CLINICAL ORAL IMPLANTS RESEARCH

Amilcar C. Freitas Júnior
Estevam A. Bonfante
Nelson R. F. A. Silva
Leonard Marotta
Paulo G. Coelho

Effect of implant–abutment connection design on reliability of crowns: regular vs. horizontal mismatched platform

Authors' affiliations:
Amilcar C. Freitas Júnior, Leonard Marotta, Paulo G. Coelho, Department of Biomaterials and Biomimetics, New York University College of Dentistry, New York, NY, USA
Estevam A. Bonfante, Postgraduate Program in Dentistry, School of Health Sciences, UNIGRANRIO University, Duque de Caxias, RJ, Brazil
Nelson R. F. A. Silva, Department of Prosthodontics, New York University College of Dentistry, New York, NY, USA

Corresponding author:
Estevam A. Bonfante
Rua Prof. José de Souza Herdy
1.160 - 25 de Agosto
Duque de Caxias, RJ 25071-202
Brazil
Tel.: +55 14 8153 0860
Fax: +55 14 3234 2566
e-mail: estevamab@gmail.com

Date:
Accepted 23 May 2011

To cite this article:
Freitas Júnior AC , Bonfante EA, Silva Nelson RFA, Marotta L, Coelho PG. Effect of implant–abutment connection design on reliability of crowns: regular vs. horizontal mismatched platform.
Clin. Oral Impl. Res. **00,** 2011, 1–4
doi: 10.1111/j.1600-0501.2011.02257.x

Key words: diameter shifting, fractography, implant–abutment connection, reliability

Abstract

Objectives: To evaluate the reliability and failure modes of regular and horizontal mismatched platforms for implant–abutment connection varying the implant diameter.

Material and methods: Regular (REG, n = 21, 4.0-mm-diameter implant) and horizontal mismatched (HM, n = 21, 4.6-mm-diameter implant) platform Ti-6Al-4V implants were restored with proprietary identical Ti-6Al-4V abutments and metal crowns (cobalt-chrome, Wirobond® 280, BEGO, Bremen, Germany) cemented. Mechanical testing comprised step-stress accelerated-life testing, where crowns were distributed in three loading profiles for fatigue in water, producing timely and clinically relevant fractures. The probability of failure vs. cycles (95% two-sided confidence intervals) was calculated and plotted using a powerlaw relationship for damage accumulation, Weibull modulus (95% two-sided confidence intervals) and then the reliability for a mission of 50,000 cycles at 125 N load (95% two-sided confidence interval) were calculated. Fractography was performed in the scanning electron microscope.

Results: The β-value for group REG (β = 1.37) indicated that fatigue was a factor accelerating the failure, whereas load alone dictated the failure for group HM (β = 0.71). The Weibull parameter contour plot showed no significantly different Weibull modulus for REG (10.24) compared to HM (10.20) and characteristic strength of 162.6 and 166.8 N, respectively ($P > 0.91$). The calculated reliability for a mission of 50,000 cycles at 125 N load was not significantly different (0.71 for REG and 0.73 for HM). Abutment screw failure was the chief failure mode.

Conclusions: Reliability was not significantly different between groups and failure modes were similar.

Following implant placement, bone remodeling in the first year commonly leads to a reduction in bone height, shown to vary as a function of arch region, bone type, surface treatment, implant design, and other factors (Manz 2000). An attempt to hinder this process has resulted in the originally called platform-switching which is consisted in the horizontal positioning of the outer edge of the implant–abutment interface toward the center of the implant (Lazzara & Porter 2006). It has been suggested that the inward shift of the implant–abutment interface, which may act as a bacterial reservoir and trigger peri-implant tissue inflammation, may account for the reduced bone loss (Luongo et al. 2008). From a mechanical perspective, finite element analysis have shown reduced stress distribution on peri-implant bone in horizontal mismatched platform implants relative to matched implant–abutment diameters (Maeda et al. 2007). In addition, promising results from a randomized controlled trial have pointed a direct correlation between increased implant/abutment mismatch and reduced marginal bone loss (Canullo et al. 2010). However, the mechanical reliability of these implant–abutment configurations tested under step-stress accelerated life-testing (SSALT) has not been addressed to date. As complications with implant–abutment connections is a common clinical problem, especially in single-tooth replacements (Jung et al. 2008b), this study tested central incisor crowns fitting abutments on implants with diameter matching or horizontally mismatched, subjected to SSALT in water (Coelho et al. 2009). The postulated null hypothesis was that there is no difference in reliability and failure modes of a regular matching implant diameter (REG) compared to a horizontal mismatched platform (HM) implant–abutment external hexagon connection.

