CLINICAL ORAL IMPLANTS RESEARCH

Marc Schätzle
Roland Männchen
Marcel Zwahlen
Niklaus P. Lang

Survival and failure rates of orthodontic temporary anchorage devices: a systematic review

Authors' affiliations:
Marc Schätzle, Roland Männchen, Clinic for Orthodontics and Pediatric Dentistry, Center for Dental and Oral Medicine and Cranio-Maxillofacial Surgery, University of Zurich, Zurich, Switzerland
Marc Schätzle, Niklaus P. Lang, Faculty of Dentistry, The Prince Philip Dental Hospital, The University of Hong Kong, Hong Kong, China
Marcel Zwahlen, Research Support Unit, Institute of Social and Preventive Medicine, Bern University, Bern, Switzerland and CTU Bern, University Hospital Bern, Bern, Switzerland

Correspondence to:
Marc Schätzle
Clinic for Orthodontics and Pediatric Dentistry
Center for Dental and Oral Medicine and Cranio-Maxillofacial Surgery
Plattenstrasse 11
CH-8032 Zürich
Switzerland
Tel.: +41 44 634 32 14
Fax: +41 44 634 43 04
e-mail: marc.schaetzle@zzmk.uzh.ch

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Abstract

Aim: The purpose of this study was to systematically review the literature on the survival rates of palatal implants, Onplants®, miniplates and mini screws.

Material and methods: An electronic MEDLINE search supplemented by manual searching was conducted to identify randomized clinical trials, prospective and retrospective cohort studies on palatal implants, Onplants®, miniplates and miniscrews with a mean follow-up time of at least 12 weeks and of at least 10 units per modality having been examined clinically at a follow-up visit. Assessment of studies and data abstraction was performed independently by two reviewers. Reported failures of used devices were analyzed using random-effects Poisson regression models to obtain summary estimates and 95% confidence intervals (CI) of failure and survival proportions.

Results: The search up to January 2009 provided 390 titles and 71 abstracts with full-text analysis of 34 articles, yielding 27 studies that met the inclusion criteria. In meta-analysis, the failure rate for Onplants® was 17.2% (95% CI: 5.9–35.8%), 10.5% for palatal implants (95% CI: 6.1–18.1%), 16.4% for miniscrews (95% CI: 13.4–20.1%) and 7.3% for miniplates (95% CI: 5.4–9.9%). Miniplates and palatal implants, representing torque-resisting temporary anchorage devices (TADs), when grouped together, showed a 1.92-fold (95% CI: 1.06–2.78) lower clinical failure rate than miniscrews.

Conclusion: Based on the available evidence in the literature, palatal implants and miniplates showed comparable survival rates of $\geq$90% over a period of at least 12 weeks, and yielded superior survival than miniscrews. Palatal implants and miniplates for temporary anchorage provide reliable absolute orthodontic anchorage. If the intended orthodontic treatment would require multiple miniscrew placement to provide adequate anchorage, the reliability of such systems is questionable. For patients who are undergoing extensive orthodontic treatment, force vectors may need to be varied or the roots of the teeth to be moved may need to slide past the anchors. In this context, palatal implants or miniplates should be the TADs of choice.

Anchorage is one of the limiting factors in orthodontics, and its control is essential for successful treatment outcomes. The term 'orthodontic anchorage' denotes the nature and degree of resistance to displacement offered by an anatomic unit. According to the intended treatment goals, desired tooth movements should, therefore, be maximized, and undesirable effects should be minimized. Traditionally, orthodontic therapy used teeth, extraoral and/or intermaxillary appliances for anchorage. Since a patient's cooperation is not always optimal (Nanda & Kierl 1992), temporary anchorage

devices (TAD) (Daskalogiannakis 2000) have been introduced. TADs are anchored in bone and removed after completion of the intended orthodontic tooth movement. They are designed to overcome the limitations of conventional orthodontic anchorage devices (COADs). Anchorage by means of TADs allows independence in relation to patient compliance (Creekmore & Eklund 1983) either by supporting the teeth of the reactive unit or by obviating the need for a reactive at large.

Usually, orthodontic patients present a complete dentition or with extraction sites to be closed. No edentulous alveolar bone ridges are generally available for the insertion of TADs. As a consequence, these must be placed in topographical regions distant to the main area of action.

New additional insertion sites have been offered by the introduction of length-reduced mid-palatal orthodontic anchorage devices such as titanium flat screws (Triaca et al. 1992), resorbable orthodontic implant anchors (Glatzmaier et al. 1995), T-shaped orthodontic implants (Wehrbein et al. 1996) (Orthosystem®, Institut Straumann, Waldenburg, Switzerland) and the Graz implant-supported pendulum (Byloff et al. 2000). Diameter-reduced temporary orthodontic anchorage devices such as miniscrews (<2 mm) in various lengths (Kanomi 1997; Costa et al. 1998) and titanium pins (Bousquet et al. 1996) are inserted into the alveolar bone and L-shaped miniplates with the long arm exposed into the oral cavity (Umemori et al. 1999), and bollard anchors (De Clerck et al. 2002) are fixed by bone screws in supra-apical regions. Another device, the Onplant® (Nobel Biocare, Zurich, Switzerland) (Block & Hoffman 1995), placed subperiostally, was supposed to adhere to bone.

