CLINICAL ORAL IMPLANTS RESEARCH

Abdullah A. Al-Kalaly
Ricky W. K. Wong
Lim K. Cheung
Shimanto K. Purkayastha
Marc Schätzle
A. Bakr M. Rabie

Evaluation of bone thickness around the mental foramen for potential fixation of a bone-borne functional appliance: a computer tomography scan study

Authors' affiliations:
Abdullah A. Al-Kalaly, Ricky W. K. Wong, Shimanto K. Purkayastha, Marc Schätzle, A. Bakr M. Rabie, Department of Orthodontics, Prince Philip Dental Hospital, Faculty of Dentistry, University of Hong Kong, Sai Ying Pun, Hong Kong, China
Lim K. Cheung, Department of Oral and Maxillofacial Surgery, Prince Philip Dental Hospital, University of Hong Kong, Sai Ying Pun, Hong Kong, China
Marc Schätzle, Department of Clinic for Orthodontics and Pediatric Dentistry, Center for Dental and Oral Medicine and Cranio-Maxillofacial Surgery, University of Zurich, Zurich, Switzerland

Corresponding author:
Prof. A. Bakr M. Rabie
Department of Orthodontics
Faculty of Dentistry
The University of Hong Kong 34 Hospital road
Sai Ying Pun
Hong Kong
SAR
China
Tel.: +852 28590260
Fax: +852 25593803
e-mail: rabie@hkusua.hku.hk

Key words: bone thickness, mandible, mini-screws, mental foramen

Abstract

Aim: A mandible bone-borne Herbst appliance (MBBHA) would avoid the proclination of the lower incisors that occurs with any teeth-borne functional appliance. But mapping of the bone characteristics at potential fixation areas around the mental foramen has not been carried out so far. The aim of this computer tomographic (CT) study was to evaluate bone thickness at specific positions around the mental foramen.

Material and methods: CT scans of 60 randomly chosen adult Hong Kong Chinese subjects (mean age 28 ± 6.3 years) were used to measure the bi-cortical bone thickness in the mandible in the mental foramen area. The thickness of buccal and lingual cortical and cancellous bone was assessed at the following locations: 10 mm (A10 mm) and 5 mm (A5 mm) anterior, 10 mm (P10 mm) and 5 mm (P5 mm) posterior, and 5 mm (Inf5 mm) below the mental foramen.

Results: The amount of buccal cortical bone thickness ranged between 1.89 mm, 10 mm anterior of the mental foramen, and 2.16 mm, 10 mm posterior to its location. At the A10 mm level, cortical thickness showed a marginal statistically significant difference between A5 and A10 mm. The total amount of bone thickness ranged from 10.19 to 12.06 mm.

Conclusion: At the locations studied around the mental foramen, a mean bicortical bone thickness of 10–12 mm was measured. No large variation in the thickness was found between bicortical bone thicknesses in the measured locations around the mental foramen. Thorough evaluation on a case-by-case basis is advisable.

The correction of a Class II division 1 malocclusion by means of functional appliances is a frequent treatment approach (O'Connor 1993). Numerous studies have focused on the mode of action of the different types of removable functional appliances, evaluating their dental and skeletal effects. Several studies reported the effectiveness of fixed functional appliance for the correction of class II malocclusion in adult human subjects (Ruf & Pancherz 1999a, 1999b, 2003, 2006; Purkayastha et al. 2008) and experimental animals (McNamara Jr et al. 2003; Xiong et al. 2005) and found a correction of 78% dental and 22% skeletal (Purkayastha et al. 2008). None of the removable and teeth-borne functional appliances available could fully address the problem of anchorage loss and the subsequent proclination of the lower anterior teeth (Pancherz 1997; Weschler & Pancherz 2005). Mandibular anchorage remains an unsolved problem in Herbst treatment, a reality with which the orthodontist has to live (Pancherz & Ruf 2008).