Material and Methods

Forty-two external hexagon Ti-6Al-4V implants (Duo & Inttegra system, Signo Vinces Ltda, Campo Largo, PR, Brazil) were divided into two groups according to their width relative to the abutment (RP, code 07.105, Signo Vinces Ltda): group REG (regular platform, 4.0-mm-diameter implant) and group HM (4.6-mm-diameter implant). Implants were embedded in orthodontic acrylic resin poured in a 25-mm-diameter plastic tube. Both groups were restored with standardized central incisor metallic crowns cemented (3M ESPE; Rely-X Unicem, Saint Paul, MN, USA) on the abutments, which presented identical dimensions (4.0-mm-diameter abutments) in all specimens.

First, single load-to-failure (SLF) ($n = 3$) was performed in a universal testing machine (INSTRON 5666, Canton, MA, USA). Load was applied by a flat tungsten carbide indenter in the incisal edge at 1 mm/min rate, in a 30° off-axis loading orientation (Fig. 1). Based upon the mean SLF values, three different profiles (mild [$n = 9$], moderate [$n = 6$], and aggressive [$n = 3$]) were designed for the SSALT ($n = 18$) (Coelho et al. 2009). These profiles are named based on the step-wise load increase that the specimen will be fatigued throughout the cycles until a certain level of load, meaning that specimens assigned to a mild profile will be cycled longer to reach the same load level of a specimen assigned to the aggressive profile. Details of this method can be found elsewhere (Nelson 2004; Abernethy 2006; Coelho et al. 2009; Bonfante et al. 2010; Silva et al. 2010). A servo-all-electric system (TestResources 800L, Shakopee, MN, USA) was used for fatigue testing (contact, load, lift-off) under water (load orientation and indenter as in SLF test) at 2 Hz. Based upon the step-stress distribution of the failures, Use Level Probability Weibull (probability of failure vs. cycles) with use stress of 200 N and 95% two-sided confidence intervals were calculated and plotted (Alta Pro 7; Reliasoft, Tucson, AZ, USA) using a powerlaw relationship for damage accumulation. If the Use Level Probability Weibull calculated β were <1 for any group, then a Probability Weibull Contour plot (Weibull modulus [m] vs. Characteristic strength [η]) was calculated using final load magnitude to failure or survival of groups. The calculated Weibull modulus (m) and characteristic strength (η) (63.2% of the specimens would fail up to the calculated "η") values were utilized to determine the confidence bounds through the maximum likelihood ratio method utilizing a chi-squared value at 95% level of significance and 1 degree of freedom (Nelson 2004; Abernethy 2006). Thus, each contoured region represent possible values given both parameters combination, and significant difference at 95% level is detected if contour overlap between groups does not exist (in such case, samples will be considered to be from different populations) (Nelson 2004; Abernethy 2006).