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. In contrast to prosthetic oral implants, the literature exploring the survival and failure rates of orthodontic TADs has not been evaluated systematically.

Therefore, the aim of the present systematic review was to determine the survival and failure rates of palatal implants, mini screws, miniplates and onplants. The focused question to be answered was: 'What are the survival and failure rates of the orthodontic TADs after a functional period of at least 12 weeks.'

Material and methods

A Medline (PubMed and Ovid) search from 1966 up to and including January 2009 was conducted for English language articles limited to human studies published based on the following searching terms: 'mini screw', 'miniscrew', 'micro screw', 'microscrew', 'micro implant', 'microimplant', 'mini implant', 'miniimplant', 'palatal implant', 'miniplate' and 'onplant'.

Manual searches of the bibliographies of all full-text articles and related reviews, selected from the electronic search, were additionally performed. Furthermore, the following journals were searched manually for the years 2004 to January 2009: *Clinical Oral Implants Research, European Journal of Orthodontics, American Journal of Orthodontics and Dentofacial Orthopedics, Angle Orthodontist, Journal of Clinical Orthodontics, Journal of Orofacial Orthopopedics, Journal of Adult Orthodontics and Orthognathic Surgery* and *International Journal of Oral & Maxillofacial Implants*.

From these searches, it was obvious that there were no randomized-controlled clinical trials (RCTs) available comparing all the different types of TADs. However, there were two RCTs comparing TADs (Onplants® and palatal implants) with compliance-dependent COADs (Feldmann & Bondemark 2008; Sandler et al. 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 with each other, this systematic review was based on the few (three) available RCTs with limited impact and all prospective or retrospective cohort studies. The additional inclusion criteria for study selection were:

- mean TAD loading time of at least 12 weeks;
- 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.

Selection of studies

Fig. 1 describes the search strategy used to identify relevant studies selected for this review. Titles and abstracts of the Medline searches were initially screened by two independent reviewers (R.M. and M.S.) for possible inclusion. From a yield of 390 titles, 71 were selected for abstract screening (Fig. 1). The agreement between the reviewers using κ-statistics was 96.2%. The full text of all studies of possible relevance (34) was then obtained for independent assessment by the two reviewers. Any disagreement was resolved by discussion.

Data were extracted independently by the same two reviewers using a data extraction form.

Excluded studies

Of the 34-full-text articles retrieved, seven were excluded from the final analysis. The main reasons for exclusion were a mean observation period of <12 weeks, loading time was not clearly indicated, less than 10 units per modality in the study and multiple publication of the same cohort in different scientific journals at different time points.

Data extraction

Information on the proportions of biological and technical complications was retrieved on the 27 studies included. Biological complications included disturbances in the function of the skeletal anchorage device leading to any early removal of the anchorage device before the end of the intended orthodontic treatment or observation period. Healing or incorporation failures were also included in this category. Technical complications were not reported in any of the studies, and therefore could not be assessed separately.

From the 27 included studies, the number and percentage of failures was extracted. Disagreement regarding data extraction was resolved by consensus.

Statistical analysis

Failure rates were calculated by dividing the number of events (failures) after at least 12 weeks of orthodontic loading in the

numerator by the total number of each TAD type in the denominator. For further analysis, the total number of events was considered to be Poisson distributed for a given number of TADs, and Poisson regression with a logarithmic link function and total number of TADs per study as an offset variable was used. To assess the heterogeneity of the study-specific event rates, the Spearman goodness-of-fit statistics and associated *P*-value were calculated. If the goodness-of-fit *P*-value was below 0.05, indicating heterogeneity, random-effects Poisson regression (with γ-distributed random effects) was used to obtain a summary estimate of the event rates. Summary failure rate estimates and 95% confidence intervals (CI) are reported.

To provide anchorage on either side of the maxilla, only one palatal implant or Onplant® was needed, whereas at least two fixtures have to be installed if miniplates or miniscrews are used.

To evaluate the possible failure of at least one out of two fixtures, it was assumed that failures of these objects may occur independently. The probability to remain free of failure was therefore calculated by multiplying the probability that each object remains free of failure: $(1 - \text{risk}_{\text{object1}}) \times (1 - \text{risk}_{\text{object2}})$. Therefore, the probability of encountering at least one failure becomes $1 - (1 - \text{risk}_{\text{object1}}) \times (1 - \text{risk}_{\text{object2}})$.

The 95% CI limits for survival proportions were calculated using the 95% confidence limits of the event rates. All analyses were performed using Stata®, version 10.1 (Stata Corporation, College Station, TX, USA).

