2-12.1)
Wiechmann et al. 2007	RCT	Miniscrew	Dual Top	1.6mm	5, 6, 7, 8 or 10mm	54	7	13%	Lingually of the mandible > all other insertion sites	13.5 (95% C.I.: 3.9-46.6)
Motoyoshi et al 2007	Prospective	Miniscrew	Biodent	1.6mm	8mm	169	25	14.8%	Implant placement Torque <5cm or >10 Ncm	11.7 (95% C.I.: 3.1-44.4)
									Mandible > Maxilla	2.0 (95% C.I.: 0.7-5.6)
									early loading (within 1 week) = delayed loading (3-5 weeks)	0.9 (95% C.I.: 0.2-4.4)
Garfinkle et al. 2008	Prospective	Miniscrew	Ostomed	1.6mm	8mm	41	8	19.5%	Mandible > Maxilla	1.3 (95% C.I.: 0.2-5.0)
									Direct placement > cortical notching	2.9 (95% C.I.: 1.1-7.6)

Table 3: Study and characteristics of the reviewed studies of palatal implants

Author	Kind of Study	Type of TAD	Manufacturer	Number of TADs	Number of Failures	% of Failures	Risk factors	estimated relative risk
Jung et al. 2009	Prospective	Palatal Implant	Straumann	30	2	6.7%	surgical failures (2)	Not assessed
Sandler et al. 2008	RCT	Palatal Implant	Straumann	26	6	23.1%	surgical failures (6)	Not assessed
Feldmann & Bondemark 2008	RCT	Palatal Implant	Straumann	30	2	6.7%	surgical failures (1) loss of anchorage >1mm (1)	Not assessed
Männchen & Schätzle 2008	Prospective	Palatal Implant	Straumann	70	4	5.7%	surgical failures (3) heavy unilateral loading (1)	Not assessed
Crismani et al. 2006	Prospective	Palatal Implant	Straumann	20	2	10%	surgical failures (2)	Not assessed

Table 4: Study and patient characteristics of the reviewed studies of Miniplates

Author	Kind of Study	Type of TAD	Manufacturer	Number of TADs	Number of Failures	% of Failures	Risk factors		estimated relative risk
Cornelis et al. 2008	Prospective	Miniplates	Surgi-Tec or KLS Martin	200	15	7.5%	Mandible (6/47)	> Maxilla (9/153)	2.3 (95% CI: 0.8 to 7.0)
							Growing patients (11/32)	> adult patients (4/65)	Not assessed
							incision in sulcus (3)	> in attached gingival (0)	Not assessed

5. Discussion

The purpose of this study was to systematically evaluate and assess the factors associated with an increased risk for early failures of skeletal temporary anchorage devices (TADs) such as Onplants®, miniplates, palatal implants and mini- or microscrews after a loading time of at least 12 weeks.

Retrospective studies cannot establish causal or temporal relationships, but may point to factors influencing early failures of TADs, and may be considered "risk indicators". However, the determination of true risk factors requires prospective longitudinal studies. A true risk factor is a component which is known to be associated with failure related conditions on the basis of epidemiological evidence. Such an attribute may be associated with an increased probability of occurrence of a particular event (early failure of a TAD) without necessarily being a causal factor. A risk factor may also be modified by interventions thereby reducing the likelihood for the development of a particular disease or failure (Beck 1994).

Based on the results of a systematic review on the survival and failure rates of orthodontic temporary anchorage devices (Schätzle et al. 2009), it was obvious that there were no randomized controlled clinical trials (RCTs) available comparing all the different types of TADs. RCTs comparing these 4 treatment modalities may be difficult to perform both from a logistic as well as ethical point of view. In the absence of RCTs, a lower level of evidence, i.e. RTC's comparing some TADs to conventional orthodontic anchorage devices (COAD) and prospective cohort studies were included in this systematic review.

In contrast to prosthetic oral implants, the literature exploring the risk factors associated with early failures of orthodontic TADs has not been evaluated systematically. The knowledge of risk factors leading to an early loss of TADs is an important factor for decision making in orthodontic treatment planning.

The dynamics of TAD loss (loss over time) is an important factor for decision making in orthodontic treatment planning. The Kaplan-Meier analysis of a RCT comparing miniscrews with 2 different diameters (1.1mm and 1.6mm) (Wiechmann et al. 2007) showed that the majority of the miniscrew failures occurred within 100 to 150 days after the start of orthodontic loading. In another prospective study (Garfinkle et al. 2008) the loss even occurred at an earlier stage. Most failures occurred within the first several months after placement. At this point of time, a change of the treatment plan may be difficult or impossible.

The risk factors identified in these studies could be divided into screw implant factors, host factors, including local host factors at recipient sites, procedure and environmental management factors.

Onplants:

There was only one study fulfilling the inclusion criteria for Onplants®. Onplants® are placed subperiostally and are supposed to adhere to bone. Due to the fact, that it is fixed to bone just by the pressure of the soft tissue and the periosteum, it might not remain stable during the healing process and therefore not osseointegrate. Narrow and high palates could cause an inappropriate contact of the disc shaped device to the bone surface. As a consequence Onplants® may become tilted during osseointegration and they might therefore not be usable due to mal-positioning. The Onplant®-system appeared to be more sensitive for anatomic restrictions and surgical technique. Improper contact to the bone surface and insufficient adhesion make this device also sensible to forces during manipulation of the suprastructure.

Miniscrews:

Even though miniscrews have been used for more than a decade, only 1 randomized clinical trial and 3 prospective cohort studies provided data on risk factors associated with an increased failure rate. Miniscrew factors, host factors including local host factors at recipient sites, procedure and environmental management factors were evaluated.

The only screw factor influencing the failure rate of miniscrew was its diameter. A decrease in diameter was associated with a decrease in the cumulative survival rate, whereas the length of implants had no statistically significant effect on implant failure rates (Wiechmann et al. 2007). Nevertheless, Park and co-workers (2006) showed a tendency for longer screws to be more stable than shorter ones.

Concerning the application of axial moments, the removal torque values of osseointegrated implants with different surface conditions in the minipig after 4, 8 and 12 weeks of heeling was tested (Buser et al. 1999). The removal torque values found in this study (13 - 26 Ncm for machined surfaces) are beyond the ones clinically used in orthodontics. Still, miniscrews are significantly smaller than the investigated design of 4.05mm of diameter, but unfortunately there exists no such investigation on miniscrews.

The torque removal value of a cylindrical screw in a homogeneous environment is proportional to the maximum sharing stress $\tau_{\max}$ at the bone-implant-interphase and equals the maximum tangential sharing force $F_{\max}$ divided by the area A of the interphase:

$$\tau_{\max} = \frac{F_{\max}}{A}$$

The interphase A is proportional to the screw diameter D and length L, whereas the maximum sharing force $F_{\max}$ is proportional to the screw diameter D only:

$$A \propto D * L \qquad\qquad F \propto D$$

Putting these equations into the equation above, the maximum sharing stress $\tau_{\max}$ becomes proportional to the square diameter of the screw but only linearly proportional to the length:

$$\tau_{\max} \propto D^2 \qquad\qquad \tau_{\max} \propto L$$

It is therefore not astonishing, that the length of the screw could so far not be detected as a significant risk factor, especially if it is considered, that bone is not homogeneous and that probably the compact bone is more important for the stability of a miniscrew than the spongeous bone. It still would be advisable to always use the thickest and longest possible screw (without contacting neighbouring roots), and bi-cortical insertion could eventually further increase the stability.

Primary stability of a miniscrew, as a prerequisite for osseointegration, is not only affected by the screw's diameter (Holmgren et al. 1998), but also by the bone stiffness (Meredith 1998), pointing to a correlation of the implant placement resistance and bone density (Friberg et al. 1995). In some cases there is an early failure of miniscrews shortly after installation and orthodontic loading. This loss may be caused by the lack of sufficient primary stability which causes an inappropriate healing and a possible premature loss of the implant (Friberg et al. 1991, Lioubavina-Hack et al. 2006). Additionally, hoop stresses, which are generated around the dental implant threads during insertion, may be beneficial in enhancing the primary stability of the implant (Meredith 1998). However, it might be warned that such stresses can be excessive, resulting in necrosis and local ischemia of the bone. Using the 1.6-mm diameter mini screws of 8mm length the ideal IPT was identified to be within a range from 5 to 10Ncm (Motoyoshi et al. 2007). IPT values below or above this threshold were associated with an 11.7-times higher risk for early failure. In situations with excessive IPT due to the bone stiffness and cortical bone thickness, predrilling or cortical notching might be considered (Motoyoshi et al. 2007, Garfinkle et al. 2008).

Excessive implant placement torque might also be the reason for a 5-times higher risk for failure in the mandible when compared to maxillary insertion sites (Park et al. 2006, Wiechmann et al. 2007). The lower jaw has a thicker and more dense cortical bone than the maxilla (Park 2002) baring the risk for overheating the bone during drilling or causing excessive stress during miniscrew installation. In addition, screw implants placed in the posterior part of the mandible can easily be irritated by food during chewing. These factors might negatively affect the clinical success of screw implants (Park et al. 2006).

Even though no critical loading or tipping force was detected, some mini screws became loose after a certain time of loading. The applied forces should, however, not have a negative impact on the peri-implant bone and impair the long-term prognosis of the mini screw. In experimental animal studies, prosthetic implants were subjected to well-defined continuous loading (Melsen & Lang 2001, Hsieh et al. 2008). None of the implants lost osseointegration, but loading significantly influenced the turnover of the alveolar bone in the vicinity of the implants. When the strain exceeded a certain threshold, the remodeling resulted in a net loss of the bone or caused tipping of the implants. These findings are in accordance with data of experimental miniscrews studies (Büchter et al. 2005) showing that excessive tipping moment at the bone edge may lead to screw loosening and early failure. Once a mini screw became mobile, it was almost 25-times more likely to fail than when it remained firm. Therefore, controlled clinical trials taking the applied tipping moments at the bone level into account are encouraged.

Management factors include poor home care, inflammation or infection, oral hygiene, and excessive load. Only inflammation was identified to increase the risk for failures by 4.8 times (Park et al. 2006). To ensure success, it is important to prevent inflammation around the screw implants. Mini screws placed in the patient's left hand side showed a 6 times lower failure risk than placed on the right hand side. This might be explained by better hygiene on the left side of the dental arch by right-handed patients, who are most of the population (Tezel et al. 2001). Oral hygiene did not affect success, but local inflammation around the screw implants did. Local inflammation can be exaggerated not only by oral hygiene but also by weak non-keratinized soft tissue around the neck of the screw implant. Once inflammation arose, it tended to persist in non-keratinized mucosa areas (Park et al. 2006).

Palatal implants:

Only one implant was lost under heavy unilateral, orthodontic loading (Männchen & Schätzle 2008). All other failed palatal implants had been lost during the healing phase prior loading and must be considered as surgical failures (Table 3). Therefore, the surgical procedure of palatal implant insertion including the special design of the emergence profile represented the highest risk factors for early loss. In contrast to conventional oral implants, some orthodontic anchorage implants of that time such as the Straumann® palatal implant yielded an emergence profile with a 90-degree shoulder. This bore the danger of "over-winding" the implant during installation with a subsequent loss of the primary stability. It is obvious that such design features caused a higher sensitivity to the installation techniques of palatal implants. A learning curve of the surgeons involved might also be taken into account when this "relatively new" technique was introduced (Sandler et al. 2008). Meanwhile, a new palatal implant with a modified (slightly concave, tulip-shaped conical emergence profile) was developed with the purpose of reducing the risk of over-winding the implant during installation (Orthoimplant®, Straumann AG, Basel, Switzerland). From a clinical point of view, once osseointegrated, palatal implants remained stable during treatment and proved to resist well orthodontic forces. Neither host factors nor environmental management factors had been identified as possible risk factors in all of the 5 studies evaluated.

Miniplates:

As miniplates are fixed to bone by 2 or more mini screws, these TADs face similar risk factors associated with early failure. Increased mobility was proportionally more frequently reported in the mandible than the maxilla, possibly related to the flap design. The initial mandibular surgical protocol was therefore modified during the study and the releasing incision was placed in the attached gingiva instead of the sulcus. No further failures were observed after this change.

It is apparent that soft tissues play an important role in implant stability. Mucosal emergence of the miniplate arm at the mucogingival junction or 1 mm within the attached gingiva enables tight closure of the tissues; this appears to be necessary for good soft-tissue healing. This points to the fact, that weak non-keratinized gingiva represents a risk factor for miniplates causing local inflammation and leading to early failure. Oral hygiene is another important factor for success (Cornelis et al. 2008).

The failure rate due to mobility was higher in growing patients than in adults. Although the surgeons were always instructed to place the attachment arm penetrating the tissue at the mucogingival junction, this might be more difficult in younger patients, when alveolar height tends to be shallow, the width of attached gingiva is less, and access is restricted.

In conclusion, the use of TADs really expands the envelope of discrepancies in which orthodontic treatment might be successful. However, the knowledge of risk factors leading to an early loss and the dynamics of TAD loss (loss over time) is an important factor for decision making in orthodontic treatment planning and for choosing the appropriate anchorage device. Failures during the orthodontic treatment may make a change of the treatment plan difficult or impossible. On the basis of this systematic review it is concluded that for the onplants® the surgical procedure and the anatomical situation represent the highest risk for early failure. For miniscrews, screw diameter (Wiechmann et al. 2007), implant placement torque (Motoyoshi et al. 2007), mobility, the patient's right side and inflammation (due to oral hygiene and weak non-keratinized gingiva) (Park et al. 2006) were associated with an increased miniscrew failure rate. Additionally mandibluar versus maxillary placement of the screws was identified as risk factor in 2 studies (Park et al. 2006, Wiechmann et al. 2007). For palatal implants, the surgical procedure insertion including the special design of the emergence profile represented the highest risk factors for early loss. However, a new modified implant with the purpose of reducing these risks have been recently introduced and showed very favorable clinical results (Jung et al. 2008). For miniplates non-keratinized gingiva, installation in the mandible and growing patients were associated with an increased risk for early failure.

However, more possible factors influencing relative effectiveness, efficiency and indication lists of all different temporary anchorage devices used for various clinical problems need to further be evaluated and assessed in prospective controlled studies.

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7. Verdankungen

Ich möchte mich noch ganz herzlich bei all den Leuten bedanken, welche mir diese Arbeit ermöglicht und mich dabei unterstützt haben. Speziell erwähnen möchte ich dabei:

- Professor Timo Peltomäki und Dr. Dr. Marc Schätzle für die Überlassung des Themas, sowie für deren stete Unterstützung und Hilfsbereitschaft

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