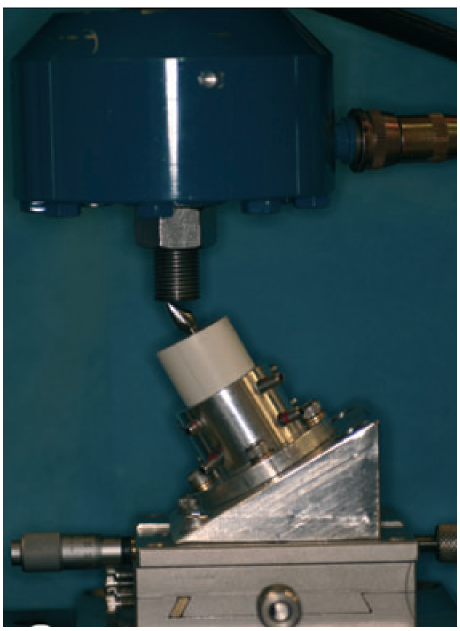

Fig. 1. Setup for mechanical tests with crowns positioned in a 30° off-axis orientation.

The reliability (the probability of an item functioning for a given amount of time without failure) for a mission of 50,000 cycles at 125 N load (two-sided 95% confidence intervals) was calculated for comparison between HM and REG. For the mission reliability and β parameters calculated in the present study, the 95% confidence interval range was calculated as follows: $CB = E(G) \pm z_{\alpha}$ sqrt(Var(G)), where CB is the confidence bound, $E(G)$ is the mean estimated reliability for the mission calculated from Weibull statistics, z_{α} is the z value concerning the given CI level of significance, and Var (G) is the value calculated by the Fisher Information matrix (Nelson 2004; Abernethy 2006). Representative failed specimens were inspected under scanning electron microscope (Model S-3500N; Hitachi, Osaka, Japan).

Results

Mean SLF values for group REG was 364.34 ± 46.48 N and 361.66 ± 51.76 N for HM. The β-values derived from Use-Level probability Weibull calculation, described as mean (95% CI range), were 1.37 (0.88–2.14) and 0.71 (0.44–1.12) for REG and HM, respectively, indicating that load alone or fatigue could have been the failure modes for both groups (β-confidence intervals go below 1 for both groups) (Fig. 2a), rationalizing the construction of a Weibull parameter contour plot (Weibull modulus [m] vs. Characteristic strength [η]) (Fig. 2b). The calculated reliability expressed as mean (95% CI range) for a mission of 50,000 cycles at 125 N load was 0.71 (0.43–0.87) for group REG and 0.73 (0.51–0.86) for group HM, meaning that cumulative damage from loads reaching 125 N would lead to implant-supported crown survival in 71% of REG compared to 73% of HM crowns. These results were not significant ($P = 0.65$).

The Weibull statistical evaluation showed $m = 10.24$ for REG and $m = 10.20$ for HM (Fig. 2b). The characteristic strength was η = 162.6 N for REG and η = 166.8 N for HM. The confidence bounds calculated through the likelihood ratio method at 95% level of significance represented by the contours in Fig. 2b showed that the groups were statistically homogenous ($P > 0.91$). All specimens failed after SSALT and fracture of the abutment screw was the chief failure mode (Fig. 3).

Discussion

Our results indicated that implants with different diameters restored with the same abutment-screw-crown system showed homogenous reliability. Fatigue possibly played little or no role for both groups and hence data were replotted according to fatigue load at failure (Reliasoft 2011), where the likelihood of the two groups' failures being from different populations, was not significant. The "m" is an indicator of strength reliability and/or the asymmetrical strength distribution as a result of materials flaws (Ritter 1995). The similar m indicated that the failure mechanism and fatigue damage accumulation over time was similar between groups (similar structural reliability), evidencing no variability of the strength (Ritter 1995). Similar results were observed in a comprehensive FEA (finite element analysis) study which showed no biomechanical compromise when horizontally mismatched were compared to matching diameter implant abutment configurations in varied clinical scenarios (Pessoa et al. 2010b).