The mandibular component of the Herbst appliance is anchored to the teeth, and the pivots that allow the attachment of the mandibular advancement mechanism are usually on the lower first premolars

Date:
Accepted 11 February 2010

To cite this article:
Al-Kalaly AA, Wong RWK, Cheung LK, Purkayastha SK, Schätzle M, Rabie ABM. Evaluation of bone thickness around the mental foramen for potential fixation of a bone-borne functional appliance: a computer tomography scan study.
Clin. Oral Impl. Res. **21**, 2010; 1288–1293.
doi: 10.1111/j.1600-0501.2010.01947.x

(Pancherz 2003). A Herbst appliance with bone-borne mandibular attachments (MBBHA) would avoid the proclination of the lower incisors that occurs with any teeth-borne functional appliance. In addition, the skeletal component to the mandible to correct mild skeletal class II malocclusion might even be increased. The use of MBBHA for the correction of the intermaxillary relationship requires awareness of the amount of available bone for support in the insertion site. Many studies have evaluated the bone in different areas of the maxilla and the mandible for possible insertions sites and enhance the stability and success of orthodontic mini-screws and distracters (Cheung et al. 2003; Schnelle et al. 2004; Deguchi et al. 2006; Poggio et al. 2006; Kang et al. 2007; Park et al. 2008; Monnerat et al. 2009). However, none appeared to have considered mapping the cortical characteristics at areas around the mental foramen for insertion of mini-screws or bone-borne distracters for the particular reason of correction of intermaxillary discrepancy.

As MBBHA would be fixed to bone by means of osteosynthesis screws or mini-screws, the stability of mini-screws in the correction of skeletal class II malocclusion will be considerably affected by the forces created by pull of the masticatory muscles (A.S. Al-Kalaly, J.E. Dyson, R.W.K. Wong, M. Schätzle & A.B. Rabie, unpublished data). These acting forces, however, should not have a negative impact on the adjacent bone or impair the long-term prognosis of the MBBHA.

It was found that the resistance to the movement of the mini-screw is greater for bicortical compared with monocortical placement (Brettin et al. 2008), pointing to the importance of evaluating the thickness of bone for deciding on the method of anchorage that would withstand the anticipated load. If the bicortical method is chosen, it is crucial to decide on the safe length of the mini-screw based on available bone thickness at the insertion site, which would confer the best stability for the anchor plates, while preserving the surrounding vital structures such as nerves or teeth roots.

The aim of this study was to evaluate the bone thickness at specific positions in relation to the mental foramen, as a contributing factor to determine the appropriate length of the screws and pattern of mini-plates to be used in these areas.

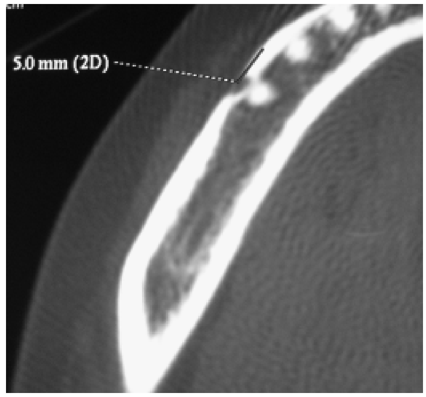

Fig. 1. Distance localization performed on an axial cut.

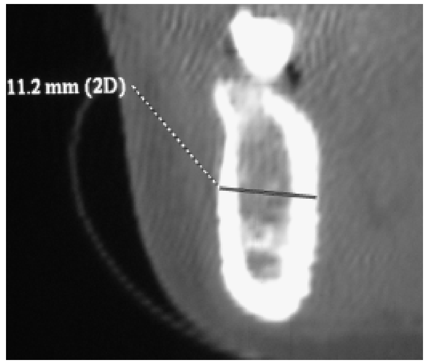

Fig. 2. Total thickness measurement on an oblique cut.

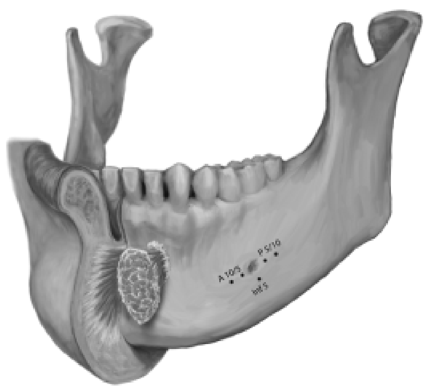

Fig. 3. Locations around the mental foramen whose bone thickness was measured: 5 mm (A5) and 10 mm (A10) anterior, 5 mm (P5) and 10 mm (P10) posterior; and 5 mm (Inf5) to the mental foramen. (Courtesy of Roger Zwahlen and Werner Käser, University of Zurich, Zurich, Switzerland.)