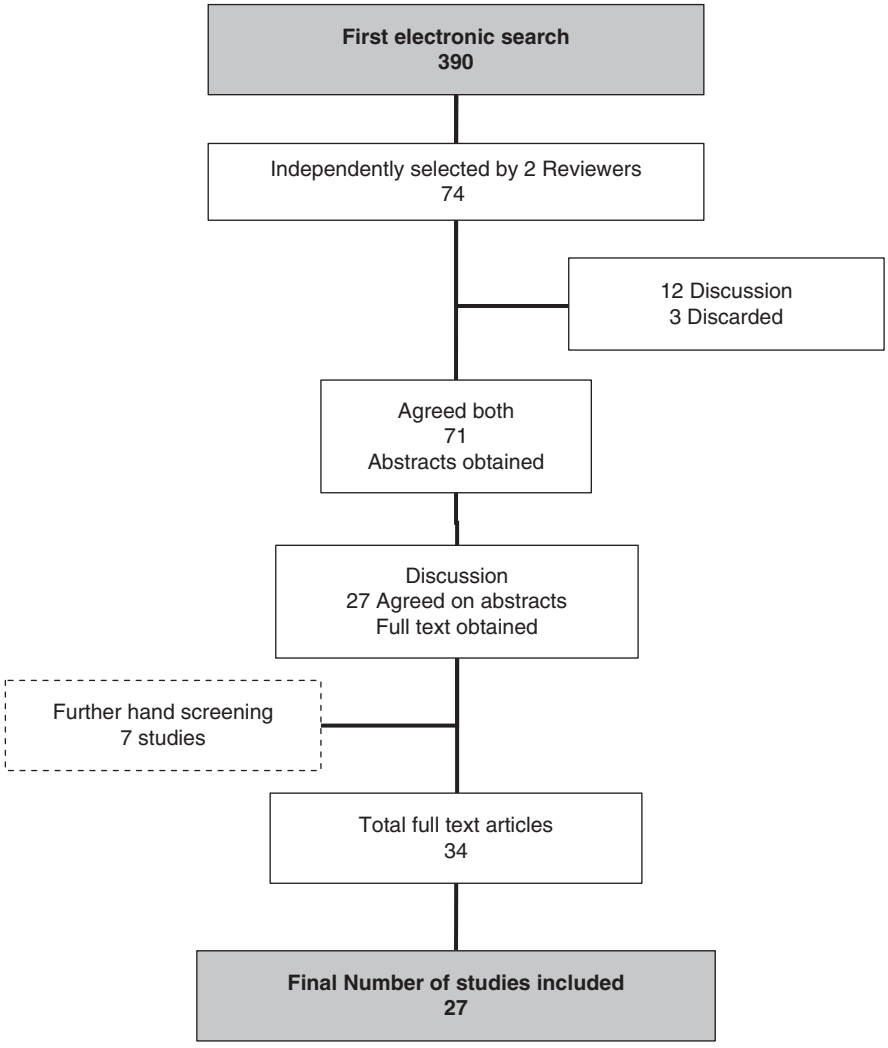

Fig. 1. Search strategy.

Results

Onplants®

There was only one article fulfilling the inclusion criteria concerning Onplants® (Feldmann & Bondemark 2008). In this RCT, five out of 29 onplants or 17.2% (95% CI: 5.9–35.8%) failed (Table 1).

Microscrews/Microimplants and Miniscrews/Miniimplants

Seventeen studies provided data on the survival of 31 different types of miniscrews (Table 2). A total of 2374 miniscrews inserted in 1196 patients with a total of 363 or 15.3% failures could be analyzed (Table 2). Seven studies reported results of prospective cohort studies, whereas the remaining 10 assessed their results retrospectively. Data of only one RCT could be extracted comparing two different screw types (Wiechmann et al. 2007). However, due to the lack of precise data reporting in all these studies no conclusive statement of survival and/or the failure rate of a specific screw type (length and diameter) regarding their favorable indication, insertion location, insertion technique and type of loading could be made.

Some reports provided detailed data on the diameter and length of the inserted miniscrews, while others pooled the results of a specific miniscrew diameter with various lengths (Table 2). The mean follow-up

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

Author	Kind of study	Type of TAD	Manufacturer	Diameter	Number of patients	Mean patient's age (years)	Number of TADs	Number of failures	Percent of failures	Loading time
Feldmann & Bondemark (2008)	RCT	Onplant®	Nobel Biocare®	7.7 mm titanium disk	29	14 ± 1.53	29	5	17.2%	Completion of treatment

TAD, temporary anchorage devices; RCT, randomized controlled clinical trials.

Table 2. **Study and patient characteristics of the reviewed studies of miniscrews/microscrews**