The screw and abutment's design was the determining factor for restoration failure rather than the relationship between implant

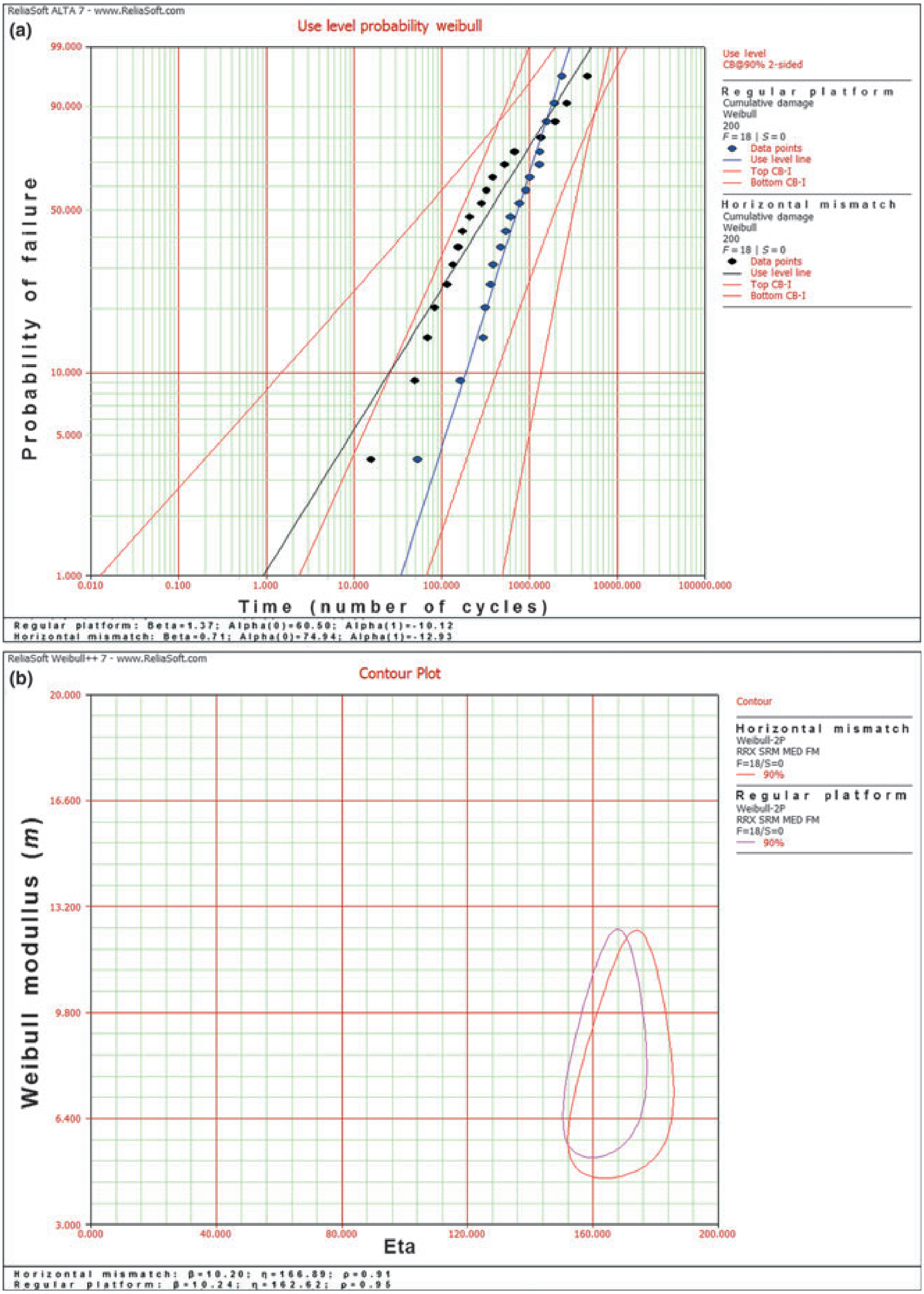

Fig. 2. (a) Use Level Probability Weibull for groups REG and HM showing the probability of failure as a function of cycles. (b) Contour plot (Weibull modulus vs. characteristic strength) for group comparisons. Note the overlap between groups showing the absence of statistical difference.

and abutment diameter. Screw fracture was observed in all fatigued specimens and the neck area represented the critical point for screw's endurance due to the shift in geometry along its length, regardless of the implant diameter. Such prevailing failure scenario may be explained by the fact that in an external hexagon connection type, oblique loading is resisted mainly by the abutment screw, whereas small amount of stress is dissipated by the connection (Pessoa et al. 2010a).