Material and methods

Computer tomographic (CT) scans of 60 randomly chosen adult Hong Kong Chinese subjects were used to measure the bicortical bone thickness in the mandible in the mental foramen area (distance between buccal and lingual cortical bone surfaces). The mean patient age was 28 $\pm$ 6.3 years, age range from 21 to 48.6 years.

The CT scans were obtained from the records of the Oral Radiology Department of the Faculty of Dentistry, The University of Hong Kong, Hong Kong, SAR, China. A Hi-speed Advantage scanner (General Electric Medical System, Milwaukee, WI, USA) was used with the following parameters: 140 kV, 80 mA, 1 mm contiguous slices, and FOV 13 cm. Axial cuts through the mandible were examined till the mental foramen became clear; the last clear mental foramen observed on the previous cross section but no longer observed in the next image was used. Using the measurement tool of the software (Advantage Workstation AW 4.0–5.0, GE Medical Systems), a starting point was placed in the middle of the foramen, from which a line was drawn parallel to the lateral part of the mandibular body (Fig. 1). A cross section was obtained for this location (Fig. 2) and the measurement procedures were performed at 90° to the bone surface following the method used by Cheung et al. (2003), where bone thickness was calculated by measuring the distance of inner and outer bony cortices and subtracting the cancellous space. The thickness of labial cortical bone, cancellous bone, and lingual cortical bone was assessed in the following locations: 10 mm (A10 mm) and 5 mm (A5 mm) anterior to the mental foramen; 10 mm (P10 mm) and 5 mm (P5 mm) posterior to the mental foramen; and 5 mm (Inf5 mm) below the mental foramen (Fig. 3). Measurements were carried out by the same examiner, a dentist familiar with distance measurement procedures on CT scans by a radiology instructor.

The measurement error was calculated for all measurements on randomly selected 15 CT scans and measured by the same observer after a 1-month interval. The calculations were performed using the Dahlberg formula (1940), $ME = \sqrt{\Sigma d/2n}$, where d is the difference between two measurements of a pair and n is the number of paired double measurements. The error of measurements ranged from 0.05 to 0.25 mm, with a mean of 0.16 mm. An unpaired sample t-test was used to compare the right and the left side measurements; no significant difference existed between measurements of all positions and the mean of the right and the left sides was used for further statistical analysis.

Data analysis was carried out using the Statistical Package for the Social Sciences version 13.0 for Windows (SPSS inc, Chicago, Illinois, USA). Data were presented as mean and standard deviation of the bone thickness. After testing for normal distribution and equality of variances using Levene's *F*-test, an independent-sample *t*-test was used to compare the variables. The level of significance was set at $\alpha = 0.05$.

Results

The mean cortical bone thickness for the buccal and lingual side as well as the thickness of the cancellous bone and standard deviation for the different points of interest is depicted in Table 1. Tables 2 and 3 show an independent samples test for A5 vs. A10 and P5 vs. P10 mm, respectively. The amount of buccal cortical bone thickness increased between 1.9 mm, 10 mm anterior of the mental foramen, and 2.2 mm, 10 mm posterior to its location, respectively. Buccal cortical thickness showed a marginal statistically significant difference between A5 and A10 mm. Also, the amount of cancellous bone increased steadily in the anterior–posterior direction from 6.3 to 7.8 mm. The thickness of the lingual cortical bone, in contrast, did not change and ranged between 2 and 2.2 mm. The total amount of bone thickness ranged from 10.2 to 12.1 mm, yielding the lowest values in the most anterior position and the highest values in the most posterior location to the mental foramen, respectively.

At the level 5 mm inferior to the mental foramen, the buccal cortical volume assessed yielded the highest values of 2.4 mm, whereas the spongeous bone yielded results similar to the values of the anterior region (6.4 mm).

Discussion

Class II malocclusion represents one of the most common orthodontic problems in Caucasian (51.1–67.7%) (Proffit et al. 1998) and in Asian populations (31%) (Chu et al. 2009). By holding the mandible in a forward position by means of removable and tooth-borne functional appliances, mechanical strain is created, which triggers the condylar tissues to express a mechanotransduction mediator, Indian Hedgehog, which in turn aids condylar growth (Tang et al. 2004; Rabie & Al-Kalaly 2008).