Author	Kind of study	Type of TAD	Manufacturer	Diameter (mm)	Length (mm)	Number of patients	Mean patient's age (years)	Number of TADs	Number of failures	Percent of failures	Loading time
Chen et al. (2008)	Retrospective	Miniscrew	Mondeal, Tuttlingen, Germany	2	8–14	194	25.1 ± 8.7	57	14	24.6	Within 36 months
Chen et al. (2008)	Retrospective	Microscrew	Bioray, Taipel, Taiwan	2	5–21	194	25.1 ± 8.7	264	25	9.6	Within 36 months
Chen et al. (2007)	Retrospective	Miniscrew	AbsoAnchor, Dentos, Daegu, Korea	1.2	4–10	129	24.5 ± 7.1	72	17	23.6	Completion of treatment
Chen et al. (2006)	Retrospective	Miniscrew	AbsoAnchor	1.2	6	29	29.8	18	5	27.8	Completion of treatment
Chen et al. (2006)	Retrospective	Miniscrew	AbsoAnchor	1.2	8	29	29.8	41	4	9.8	Completion of treatment
Cheng et al. (2004)	Prospective	Miniscrew	Leibinger and Mondela, Mondeal Tuttlingen, Germany	2	9	44	29 ± 8.9	31	2	6.5	Completion of treatment
Cheng et al. (2004)	Prospective	Miniscrew	Leibinger or Mondela	2	11	44	29 ± 8.9	31	2	6.5	Completion of treatment
Cheng et al. (2004)	Prospective	Miniscrew	Leibinger or Mondela	2	13	44	29 ± 8.9	20	3	15	Completion of treatment
Cheng et al. (2004)	Prospective	Miniscrew	Leibinger or Mondela	2	15	44	29 ± 8.9	10	1	10	Completion of treatment
Park et al. (2006)	Prospective	Miniscrew	Stryker/Leibinger, Leibinger, Mühlheim-Stelten,Germany	1.2	5	10	15.5 ± 8.3	19	3	15.8	Completion of treatment
Park et al. (2006)	Prospective	Miniscrew	OstoMed, Addison, TX, USA	1.2	6–10	67	15.5 ± 8.3	157	10	6.4	Completion of treatment
Park et al. (2006)	Prospective	Miniscrew	AbsoAnchor	1.2	4, 6, 7, 8 or 10	16	15.5 ± 8.3	46	5	10.9	Completion of treatment
Wiechmann et al. (2007)	RCT	Miniscrew	AbsoAnchor	1.1	5, 6, 7, 8 or 10	49	26.9 ± 8.9	79	24	30.4	4 months
Wiechmann et al. (2007)	RCT	Miniscrew	Dual Top, Jeil Medical, Seoul, Korea	1.6	5, 6, 7, 8 or 10	49	26.9 ± 8.9	54	7	13	4 months
Liou et al. (2004)	Prospective	Miniscrew	Leibinger, Mühlheim-Stelten, Germany	2	17	16	22–29	32	3	9.4	9 months
Park et al. (2005)	Prospective	Miniscrew	Oesteomed	1.2	6	13	17.9 ± 5.7	30	3	10	12.3 ± 5.7 months
Kuroda et al. (2007a)	Retrospective	Miniscrew	AbsoAnchor	1.3	6, 7, 8, 10 or 12	110	22.5 ± 8.1	237	42	17.7	>12 months or completion of treatment
Kuroda et al. (2007a)	Retrospective	Miniscrew	Gebrüder Martin GmbH, Tuttlingen, Germany	1.5	9	110	22.5 ± 8.1	25	4	16	>12 months or completion of treatment
Kuroda et al. (2007b)	Retrospective	Miniscrew	KeiSei Medical Ind., Tokyo, Japan	2 or 2.3	7 or 11	18	21.8	37	7	18.9	>12 months or completion of treatment
Kuroda et al. (2007b)	Retrospective	Miniscrew	AbsoAnchor	1.3	6, 7, 8, 10 or 12	40	21.8	79	9	11.4	>12 months or completion of treatment
Luzi et al. (2007)	Retrospective	Miniscrew	Ashus-Miniscrew, Medicon, Tuttlingen, Germany	1.5 or 2	9.6 or 11.6	98	34.3	140	13	9.3	4 months
Motoyoshi et al. (2006)	Prospective	Miniscrew	Biodent, Biodent, Tokyo, Japan	1.6	8	57	20.8	169	25	14.8	>6 months
Tseng et al. (2006)	Retrospective	Miniscrew	Stryker Leibinger	2	8	25	29.9	15	3	20	Completion of treatment
Tseng et al. (2006)	Retrospective	Miniscrew	Stryker Leibinger	2	10	25	29.9	10	1	10	Completion of treatment
Tseng et al. (2006)	Retrospective	Miniscrew	Stryker Leibinger	2	12	25	29.9	12	0	0	Completion of treatment
Miyawaki et al. (2003)	Retrospective	Miniscrew	Not specified	1	6	3	21.8 ± 7.8	10	10	100	>12 months or completion of treatment
Miyawaki et al. (2003)	Retrospective	Miniscrew	Not specified	1.5	11	31	21.8 ± 7.8	101	16	15.8	>12 months or completion of treatment
Miyawaki et al. (2003)	Retrospective	Miniscrew	Not specified	2.3	14	10	21.8 ± 7.8	23	3	13	>12 months or completion of treatment
Garfinkle et al. (2008)	Prospective	Miniscrew	Osteomed	1.6	8	13	14.83	41	8	19.5	Space closure
Justens & De Bruyn (2008)	Retrospective	Miniscrew	Dual Top	1.6 or 2	8 or 10	21	21.4	50	17	34	Completion of treatment
Moon et al. (2008)	Retrospective	Miniscrew	Dual Top	1.6	8	209	20.3	480	78	16.3	8 months

TAD, temporary anchorage devices; RCT, randomized controlled clinical trials.

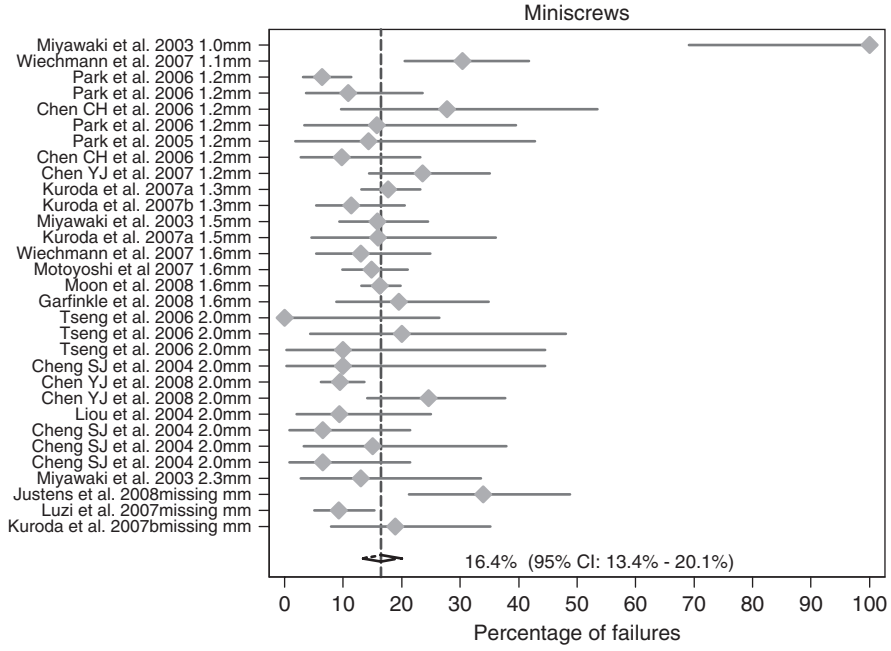

Fig. 2. Failure rates of miniscrews and summary estimate from meta-analysis and their 95% confidence intervals (95% CI) by study.

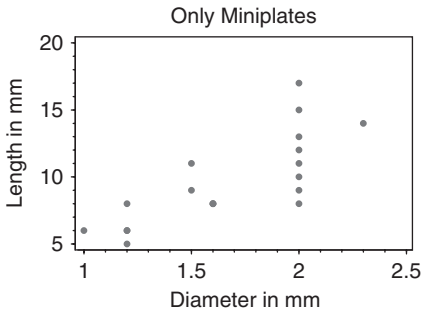

Fig. 3. Distribution of screw length by screw diameter.

time ranged between 120 days and more than 1 year or completion of the intended orthodontic treatment.

By meta-analysis, the failure rate (Fig. 2) was estimated at 16.4% (95% CI 13.4–20.1%). By analyzing the influence of screw length and diameter, only the data of screws with detailed characteristics were considered. Three groups of diameter were created, which basically separate these three 'clouds' of diameter and length types (Fig. 3). The miniscrews with a diameter of 2 mm or more showed a significantly 1.8-fold lower risk (95% CI: 1.1–3) of failing than miniscrews of a diameter of 1.2 mm or less.

Palatal implants

One retrospective and five prospective cohort studies provided data fulfilling the inclusion criteria on the survival and failure rate of palatal implants (Table 3). Two out of these were RCTs comparing palatal implants with conventional compliance-dependent orthodontic anchorage (CDOA) (Sandler et al. 2008) only or with CDOA and Onplants® (Feldmann & Bondemark 2008). However, only one report evaluated the clinical outcome of a larger number of palatal implants (Männchen & Schätzle 2008). Data of a total of 190 palatal implants with a follow-up time of at least 12 weeks up to more than 22 months or completion of the intended orthodontic treatment could be assessed. Nineteen or 10% out of 190 palatal implants did not provide sufficient anchorage and were lost early or before the time point of evaluation. In meta-analysis, the failure rate for the whole group of studies was estimated at 10.5% (95% CI: 6.1–18.1%) (Fig. 4).

Miniplates

Seven studies out of the 27 included reports provided data on the survival and failure rates of miniplates (Table 4). Two were prospective cohort studies, and the remaining five evaluated the material presented retrospectively. A total of 586 miniplates in 406 patients could be followed for at least 120 days up to 1.5 years or completion of the intended orthodontic treatment, respectively. Forty-three or 7.3% out of

Table 3. **Study and patient characteristics of the reviewed studies of palatal implants**

Author	Kind of study	Type of TAD	Manufacturer	Diameter (mm)	Length (mm)	Number of patients	Mean patient's age (years)	Number of TADs	Number of failures	Percent of Failures (%)	Loading time
Jung et al. (2009)	Prospective	Palatal implant	Straumann	4.1	4.2	30	19.7	30	2	6.7	6 months
Sandler et al. (2008)	RCT	Palatal implant	Straumann	3.3 or 4	4	24	15.7	26	6	23.1	25.8 ± 7 months
Feldmann & Bondemark (2008)	RCT	Palatal implant	Straumann	3.3	4	30	14.6 ± 2	30	2	6.7	Completion of treatment
Männchen & Schätzle (2008)	Prospective	Palatal implant	Straumann	3.3 or 4	4 or 6	70	22.5 ± 10.8	70	4	5.7	18.8 ± 10.7 months
Arcuri et al. (2007)	Retrospective	Palatal implant	Straumann	3.3	4 or 6	14	>20	14	3	21.4	22.8 months
Crismani et al. (2006)	Prospective	Palatal implant	Straumann	3.3	4	20	26.4	20	2	10	3 months

TAD, temporary anchorage devices; RCT, randomized controlled clinical trials.

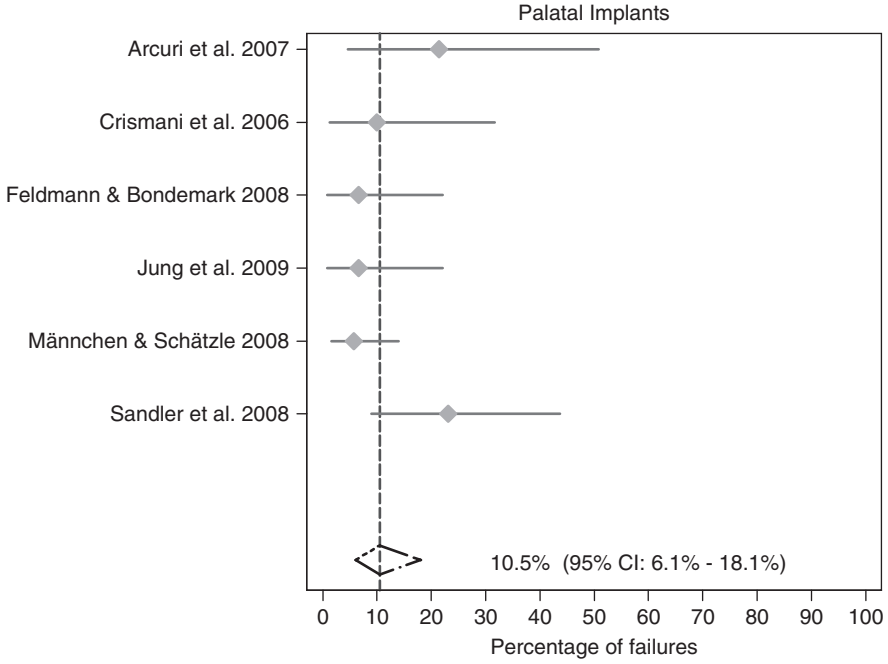

Fig. 4. Failure rates of palatal implants and summary estimate from meta-analysis and their 95% confidence intervals (95% CI) by study.

these did not remain stable and had to be removed early. In meta-analysis, the failure rate (Fig. 5) was estimated at 7.3% (95% CI: 5.4–9.9%).

On comparing miniplates, palatal implants and miniscrews with each other, none of them showed statistically significantly higher survival rates than the other due to the wide scattering within the groups. However, when miniplates and palatal implants representing torque-resisting TAD were grouped together, they showed a statistically significant 1.9-fold (95% CI: 1.1–2.8, $P = 0.005$) lower clinical failure rate than did miniscrews.

To achieve the same clinical anchorage on both sides of the arch as with a palatal implant (10.5% failure rate, 95% CI: 6.1–18.1%), two minicrews or miniplates have to be inserted. The probability of having at least one failure, when two of these TADs are installed in the maxilla, was 14.1% (95% CI: 10.5–18.8%) for miniplates and 29.4% (95% CI: 24.3–36%) for miniscrews, respectively.

Discussion

The purpose of this systematic review was to evaluate the survival and failure rates of skeletal TADs such as Onplants®, miniplates, palatal implants and mini- or microscrews after a loading time of at least 12 weeks. No RCTs were available comparing all types of these TADs. RCTs comparing these four treatment modalities may be difficult to conduct both from a logistic as well as an ethical point of view since this anchorage is usually chosen on specific patient indications. In the absence of these kinds of RCTs, a lower level of evidence, i.e. RCTs comparing some TADs with COAD and prospective and retrospective cohort studies were included in this systematic review. TAD survival and failure rates are only meaningful if anchorage is provided at least for the major part of orthodontic therapy. Hence, a minimal period of 12 weeks of functional anchorage was chosen in the evaluation.

Before the use of TADs, COADs offered the only possibility for sufficient anchorage to control undesired tooth movements. The main disadvantage of many of these devices was the fact that treatment outcomes depended to a high degree on patient compliance (Nanda & Kierl 1992). Hence, the comparison of survival and failure rates of the different types of TADs is of great prognostic value in future orthodontic treatment planning. But it has to be remembered that TADs are usually inappropriate in growing patients in whom influencing the skeletal growth is additionally indicated.