As the implant–abutment interface misfit observed in external connections may allow bacterial colonization (Duarte et al. 2006) and peri-implant soft tissue inflammation, concerns regarding the long-term maintenance of bone height around implants have been raised. Because the horizontal mismatch concept has shown its potential to preserve bone levels in *in vivo* animal (Jung et al. 2008a; Cochran et al. 2009), and clinical studies (Canullo et al. 2010), this investigation aimed to provide insight into the systems mechanical behavior and failure modes.

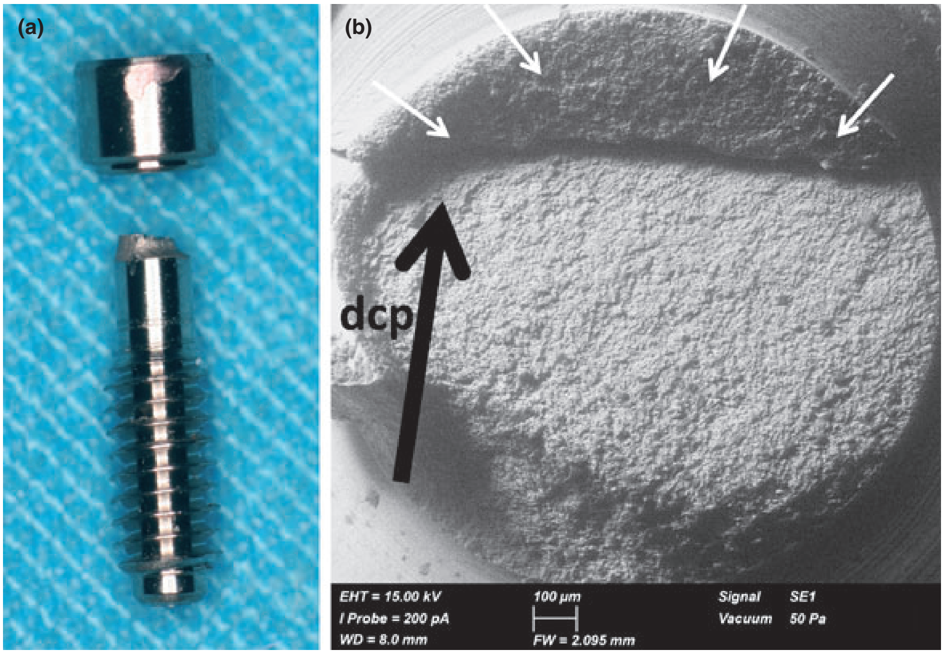

Fig. 3. (a) Chief failure mode in both groups: screw fracture at neck area. (b) Representative SEM micrograph of a screw fracture showing typical marks indicating the direction of crack propagation (dcp – black arrow) from lingual to buccal. The white arrows show a compression curl which evidences fracture origin at the opposing tensile side.

While not adhering to the ISO 14801 (dynamic fatigue test for endosseous dental implants) the present testing methodology was aimed at increasing the database for future assessment and improvement of methods used in different laboratories in the quest to reproduce clinically relevant failures.

From a clinical perspective it must be acknowledged that the horizontal mismatch configuration alone and the consequent placement of the unsealed implant–abutment gap away from peri-implant tissues is only one factor playing a role in crestal bone remodeling. Several other factors must be considered, such as the implant–abutment connection type, the implant macrogeometry at the cervical area (presence of threads), surface treatment, implantation time, loading schedules, and others (Shin et al. 2006; Hermann et al. 2007; Coelho et al. 2010).