None of the available removable and tooth-borne functional appliances could address the problem of anchorage loss and the subsequent proclination of the lower anterior teeth (Pancherz 1997; Weschler & Pancherz 2005). But if temporary anchorage devices (TAD), as they are in direct contact with bone and do not move when low forces are applied (Melsen & Lang 2001), could be used in a way for skeletal Class II corrections, it would offer the field of orthodontics greater possibilities.

A mandibular bone-borne Herbst appliance (MBBHA) would avoid the proclination of the lower incisors that occurs with any teeth-borne functional appliance, whereas additionally, the skeletal component to the mandible to correct mild skeletal class II malocclusion might even be increased. Less proclination of the lower incisors should allow more advancement with the subsequent added skeletal effect (Rabie & Al-Kalaly 2008; Purkayastha et al. 2008). The purpose of this CT study was to assess the average bone thickness in the mandibular basal bone in areas around the mental foramen as potential fixation sites for MBBHA for interarch antero-posterior correction.

Conventional CT is considered to be an accurate measurement tool for bony

Table 1. **Mean values and standard deviations for the different areas around the mental foramen**

Location	*N*	Buccal cortical bone		Cancellous bone		Lingual cortical bone		Total distance	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
A5	60	2.01	0.34	6.33	1.75	2.04	0.37	10.37	1.96
A10	60	1.89	0.3	6.28	1.85	2.02	0.34	10.19	1.97
P5	60	2.1	0.39	7.19	2.2	2.2	0.49	11.48	2.45
P10	60	2.16	0.37	7.83	2.3	2.07	0.59	12.06	2.67
Inf5	60	2.38	0.33	6.39	1.7	1.97	0.42	10.73	1.93

Table 2. **Independent samples test for A5 vs. A10 mm**

	Levene's test for equality of variances		*t*-test for equality of means						
			t	df	Signed (two-tailed)	Mean difference	SE difference	95% confidence interval of the difference	
	F	Signed						Upper	Lower
Buccal									
Equal variances assumed	1.194	0.277	1.993	118	0.049*	0.117	0.059	0.001	0.233
Equal variances not assumed			1.993	116.121	0.049*	0.117	0.059	0.001	0.233
Cancellous									
Equal variances assumed	0.003	0.958	0.157	118	0.876	0.052	0.329	− 0.6	0.704
Equal variances not assumed			0.157	117.644	0.876	0.052	0.329	− 0.6	0.704
Lingual									
Equal variances assumed	0.191	0.663	0.182	118	0.856	0.012	0.064	− 0.115	0.139
Equal variances not assumed			0.182	117.141	0.856	0.012	0.064	− 0.115	0.139
Total									
Equal variances assumed	0.009	0.926	0.502	118	0.617	0.18	0.359	− 0.53	0.89
Equal variances not assumed			0.502	117.997	0.617	0.18	0.359	− 0.53	0.89

*$P = 0.05$.

Table 3. **Independent samples test for P5 vs. P10 mm**

	Levene's test for equality of variances		*t*-test for equality of means						
			t	df	Signed (two-tailed)	Mean difference	SE difference	95% confidence interval of the difference	
	F	Signed						Upper	Lower
Buccal									
Equal variances assumed	.098	.755	−.933	118	.353	−.065	.07	−.203	.073
Equal variances not assumed			−.933	117.779	.353	−.065	.07	−.203	.073
Cancellous									
Equal variances assumed	.248	.619	−1.558	118	.122	−.64	.411	−1.454	.174
Equal variances not assumed			−1.558	117.777	.122	−.64	.411	−1.454	.174
Lingual									
Equal variances assumed	.016	.9	1.288	118	.2	.128	.1	−.069	.326
Equal variances not assumed			1.288	114.271	.2	.128	.1	−.069	.326
Total									
Equal variances assumed	.517	.474	−1.234	118	.22	−.577	.467	−1.502	.349
Equal variances not assumed			−1.234	117.131	.22	−.577	.467	−1.502	.349

structures (Suomalainen et al. 2008). A CT scan provides better accuracy than conventional radiographic methods (Sonick et al. 1994; Bou Serhal et al. 2002), where the measurement discrepancies during the use of different radiographic methods for the evaluation of the amount of bone coronal to the mental foramen had an average linear error of 24% for panoramic radiographs, 14% for periapical films, and 1.8% for CT scans (Sonick et al. 1994).

The conventional use of mini-screws for orthodontic purposes does not necessitate their use close to the mental foramen. Working in close proximity to the nerve could result in stretching, compressed, or transection of the nerve, which may lead to various degrees of numb feeling, sensitivity, pain in the lower teeth and lower lip, or the surrounding soft tissues (Sharawy & Misch 1999; Greenstein & Tarnow 2006).

The choice of the positions for the measurement of bone thickness in this study is adapted from locations considered to be within the safety zone recommended for placing dental implants in relation to the mental foramen, while taking into consideration the probability of the existence of an anterior loop of the mental nerve (Misch & Crawford 1990; Bavitz et al. 1993; Wismeijer et al. 1997; Mardinger et al. 2000; Kieser et al. 2002; Kuzmanovic et al. 2003). A safety zone of 2 mm is recommended for the placement of dental implants above the mental foramen and inferior alveolar canal (Greenstein & Tarnow 2006). This could be applied to mini-screws. Furthermore, in the anterior position after verification of the presence or absence of the anterior loop of the mental nerve, a 2 mm or more anterior to the mental foramen is advised for the placement of the dental implant (Greenstein & Tarnow 2006) and likewise could be assumed for the mini-screws.

Evaluation of the difference in bone thickness at different distances anterior, posterior as well as inferior to the mental foramen would help us decide the pattern and position of mini-plates anchored by mini- or osteosynthesis screws. The thickness of bone at insertion sites plays an important role in the stability of mini-screws (Miyawaki et al. 2003).

Single mini- and osteosynthesis screws commonly used nowadays in orthodontics will not withstand the pullback effect of the masticatory muscles (Melsen & Lang 2001; Büchter et al. 2005; Hsieh et al. 2008). The voluntary muscle retrusion force could be as high as 280 N of tangential force (A.S. Al-Kalaly, J.E. Dyson, R.W.K. Wong, M. Schätzle & A.B. Rabie, unpublished data). Therefore, one would expect that multiple mini-screws connected by some sort of a plate could deliver a system that might withstand such high forces. The recent work by our group (Leung et al. 2008) reported that mini-implants connected with mini-plates provided higher pullout force, stiffness, and yield force to resist pulling force and deformation compared to mini-implants connected with wire connection system. Furthermore, even though the length of mini-screws was not identified as a risk factor for early failure (Schätzle et al. 2009; R. Männchen, K. Schätzle-Mayor, T. Peltomäki, R. Suuronen, & M. Schätzle, unpublished data), bicortical mini-screws would provide the orthodontist superior anchorage resistance, reduced cortical bone stress, and superior stability compared with monocortical screws (Brettin et al. 2008).

It is crucial therefore to adequately evaluate the area of preference for insertion of the mini-screws. Based on the available thickness at each position, the information gained in this study would help identify the location of insertion in areas with the best resistance to forces of the masticatory musculature.

In the mandibular canine fossa area, in 20 white subjects, the bicortical distance was assessed to be 9.97 mm (Costa et al. 2005), which is below the bicortical averages found in this study (10.2–12.1 mm). This difference may be attributed to different factors such as evaluating a region (Costa et al. 2005) rather than a determined point, a difference in the population ethnic origin (Ong & Stevenson 1999), and angulations of the measurements (perpendicular vs. oblique). It is known that by angulating the mini-screw, the thickness of cortical bone contact with the mini-screw might increases (Deguchi et al. 2006), which implies that the measurements would vary if taken at 90° to the bone surface as in the current study. As a consequence, the thickness of perpendicular measurements would therefore represent the least thickness available scenario in cases wherein anatomy or other factors may not allow angulations of the mini-screw during insertion.

In another CT scan study, lingual cortical bone thickness yielded slightly thicker values at the second premolar area (2.4 mm), but these measurements were performed horizontally and not perpendicular to the bone surface. They did not measure the cancellous bone thickness and therefore no bicortical width could be compared (Tsunori et al. 1998).

A wide array of lengths and configurations of mini-screws are being used nowadays with a length that varies from 4 to 15 mm (Schätzle et al. 2009). Some studies found an association between the success rate of mini-screws and diameter but not length (Schätzle et al. 2009; R. Männchen, K. Schätzle-Mayor, T. Peltomäki, R. Suuronen, & M. Schätzle, unpublished data).

The bone at the studied positions in the basal bone could support mini- or osteosynthesis screws of larger diameters that could withstand the high forces required for inter-arch correction. However, the unusually high forces that could be produced during skeletal correction (A.S. Al-Kalaly, J.E. Dyson, R.W.K. Wong, M. Schätzle & A.B. Rabie, unpublished data), the length in addition to diameter might be of importance for the stability of mini- and osteosnthesis screws, which should be evaluated in future studies.

Although the total thickness at the P5 vs. P10 mm was not statistically significant, there still may be a clinical relevance when deciding the length of the mini-screw to be used in this area as the inferior alveolar canal runs superiorly as it moves posteriorly and would therefore, for example, dictate the use of an 11 mm screw at the P5 mm due to inability to use a 12 mm screw at the P10 mm due to canal location. The statistically significant difference in the buccal thickness of A5 vs. A10 mm may not be of clinical significance either, but the location of the anterior canal loop should be considered in relation to the choice of the mini-screw. The bone thickness at the stated locations of this sample of adult Chinese individuals would generally allow the insertion of slightly different lengths of mini-screws and preference would be given to the appropriate mini-plate design and the required direction of force application. Nevertheless, due to individual variation, a thorough evaluation on a case-by-case basis should be carried out with particular attention to the length of teeth roots from the mental foramen and the path of the inferior alveolar canal. This study highlights the possible areas around the mental foramen that could be potential sites for insertion of mini- and/or osteosynthesis screw-supported mini-plates to withstand high forces for skeletal correction; however, further research is required to reach the best specification and configuration of the screws to be used for this purpose.

Conclusion

The results at the studied locations around the mental foramen in this adult Chinese sample showed a mean bicortical bone thickness of 10–12 mm. No large variation in thickness was found between bicortical bone thicknesses in the measured locations around the mental foramen.

In general, there is adequate bone to support mini-screws around 10 mm in length to be placed 5 and 10 mm anterior and 5 mm inferior to the mental foramen and mini-screws around 11 mm in length to be placed 5 mm posterior to the mental foramen and mini-screws around 12 mm in length to be placed 10 mm posterior to the mental foramen.

Caution should be exercised before applying these values in clinical settings due to individual variations, and the need for a thorough case-by-case evaluation is emphasized.

Acknowledgement: The present study was supported by RGC CERG grant number: 10206968.22311.08003.324.01 (HKU 7623/06M). This article was based on work submitted to The University of Hong Kong for the award of a PhD degree.

References

Bavitz, J.B., Harn, S.D., Hansen, C.A. & Lang, M. (1993) An anatomical study of mental neurovascular bundle-implant relationships. *The International Journal of Oral & Maxillofacial Implants* **8**: 563–567.

Bou Serhal, C., Jacobs, R., Flygare, L., Quirynen, M. & van Steenberghe, D. (2002) Perioperative validation of localisation of the mental foramen. *Dentomaxillofacial Radiology* **31**: 39–43.

Büchter, A., Wiechmann, D., Koerdt, S., Wiesmann, H.P., Piffko, J. & Meyer, U. (2005) Load-related implant reaction of mini-implants used for orthodontic anchorage. *Clinical Oral Implants Research* **16**: 473–479.

Brettin, B.T., Grosland, N.M., Qian, F., Southard, K.A., Stuntz, T.D., Morgan, T.A., Marshall, S.D. & Southard, T.E. (2008) Bicortical vs monocortical orthodontic skeletal anchorage. *American Journal of Orthodontics and Dentofacial Orthopedics* **134**: 625–635.

Cheung, L.K., Zhang, Q., Wong, M.C. & Wong, L.L. (2003) Stability consideration for internal maxillary distractors. *Journal of Craniomaxillofacial Surgery* **31**: 142–148.

Chu, C.H., Choy, B.H. & Lo, E.C. (2009) Occlusion and orthodontic treatment demand among Chinese young adults in Hong Kong. *Oral Health Preventive Dentistry* **7**: 83–91.

Costa, A., Pasta, G. & Bergamaschi, G. (2005) Intraoral hard and soft tissue depths for temporary anchorage devices. *Seminars in Orthodontics* **11**: 10–15.

Dahlberg, G. (1940) *Statistical Methods for Medical and Biological Students*. New York: Interscience.

Deguchi, T., Nasu, M., Murakami, K., Yabuuchi, T., Kamioka, H. & Takano-Yamamoto, T. (2006) Quantitative evaluation of cortical bone thickness with computed tomographic scanning for orthodontic implants. *American Journal of Orthodontics and Dentofacial Orthopedics* **129**: 721.e7–721.e12.

Greenstein, G. & Tarnow, D. (2006) The mental foramen and nerve: clinical and anatomical factors related to dental implant placement: a literature review. *Journal of Periodontology* **77**: 1933–1943.

Hsieh, Y.D., Su, C.M., Yang, Y.H., Fu, E., Chen, H.L. & Kung, S. (2008) Evaluation on the movement of endosseous titanium implants under continuous orthodontic forces: an experimental study in the dog. *Clinical Oral Implants Research* **19**: 618–623.

Kang, S., Lee, S.J., Ahn, S.J., Heo, M.S. & Kim, T.W. (2007) Bone thickness of the palate for orthodontic mini-implant anchorage in adults. *American Journal of Orthodontics and Dentofacial Orthopedics* **131**: 74–81.

Kieser, J., Kuzmanovic, D., Payne, A., Dennison, J. & Herbison, P. (2002) Patterns of emergence of the human mental nerve. *Archives of Oral Biology* **47**: 743–747.

Kuzmanovic, D.V., Payne, A.G., Kieser, J.A. & Dias, G.J. (2003) Anterior loop of the mental nerve: a morphological and radiographic study. *Clinical Oral Implants Research* **14**: 464–471.

Leung, M.T., Rabie, A.B. & Wong, R.W. (2008) Stability of connected mini-implants and miniplates for skeletal anchorage in orthodontics. *European Journal of Orthodonitcs* **30**: 483–489.

Mardinger, O., Chaushu, G., Arensburg, B., Taicher, S. & Kaffe, I. (2000) Anterior loop of the mental canal: an anatomical–radiologic study. *Implant Dentistry* **9**: 120–125.

McNamara, J. Jr, Peterson, J. Jr & Pancherz, H. (2003) Histologic changes associated with the Herbst appliance in adult rhesus monkeys (*Macaca mulatta*). *Seminars in Orthodontics* **9**: 26–40.

Melsen, B. & Lang, N.P. (2001) Biological reactions of alveolar bone to orthodontic loading of oral implants. *Clinical Oral Implants Research* **12**: 144–152.

Misch, C.E. & Crawford, E.A. (1990) Predictable mandibular nerve location – a clinical zone of safety. *International Journal of Oral Implantology* **7**: 37–40.

Miyawaki, S., Koyama, I., Inoue, M., Mishima, K., Sugahara, T. & Takano-Yamamoto, T. (2003) Factors associated with the stability of titanium screws placed in the posterior region for orthodontic anchorage. *American Journal of Orthodontics and Dentofacial Orthopedics* **124**: 373–378.

Monnerat, C., Restle, L. & Mucha, J.N. (2009) Tomographic mapping of mandibular interradicular spaces for placement of orthodontic mini-implants. *American Journal of Orthodontics and Dentofacial Orthopedics* **135**: e421–e429; discussion 428–429.

O'Connor, B.M. (1993) Contemporary trends in orthodontic practice: a national survey. *American Journal of Orthodontics and Dentofacial Orthopedics* **103**: 163–170.

Ong, R.G. & Stevenson, M.R. (1999) Evaluation of bone density in the mandibles of young Australian adults of mongoloid and Caucasoid descent. *Dentomaxillofacial Radiology* **28**: 20–25.

Pancherz, H. (1997) The effects, limitations, and long-term dentofacial adaptations to treatment with the Herbst appliance. *Seminars in Orthodontics* **3**: 232–243.

Pancherz, H. (2003) History, background, and development of the Herbst appliance. *Seminars in Orthodontics* **9**: 3–11.

Pancherz, H. & Ruf, S. (eds.) (2008) Anchorage problems. In: *The Herbst Appliance: Research-Based Clinical Management*. pp. 161–170. Quintessence Publishing.

Park, H.S., Lee, Y.J., Jeong, S.H. & Kwon, T.G. (2008) Density of the alveolar and basal bones of the maxilla and the mandible. *American Journal of Orthodontics and Dentofacial Orthopedics* **133**: 30–37.

Proffit, W.R, Fields, H.W. & Moray, L.J. (1998) Prevalence of malocclusion and orthodontic treatment need in the United States: estimates from the NHANES-III survey. *International Journal of Adult Orthodontics and Orthognathic Surgery* **13**: 97–106.

Poggio, P.M., Incorvati, C., Velo, S. & Carano, A. (2006) ''Safe zones'': a guide for miniscrew positioning in the maxillary and mandibular arch. *Angle Orthodontist* **76**: 191–197.

Purkayastha, S.K., Rabie, A.B. & Wong, R. (2008) Treatment of skeletal class II malocclusion in adults: stepwise vs single-step advancement with the Herbst appliance. *World Journal of Orthodontics* **9**: 233–243.

Rabie, A.B. & Al-Kalaly, A. (2008) Does the degree of advancement during functional appliance therapy matter? *European Journal of Orthodontics* **30**: 274–282.

Ruf, S. & Pancherz, H. (1999a) Dentoskeletal effects and facial profile changes in young adults treated with the Herbst appliance. *Angle Orthodontist* **69**: 239–246.

Ruf, S. & Pancherz, H. (1999b) Temporomandibular joint remodeling in adolescents and young adults during Herbst treatment: a prospective longitudinal magnetic resonance imaging and cephalometric radiographic investigation. *American Journal of Orthodontics and Dentofacial Orthopedics* **115**: 607–618.

Ruf, S. & Pancherz, H. (2003) When is the ideal period for Herbst therapy – early or late? *Seminars in Orthodontics* **9**: 47–56.

Ruf, S. & Pancherz, H. (2006) Herbst/multibracket appliance treatment of Class II division 1 malocclusions in early and late adulthood. a prospective cephalometric study of consecutively treated subjects. *European Journal of Orthodontics* **28**: 352–360.

Schätzle, M., Männchen, R., Zwahlen, M. & Lang, N.P. (2009) Survival and failure rates of orthodontic temporary anchorage devices. A systematic review. *Clinical Oral Implants Research* **20**: 1351–1359.

Schnelle, M.A., Beck, F.M., Jaynes, R.M. & Huja, S.S. (2004) A radiographic evaluation of the availability of bone for placement of miniscrews. *Angle Orthodontist* **74**: 832–837.

Sharawy, M. & Misch, C.E. (1999) Anatomy for dental implants. In: Misch, C.E., ed. *Contemporary Implant Dentistry*. 2nd edition pp. 217–224. St Louis: CV Mosby Company.

Sonick, M., Abrahams, J. & Faiella, R.A. (1994) A comparison of the accuracy of periapical, panoramic, and computerized tomographic radiographs in locating the mandibular canal. *The International Journal of Oral & Maxillofacial Implants* **9**: 455–460.

Suomalainen, A., Vehmas, T., Kortesniemi, M., Robinson, S. & Peltola, J. (2008) Accuracy of linear measurements using dental cone beam and conventional multislice computed tomography. *Dentomaxillofacial Radiology* **37**: 10–17.

Tang, G.H., Rabie, A.B. & Hägg, U. (2004) Indian hedgehog: a mechanotransduction mediator in condylar cartilage. *Journal of Dental Research* **83**: 434–438.

Tsunori, M., Mashita, M. & Kasai, K. (1998) Relationship between facial types and tooth and bone characteristics of the mandible obtained by CT scanning. *Angle Orthodontist* **68**: 557–562.

Weschler, D. & Pancherz, H. (2005) Efficiency of three mandibular anchorage forms in Herbst treatment: a cephalometric investigation. *Angle Orthodontist* **75**: 23–27.

Wismeijer, D., van Waas, M.A., Vermeeren, J.I. & Kalk, W. (1997) Patients' perception of sensory disturbances of the mental nerve before and after implant surgery: a prospective study of 110 patients. *British Journal of Oral and Maxillofacial Surgery* **35**: 254–259.

Xiong, H., Rabie, A.B. & Hägg, U. (2005) Mechanical strain leads to condylar growth in adult rats. *Frontiers in Bioscience* **10**: 67–73.