Table 4. **Study and patient characteristics of the reviewed studies of miniplates**

Author	Kind of study	Type of TAD	Manufacturer	Diameter (mm)	Length (mm)	Number of patients	Mean patient's age (years)	Number of TADs	Number of failures	Percent of failures	Loading time
Chen et al. (2008)	Retrospective	Miniplates	Mondeal or Leibinger	2	5–9	194	25.1 ± 8.7	171	8	4.7	During 36 months period
Cornelis et al. (2008)	Prospective	Miniplates	Surgi-Tec or KLS Martin		5 or 7	97	23.7	200	15	7.5	12 ± 8.4 months
Chen et al. (2008)	Retrospective	Miniplates	Leibinger	2	5 or 7	25	27.5	44	2	4.5	15 months
Kuroda et al. (2007)	Retrospective	Miniplates	KeSei Medical Ind.	2 or 2.3	7 or 11	22	21.8	38	5	13.2	>12 months or completion of treatment
Choi et al. (2005)	Retrospective	Miniplates	Martin	2	5	17	21.2	68	5	7.4	At least 6 months
Miyawaki et al. (2003)	Retrospective	Miniplates	Not specified	2	5	7	21.8 ± 7.8	17	1	5.9	>12 months or completion of treatment

TAD, temporary anchorage devices.

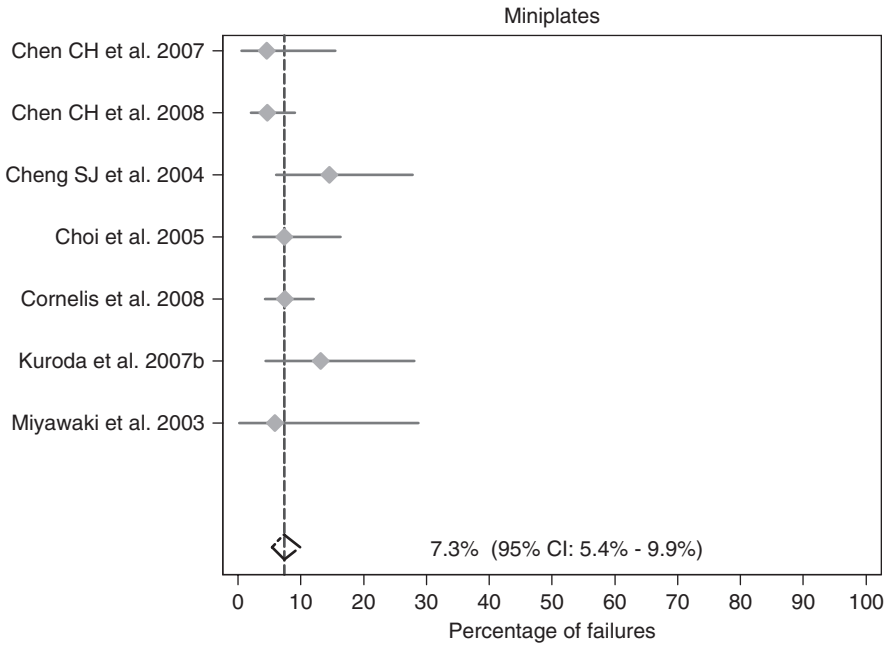

Fig. 5. Failure rates of miniplates and summary estimate from meta-analysis and their 95% confidence intervals (95% CI) by study.

There were only two RCTs (Feldmann & Bondemark 2008; Sandler et al. 2008) comparing the efficacy of COADs with TADs (palatal implants or Onplants®) within the same patient cohort. One of these studies reported significantly higher proportions of failed palatal implants than the other (Sandler et al. 2008). Most of the failed palatal implants had been placed during the initial phase of the investigation, representing the results of a learning curve of the surgeons involved with this 'relatively new' technique. Similar problems were encountered in one retrospective study (Arcuri et al. 2007).

In contrast to conventional oral implants, the orthodontic anchorage implants of the time such as palatal implant yielded an emergence profile with a 90° 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 designed features made the installation of palatal implants technique sensitive. If the two studies mentioned are eliminated from the analysis, palatal implants showed a failure rate of only 6.7%. This is slightly below that reported for miniplates[7.3% (95% CI: 5.4–9.9%].

In recent years, 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). To date, only one prospective cohort study is available on this new generation of palatal implants (Jung et al. 2009) reporting very favorable survival rates (93.3%) (Table 3). Furthermore, a recently published experimental human study on palatal implants with this novel design (Schätzle et al. 2009) yielded a high primary stability and a 100% survival for the whole observation period. Considering all studies on palatal implants, the meta-analysis presented a mean failure rate of 10.5% (95% CI: 6.1–18.1%), rendering this treatment a reliable option with sufficient predictability for routine clinical use (Fig. 3).

Compared with COAD (headgear, transpalatal arch), palatal implants provided equal (compliant patients, Sandler et al. 2008) or statistically significantly better clinical anchorage reinforcement (Feldmann & Bondemark 2008). There were more technical problems and a significantly higher failure rate with the Onplant® system and hence the palatal implant may be considered the anchorage system of choice for TAD (Feldmann & Bondemark 2008). Palatal implants were better tolerated than Onplant® devices as well as extraction of premolars in terms of patient-centered outcomes (pain intensity, discomfort and analgesic consumption) (Feldmann et al. 2007).

After an observation period of at least 12 weeks, miniplates showed a slightly higher success rate of 92.7% than palatal implants (89.5%). It has to be realized, however, that this difference was mainly caused by early surgical failures in two studies mentioned above (Arcuri et al. 2007; Sandler et al. 2008). A direct comparison of the efficacy of miniplates with that of palatal implants with respect to survival has not been performed. Considering the fact that two miniplates have to be installed instead of one palatal implant to achieve the same anchorage in the maxilla, the presumptive risk for failure for the miniplates has to be assumed at 14.1% (95% CI: 10.5–18.8%) for the miniplates.

Even though the majority of the studies included in this review deal with miniscrews, there was no study describing clinical or diagnostic criteria in relation to screw length or screw diameter. Only one RCT (Wiechmann et al. 2007) directly compared two different screw diameters (1.1 and 1.6 mm) of various lengths with each other. A small screw diameter was identified as a risk factor for failure. These findings are in accordance with the results of this present systematic review. An approximately two-fold increased failure rate was identified for miniscrews with a diameter of $\leq$ 1.2 mm compared with miniscrews with a diameter of 2 mm or more. Moreover, two other single retrospective studies (Miyawaki et al. 2003; Chen et al. 2007) came to the same conclusion. But in contrast to another retrospective study (Chen et al. 2006), this RCT (Wiechmann et al. 2007) failed to identify screw length as a possible risk factor for failure. Too many different screw lengths and insertion sites had been included in the study, resulting in a wide scattering of the data. However, it seems to be important that the tipping moment at the bone edge be considered (Büchter et al. 2005). These findings are in accordance with data from two experimental implant studies dealing with different force levels (Melsen & Lang 2001; Hsieh et al. 2008). Therefore, controlled clinical trials with clear selection criteria for screw length and diameter including the applied tipping moments should be encouraged.

The dynamics of TAD loss (loss over time) is an important factor for decision

making in orthodontic treatment planning. The Kaplan–Meier analysis of Wiechmann et al. (2007) showed that the major miniscrew failures occurred within 100–150 days after the start of orthodontic loading. At this point, a change in the treatment plan may be difficult or impossible. With respect to palatal implants, reports indicate that implant loss occurred predominantly in the unloaded healing period (Arcuri et al. 2007; Männchen & Schätzle 2008; Sandler et al. 2008). This in turn means that once a palatal implant is osseointegrated, no implant loss is to be expected.

It is clear that the placement and removal of a miniplate or a palatal implant is a more complex procedure than that associated with the installation of a miniscrew. The surgical intervention for both devices is generally well tolerated by the patients (Kuroda et al. 2007b; Cornelis et al. 2008) and pain intensity after surgical installation of a palatal implant is less than that after premolar extraction (Feldmann et al. 2007). It seems that the greater flexibility and torque resistance provided by palatal implants and miniplates provides an advantage.

For example, during 'en-masse' movement of an entire dental arch of >2 mm, placing a palatal implant in the maxilla or two miniplates in the mandible would be preferable to choosing miniscrew anchorage. Palatal implants as well as miniplate systems allow changes of the force vectors without the need for repositioning of the TAD. Palatal implants and miniplates are associated with a statistically significant 1.9-fold lower risk (95% CI: 1.06–2.78) of failure than miniscrews. Moreover, as there is a chance that miniscrews do not remain stationary under orthodontic forces, a safety zone for root or nerve proximity might be required (Liou et al. 2004; Wang & Liou 2008). This could further restrict possible insertion sites, limit the amount of tooth movement and/or miniscrews have to be repositioned several times during treatment, further increasing the risk for failures. For patients who are undergoing extensive orthopedic corrections or other treatments (maxillary/mandibular protraction or intrusion), the TADs are expected to be in place for a long time. During this time, force vectors may need to be varied or roots of the teeth to be moved may need to slide past the anchors. In this context, palatal implants or miniplates should be the TADs of choice.

It seems obvious that all TADs have the potential to provide some kind of anchorage, which enables orthodontic tooth movements that might be impossible with conventional anchorage methods. However, no orthopedic effects can be achieved in growing children, except for autorotation of the mandible due to vertical manipulations of the buccal segments or in combination with compliance-dependent extraoral or intermaxillary forces.

In conclusion, the use of TADs really expands the envelope of discrepancies in which orthodontic treatment might be successful. On the basis of this systematic review it is concluded that for the maxillary arch, palatal implants are a clearly superior treatment option compared with all other skeletal anchorage devices, whereas in the mandible, miniplates yielded the most favorable results. Both palatal implants as well as miniplates offer safe and effective anchorage possibilities with a high survival rate ($>90\%$), with few side effects or problems during treatment. Palatal implants as well as miniplates might simplify orthodontic treatment and enhance the possibility of treatments that might have been considered unfeasible without skeletal anchorage. However, the relative effectiveness, efficiency and indication list of all different TADs used for various clinical problems need to be evaluated further in prospective controlled studies.

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