Conclusions

No difference in reliability or failure modes of a REG compared to a HM implant–abutment external hexagon connection was observed. Thus, our postulated null hypothesis was confirmed.

References

Abernethy, R. (2006) The New Weibull Handbook, 5th edition. North Palm Beach: Dr. Robert B. Abernethy.

Bonfante, E.A., Coelho, P.G., Navarro, J.M. Jr, Pegoraro, L.F., Bonfante, G., Thompson, V.P. & Silva, N.R. (2010) Reliability and failure modes of implant-supported y-tzp and mcr three-unit bridges. *Clinical Implant Dentistry and Related Research* **12**: 235–243.

Canullo, L., Fedele, G.R., Iannello, G. & Jepsen, S. (2010) Platform switching and marginal bone-level alterations: the results of a randomized-controlled trial. *Clinical Oral Implants Research* **21**: 115–121.

Cochran, D.L., Bosshardt, D.D., Grize, L., Higginbottom, F.L., Jones, A.A., Jung, R.E., Wieland, M. & Dard, M. (2009) Bone response to loaded implants with non-matching implant–abutment diameters in the canine mandible. *Journal of Periodontology* **80**: 609–617.

Coelho, P.G., Bonfante, E.A., Silva, N.R., Rekow, E. D. & Thompson, V.P. (2009) Laboratory simulation of y-tzp all-ceramic crown clinical failures. *Journal of Dental Research* **88**: 382–386.

Coelho, P.G., Marin, C., Granato, R., Bonfante, E. A., Lima, C.P. & Suzuki, M. (2010) Surface treatment at the cervical region and its effect on bone maintenance after immediate implantation: an experimental study in dogs. *Oral Surgery Oral Medicine Oral Pathology Oral Radiology and Endodontology* **110**: 182–187.

Duarte, A.R., Rossetti, P.H., Rossetti, L.M., Torres, S.A. & Bonachela, W.C. (2006) *In vitro* sealing ability of two materials at five different implant–abutment surfaces. *Journal of Periodontology* **77**: 1828–1832.

Hermann, F., Lerner, H. & Palti, A. (2007) Factors influencing the preservation of the periimplant marginal bone. *Implant Dentistry* **16**: 165–175.

Jung, R.E., Jones, A.A., Higginbottom, F.L., Wilson, T.G., Schoolfield, J., Buser, D., Hammerle, C.H. & Cochran, D.L. (2008a) The influence of non-matching implant and abutment diameters on radiographic crestal bone levels in dogs. *Journal of Periodontology* **79**: 260–270.

Jung, R.E., Pjetursson, B.E., Glauser, R., Zembic, A., Zwahlen, M. & Lang, N.P. (2008b) A systematic review of the 5-year survival and complication rates of implant-supported single crowns. *Clinical Oral Implants Research* **19**: 119–130.

Lazzara, R.J. & Porter, S.S. (2006) Platform switching: a new concept in implant dentistry for controlling postrestorative crestal bone levels. *International Journal of Periodontics and Restorative Dentistry* **26**: 9–17.

Luongo, R., Traini, T., Guidone, P.C., Bianco, G., Cocchetto, R. & Celletti, R. (2008) Hard and soft tissue responses to the platform-switching technique. *International Journal of Periodontics and Restorative Dentistry* **28**: 551–557.

Maeda, Y., Miura, J., Taki, I. & Sogo, M. (2007) Biomechanical analysis on platform switching: Is there any biomechanical rationale? *Clinical Oral Implants Research* **18**: 581–584.

Manz, M.C. (2000) Factors associated with radiographic vertical bone loss around implants placed in a clinical study. *Annals of Periodontology* **5**: 137–151.

Nelson, W. (2004) Accelerated Testing: Statistical Models, Test Plans and Data Analysis: 493-520. New York: John Wiley & Sons.

Pessoa, R.S., Muraru, L., Junior, E.M., Vaz, L.G., Sloten, J.V., Duyck, J. & