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Original article

Success of miniscrews used as anchorage for orthodontic treatment: analysis of different factors

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ABSTRACT

Objectives: To examine factors involved in clinical success of miniscrew implants used for orthodontic anchorage in the upper jaw.
Materials and methods: One hundred and forty-four patients (93 females and 51 males) were fitted with a total of 324 miniscrew implants of two different morphologies (cylindrical and conical), and of different lengths and diameters. The clinical factors examined were screw length, side of insertion, miniscrew shape and diameter, bone quality, skeletal type, and relationship between bone quality and skeletal type and patient age.
Results: The mean overall success rate of the implants was 91.4%. The length and shape of the miniscrews significantly influenced the success rate, whereas side of insertion (left or right), screw diameter and skeletal type showed no significant effects. Poor (soft) bone quality and good (hard) bone quality are risk factors for miniscrew failure, with the best results obtained when the screws are inserted into bone of medium quality (10-15 Ncm).
Conclusion: In the posterior areas of the upper jaw, long, conical miniscrews showed a significantly greater success rate. An insertion torque of 10 Ncm to 15 Ncm is also a significant index of higher success rate.

1. Introduction

Titanium miniscrews are highly adaptable and well suited to the demands and timeframes of current orthodontic treatment. Their insertion is quite simple, with a relative lack of trauma for the patient. Furthermore, they can be subjected to immediate loading, patient compliance is not necessary, the reaction force is discharged away from the dental structures, and they can be removed easily.

The literature relating to the use of titanium miniscrews consists primarily of descriptions of clinical cases, with only a few systematic analyses of their associated success rates. Initially Miyawaki *et al.*[1] identified the most common causes of miniscrew failure as inflammation of nearby tissues, hyperdivergency (thin bone cortex), and screw diameter of 1 mm or less. Inflammation around the screws was again implicated in mini-implant failure, along with mandibular insertion and application on the right side.[2] However, more recently, Luzi *et al.*[3] identified incorrect surgical procedure, bone characteristics, soft tissue thickness, poor oral hygiene, and screw breakage as responsible for miniscrew failure.

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The aim of the present study was to examine the factors involved in clinical success of miniscrew implants used for orthodontic anchorage in the upper jaw.

2. Materials and methods

The 144 patients recruited for this study (51 males and 93 females) who were treated with fixed edgewise appliances had a mean age of 24.6 years (SD, ± 14.1 years). All of the patients provided written informed consent.

A total of 324 miniscrews were applied (2-mm diameter, 84; 1.5-mm diameter, 240), giving a mean of 2.2 miniscrews per patient. The procedures were all carried out in the private practice of the senior author (BGM), who positioned and tested all of the miniscrews, to avoid operator variability. When the miniscrews were applied, a series of variables were recorded for each patient. These included the number and type (form, length and diameter) of the screws used, the site of insertion, the type of bone (hard, medium, soft based on the classification of Lekholm-Zarb[4]), the degree of facial divergence, the maximum load exerted during the treatment, the duration of the treatment, and any failures and their causes.

Three types of titanium alloy miniscrews of different lengths were used (lengths, 7-11 mm) (Spider Screw HDC, Sarcedo, Vicenza, Italy) (Fig. 1). The screws were either cylindrical with a diameter of either 1.5 mm or 2.0 mm, or conical with a diameter of 1.5 mm. Their threads were asymmetric, to provide maximum resistance to pull-out strength.[5] The sites of insertion were in the upper jaw: the maxillary tuberosity (Fig. 2), the edentulous zones, the interdental septa (Figs. 3–5) and the hard palate (Fig. 6). When application was required in anatomically delicate regions, a surgical guide[6] was used.

Insertion of the conical screws was performed with a drill-free procedure, while calibrated drills with stops of 1.1 mm and 1.6 mm were used for the 1.5-mm-diameter and 2.0-mm-diameter cylindrical screws, respectively. The insertions were carried out in an orthogonal direction with respect to the forces applied and the heads of the screws, which were exposed in all cases. The height and positioning of the point of insertion of the screws in relation to the mucogingival line was selected exclusively according to the biomechanical considerations linked to the treatment required.

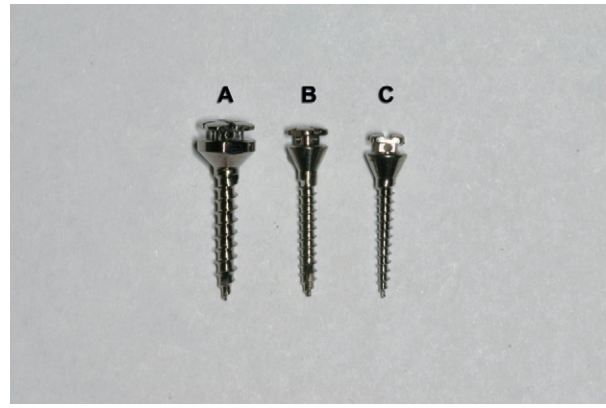

Fig. 1 – Three types of miniscrews; from the left: Cylindrical diameter 2.0 mm. Cylindrical diameter 1.5 mm. Conical diameter 1.5 mm.

The bone quality was defined by the torque required for screw insertion: poor quality (soft), from 5 Ncm to 10 Ncm; medium quality, from 10 Ncm to 15 Ncm; and good quality (hard), >15 Ncm. For the measurements of torque, when manual insertion was used, they were carried out with a torque driver (HDC, Sarcedo, Vicenza, Italy), and when mechanical insertion was required, they were carried out with a mechanical system (W&H Dentalwerke, Bürmoos, Austria).

The patients were subdivided into three skeletal subgroups according to the angle of inclination of their mandibular plane in relation to the anterior cranial base (SN-GoGn; S [sella], N [nasion], Go [gonion], Gn [gnathion]), as hypodivergent (<30°), normodivergent (30°-37°), and hyperdivergent (>37°).

The stabilities of the miniscrews were determined immediately following their placement, and then monthly during the course of normal routine checks, where the inflammation around the miniscrews was also reported (absent or present), based on any swelling or reddening of the peri-implant tissues. The screws were immediately loaded with forces <150 g for the first two months of treatment. Subsequently, the forces were increased according to need, without exceeding 300 g.

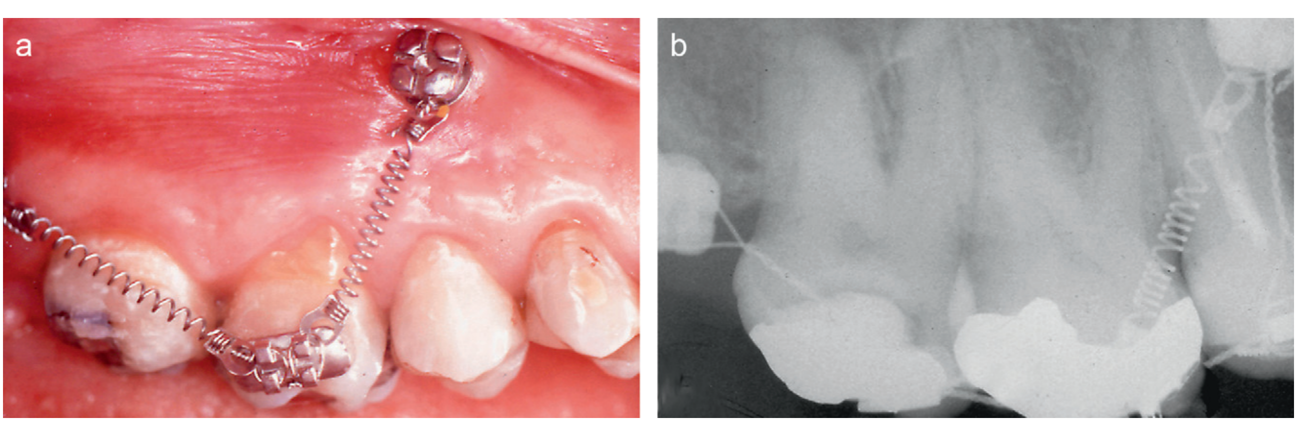

Fig. 2 – (a) Cylindrical Miniscrew used to intrude upper molar applied in the mobile mucosa. (b) Periapical x-ray of 2 cylindrical miniscrews (same case of Fig. 2a); one applied in the tuberosity and one in the interproximal space between the two premolars.

Fig. 3 – (a,b,c) M.B. Age 11, showing Class II division 1 malocclusion with deep bite. Intraoral views before treatment.

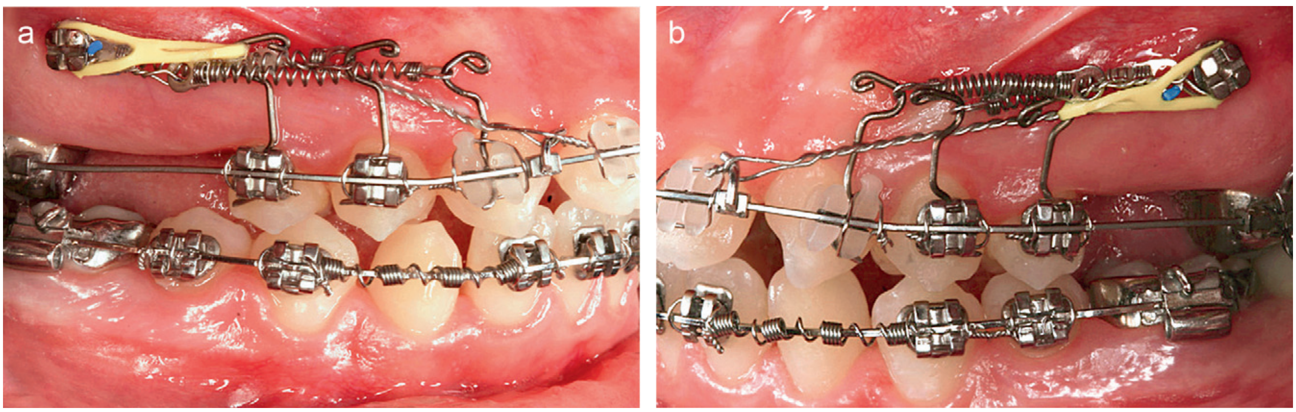

Fig. 4 – (a,b) M.B. Age 12, during treatment. Two miniscrews (conical shape 1.5 mm) were applied mesially to the first molars at the mucogingival junction to retract simultaneously bicuspids and cuspid (phase 2) and to retract incisors later (phase 3).

The patients were instructed to use 0.3% chlorhexidine gel for the first seven days after miniscrew application.

Miniscrew removal was carried out manually in most cases, without the use of local anaesthesia. The success of the miniscrews was then evaluated clinically, based on the screw endurance and clinical usefulness over the course of the orthodontic treatment.

To determine the statistical relationships between the miniscrew characteristics and the relative failure rates, the data were analysed with z tests on proportions, with Bonferroni's correction for multiple comparisons. The P for statistical significance was set at 0.01.

3. Results

Of the total miniscrews applied ($N = 324$), 296 applications (91.4%) were successful, and 28 (8.6%) failed. The mean period of use of the miniscrews was 13.7 months (SD, 8.7 months). The mean age of the patients treated with success was 24.6 years (SD, 14.0 years), and that of the patients in whom the miniscrews failed was 23 years (SD, 13.6 years) (13 [68.4%] females and 6 [31.6%] males).

For the miniscrews of different lengths, the failure rate for a length of 8 mm was significantly higher than the mean failure rate (Table 1; $P < 0.01$). However, the failure rate was not influenced by side of insertion (Table 1). In terms of the miniscrew diameters and shapes, there were no substantial differences in the clinical outcomes between miniscrews of diameters of 1.5 mm and 2.0 mm; however, for the shape, overall, the conical screws showed fewer failures, although this did not reach significance in comparison with the total mean failure rate (Table 1). With the classification of the bone quality at the insertion site as poor (soft), medium or good (hard), more failures occurred in both the poor (soft) and the good (hard) quality bone. Thus the failure rate of the miniscrews applied to

Fig. 5 – (a,b,c) M.B. Age 13, intraoral views after treatment.

Table 1 – Analysis of miniscrew and bone characteristics.

Characteristic	Number of screws	Percentage total (%)	Number of failures	Percentage failures (%)	Significance *versus* total mean failure rate*
Miniscrew length (mm)					
7	3	0.9	0	0	NA
8	50	15.4	12	24	S
9	32	9.9	4	12.5	NS
10	186	57.4	7	3.8	NS
11	53	16.4	5	9.4	NS
Total mean failure rate	324		28	8.6	
Site of insertion of miniscrew					
Right side	155	47.8	10	6.5	NS
Left side	165	50.9	14	8.3	NS
Undefined	4	1.3	0	0.0	NA
Total mean failure rate	324		7	7.0	
Miniscrew shape, diameter (mm)					
Cylindrical, 1.5	128	39.5	13	10.2	NS
Cylindrical, 2.0	84	25.9	9	10.7	NS
Conical, 1.5	112	34.6	6	5.4	NS
Total mean failure rate	324		28	8.6	
Bone quality					
Poor (soft)	24	7.4	6	25.0	NS
Medium	254	78.4	14	5.5	S
Good (hard)	26	8.0	5	19.2	NS
Undefined	20	6.2	3	15.0	NS
Total mean failure rate	324		28	16.2	

S, significant, $P < 0.01$; NS, not significant, $P > 0.01$; NA, not applicable.
* Bonferroni t test.

bone of medium quality was significantly lower in comparison with the total mean failure rate (Table 1; $P < 0.01$). Finally for the bone quality, the specific comparison of the failure rates for the miniscrew types (cylindrical *versus* conical) used only in the hard bone type showed no significant difference here (Table 2).

Table 2 also summarises the results obtained in the comparison of the different methods of insertion of the miniscrews, where it can be seen that although there was a more favourable clinical outcome without pre-drilling (drill-free), this difference did not reach significance (Table 2).

Regarding the skeletal type, our data revealed no substantial effects on the success rates, except for a relative increase in miniscrew failures in the normodivergent patients; however, this did not reach statistical significance in comparison with the total mean failure rate (Table 3). Similarly, although there were some indications of increased failure rates across the forces exerted on the miniscrews, none of these reached statistical significance in comparison with the total mean failure rate (Table 3).

Across the bone quality as a correlation to skeletal type, there was a prevalence of good quality bone (hard) in the normodivergent patients, with bone quality very similar otherwise among these skeletal types (Table 4). The data in Table 4 also show that although there was some variability across the years, and with specifically low numbers for patients >60 years of age, the bone quality decreased with age, as might be expected.

Table 2 – Analysis of miniscrew bone insertion.

Miniscrew insertion characteristic	Number of screws	Percentage total (%)	Number of failures	Percentage failures (%)	Statistical comparison*
Type of screw inserted into 'hard' quality bone					
Cylindrical	17	65.4	3	17.6	NS
Conical	9	34.6	2	22.2	
Means of insertion of all miniscrews					
Pre-drilled	212	65.4	22	10.4	NS
Drill free	112	34.6	6	5.4	

NS, not significant, $P > 0.01$.
* Bonferroni t test.

Table 3 – Analysis of skeletal and force characteristics.

Skeletal and force characeristic	Number of screws	Percentage total (%)	Number of failures	Percentage failures (%)	Significance *versus* total mean failure rate*
Skeletal type					
Normodivergent	132	40.7	17	12.9	NS
Hyperdivergent	60	18.6	4	6.7	NS
Hypodivergent	97	29.9	5	5.2	NS
Undefined	35	10.8	2	5.7	NS
Total mean failure rate	324		28	7.6	
Force exerted (g)					
50	13	4.0	1	7.7	NS
100	37	11.4	6	16.2	NS
150	134	41.4	14	10.5	NS
200	55	17.0	0	0.0	NA
250	3	0.9	0	0.0	NA
300	46	14.2	5	11.1	NS
Undefined	36	11.1	2	5.6	NS
Total mean failure rate	324		28	7.3	

NS, not significant, $P > 0.01$; NA, not applicable.
* Bonferroni t test.

Of note, in all cases of miniscrew failure, inflammation was always seen.

4. Discussion

The causes of orthodontic miniscrew failure appear to be varied and might also be attributable to factors that were not included as objectives of this study, such as metabolic disturbance, smoking, and specific local parafunctions. Surgical technique can also have a strong influence on the stability of miniscrews.[21,22] Indeed, an inappropriate application technique can lead to initial instability, overheating of the bone, and/or poor adaptation of the miniscrew to the cortical perforation.

In the present study, we paid particular attention to the structural characteristics of the miniscrews: length, diameter and shape (cylindrical or conical), along with the factors

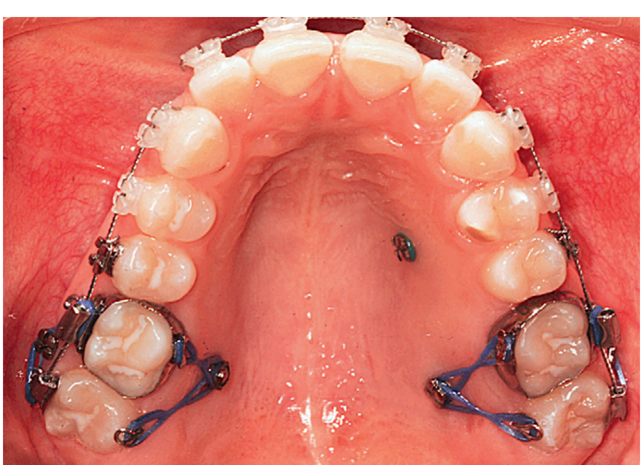

Fig. 6 – Miniscrews (conical shape 1.5 mm of diameter) used in the interproximal spaces from the buccal and the palatal sides to intrude upper molars.

influenced by the maintenance protocol, such as side of insertion and any differences related to hygiene and loads applied. A light screw mobility appears in itself not to jeopardize its clinical use[1,2] and hence this clinical observation was omitted in the present study.

Previous studies on implants have revealed that bone quality appears to influence miniscrew success rates.[7] Lekholm and Zarb[4] were the first to classify the bone types when they divided the osseous quality into four types based on the different thickness of the cortex and quality of the medulla. It is likely that the poorest quality of bone will have the largest detrimental effects on the primary implant stability.[8] In the present study, all of the miniscrews were applied to the upper jaw, where we found that the insertion can usually be carried out with torque values of 10 Ncm to 15 Ncm.

Regarding the screw stability and the forces applied, the essential relevant clinical factors must consider both the primary stability and the eventual secondary stability that will be linked to the degree of osseointegration of the titanium miniscrews. In a study on experimental animals, Ohmae *et al.*[9] applied no immediate load and also forces from 50 g to 150 g, and they reported osseointegration of <25%. However, in another experimental study, on dogs, with a later loading protocol and a healing period of at least three weeks, osseointegration was reported to occur in an extremely high percentage of cases (97%).[10] On the other hand, Melsen and Costa,[11] demonstrated in a monkey study that immediate application of loads of forces of between 25 g and 50 g to the screws helped to promote osseointegration, the degree of which increased over time. It was therefore logical in the present study to adopt a loading protocol with progressively increasing forces, especially in cases where the bone quality was poor, and thus the stability would be compromised from the beginning. The maximum force applied here did not exceed 300 g in any case.

In terms of the length of the miniscrews, we see here that the most favourable length is 10 mm. However, the lower success rate of the 11-mm-length screws, seems to contradict this

Table 4 – Bone quality characteristics with respect to skeletal type and patient age.

Bone quality	Skeletal type (n; [%total])				Age range (n; [%total])					
	Hyper divergent	Hypo divergent	Normo divergent	Undefined	11-20 years	21-30 years	31-40 years	41-5 years	51-60 years	61-70 years
Poor (soft)	2 (3.3)	4 (4.1)	10 (7.6)	8 (22.8)	2 (1.1)	6 (13.6)	5 (11.1)	5 (23.8)	6 (24.0)	0 (0)
Medium	56 (93.4)	90 (92.8)	87 (65.9)	21 (60)	163 (88.1)	28 (63.6)	34 (75.6)	10 (47.6)	15 (60.0)	4 (100)
Good (hard)	0 (0)	2 (2.1)	22 (16.7)	2 (5.7)	14 (7.6)	5 (11.4)	2 (4.4)	4 (19.1)	1 (4.0)	0 (0)
Undefined	2 (3.3)	1 (1)	13 (9.8)	4 (11.5)	6 (3.2)	5 (11.4)	4 (8.9)	2 (9.5)	3 (12.0)	0 (0)
Total	60	97	132	35	185	44	45	21	25	4

result, but they were generally applied in anatomical regions of bone of lower quality, and this might well explain the tendency towards negative results with respect to the average failure rate. In this, our data agree with those of others who have also noted that the length of miniscrews can influence their stability.[12,13] Screw stability is dependent upon how they 'grip' onto the bone cortex, and the thicker and denser the cortex, the more stable the screws should be. However, the length of a miniscrew can also limit the associated flexion movement and the mechanical stress linked to the application of a force at the level of its passage through the cortex. Moreover, bone-modelling phenomena and an increased lamellar component might develop following insertion of such mini-implants,[14] with an increased contact surface between the bone and the miniscrew. This contact area will be proportionally larger when longer miniscrews are used, with a resulting improved loading capacity.

The direction of our miniscrew insertion was, on average, at 90° to the surface of the bone, and small variations in this angulation from 60° to 90° should not be of clinical significance.[15] However, a study carried out by Wilmes et al.[16] showed that a direction of insertion of 70° is preferable for the best primary stability. Pickard et al.[17] also noted in an animal study that the more closely the long axis of the implant approximates to the line of the applied force, the greater its resistance to failure. From a clinical point view, though, when applying miniscrews in thin interproximal spaces, the possibility to vary the miniscrew inclination, in relation to the applied forces, is limited.

We also investigated whether there might be any differences in the success of mini-implants inserted into the left or the right side of the mouth. This was in consideration of the potential need for a more complex operator technique together with better maintenance of oral hygiene from the point of view of the (left-handed or right-handed) patient,[18] and so whether this can influence clinical outcome. The results of our study showed no differences between the two sides of the mouth, although a greater percentage of success on the left side has been reported previously.[2]

The diameter of the screws (as 1.5 mm or 2.0 mm here) did not have any demonstrable influence on the miniscrew success rates. Indeed, previous studies have indicated no differences in clinical outcome with screw diameters of at least 1.5 mm, and that increasing the diameter to at least up to 2.0 mm did not lead to significant differences in success rates.[1,2] From a clinical perspective, a diameter of 1.5 mm is more often indicated, especially in the inter-radicular zones, as this will represent the best compromise for screw strength and reduced incidence of screw fractures.

In the present study, the quality of bone was related to higher success rates when the torque required for insertion of self-drilling miniscrews of 1.5 mm in diameter was from 10 Ncm to 15 Ncm. The failure rates were however higher in cases with harder bone quality (insertion torque > 15 Ncm), in agreement with previous data.[19,20] A possible explanation for this apparent discrepancy might be that there is increased local damage to the osseous structures upon insertion of a mini-implant into more compact bone, where critical temperatures of over 47 °C will be reached in cases where pre-drilling is carried out.[21,22]

The success rates of the two different screw shapes, as cylindrical (pre-drilling necessary) and conical (self-drilling), showed that the conical screws had fewer failures, which was probably due to better primary stability and bone-to-implant contact of the conical miniscrews, as has been reported in other studies.[23–25] However the fact that this difference is not statistically significant, could be linked to the relatively low number of failures observed (6 out of 112 miniscrews), and this should perhaps be evaluated in a larger sample.

With regard to the skeletal type, our results did not agree with those of Miyawaki et al.,[1] as we did not see any differences between hyperdivergent and hypodivergent patients. Studies that have demonstrated differences in cortical thickness between hyperdivergent and hypodivergent patients were carried out with the lower jaw,[26,27] while in the present study the miniscrews were applied exclusively to the upper jaw. It cannot therefore be determined whether studies carried out on one arch are applicable to another arch that has very different osseous characteristics. In terms of the bone quality of the upper jaw seen here, there was only a slightly increased prevalence of denser bone in the younger age groups, while there were no differences between skeletal types.

5. Conclusions

In the present study, the overall success rate for these miniscrews was 91.4%, for a total of 324 miniscrews, and with force applied over a mean period of 13.7 months. Neither the miniscrew diameter (1.5 or 2.0 mm), nor the skeletal pattern were associated with differences in the success rates of the miniscrews. Longer miniscrews had a greater success rate, as did conical (self-drilling) miniscrews. Application of the miniscrews with a mean torque of 10 Ncm to 15 Ncm increased the success rates when miniscrews with a diameter of 1.5 mm and a length of 10 mm were used. Finally, there were no differences in clinical outcome that could be attributed to skeletal type.

Conflict of interest

The authors have reported no conflict of interest.

Riassunto

Obiettivi: *Esaminare i fattori coinvolti nel successo clinico dei mini impianti utilizzati come ancoraggio ortodontico nel mascellare.*

Materiali e metodi: *Sono stati esaminati 144 pazienti (93 femmine e 51 maschi) trattati consecutivamente con un totale di 324 miniviti di due differenti tipologie (coniche e cilindriche), differente lunghezza e diametro. I fattori clinici esaminati sono stati la lunghezza delle viti, il lato di inserzione, la forma e il diametro delle miniviti la qualità dell'osso, la tipologia scheletrica, la relazione tra la qualità dell'osso, la tipologia scheletrica e l'età del paziente.*

Risultati: *Il tasso di successo medio dei mini impianti è stato del 91,4% nel complesso. L'influenza della lunghezza e della forma delle miniviti è risultata significativa per il loro successo, mentre il lato di inserzione (desto o sinistro), il diametro della vite e la tipologia scheletrica non hanno mostrato effetti significativi. Una qualità dell'osso scarsa e un osso molto duro rappresentano fattori di rischio per il fallimento delle miniviti con i migliori risultati ottenuti quando le viti vengono inserite in osso di qualità media (10-15 Ncm).*

Conclusioni: *Nell'area posteriore del mascellare miniviti lunghe e di forma conica hanno mostrato la maggior percentuale di successo. Un valore di torque di inserzione compreso tra 10 e 15 Ncm può essere considerato un indice di una percentuale di successo maggiore quando vengono usate miniviti con diametro 1,5 mm e lunghezza di 10 mm.*

Résumé

Objectifs: *Examiner les facteurs impliqués dans le succès clinique des implants à minivis utilisés pour l'ancrage orthodontique dans le maxillaire supérieur.*

Matériels et méthodes: *Cent cinquante-quatre patients (93 femmes et 51 hommes) ont reçu au total 324 implants à minivis ayant deux morphologies (cylindrique et conique), des longueurs et des diamètres différents. Les facteurs cliniques examinés ont porté sur la longueur des vis, le côté d'insertion, la forme et le diamètre des minivis, la qualité de l'os, le type de squelette et la relation entre qualité de l'os et type de squelette et l'âge du patient.*

Résultats: *Le taux de succès général moyen a atteint 91,4%. La longueur et la forme des minivis ont énormément influencé le taux de succès, alors que le côté d'insertion (à droite ou à gauche), le diamètre des vis et le type de squelette n'ont pas montré d'effets remarquables. Une qualité osseuse faible (molle) et une qualité osseuse bonne (dure) constituent des facteurs de risque pour l'éventuel échec des minivis, les résultats les meilleurs étant obtenus quand les vis sont insérées dans un os de qualité moyenne (10-15 Ncm).*

Conclusions: *En arrière du maxillaire supérieur, les minivis coniques et longues ont fait état d'un taux de succès nettement plus élevé. Un couple d'insertion 10 Ncm à 15 Ncm est également un indice d'un taux de succès plus élevé.*

Resumen

Objetivos: *Examinar los factores involucrados en el éxito clínico de los implantes de minitornillo utilizados para los anclajes ortodónticos en el maxilar superior.*

Materiales y métodos: *En ciento cuarenta y cuatro pacientes (93 mujeres y 51 varones) se colocaron un total de 324 implantes de minitornillo de dos morfologías diferentes (cilíndrica y cónica), y con distintos diámetros y largos. Los factores clínicos estudiados fueron la longitud del tornillo, el lado de inserción, la forma y el diámetro del minitornillo, la calidad ósea, el tipo de esqueleto y la relación entre calidad ósea y tipo de esqueleto y edad del paciente.*

Resultados: *La tasa promedio de éxito general ascendió al 91,4%. La longitud y la forma de los minitornillos influyeron importantemente en la tasa de éxito, mientras que el lado de inserción (a la derecha o a la izquierda), el diámetro del tornillo y el tipo de esqueleto no destacaron efectos significativos. Una pobre calidad ósea (blanda) y una buena calidad ósea (dura) son factores de riesgo en cuanto al posible fallo de los minitornillos, con los mejores resultados que se consiguen cuando los tornillos se colocan en hueso de mediana calidad (10-15 Ncm).*

Conclusiones: *En la región posterior del maxilar superior, los minitornillos largos y cónicos experimentaron una tasa de éxito marcadamente superior. Un par de inserción de 10 Ncm a 15 Ncm también es un índice significativo de una tasa de éxito más alta.*

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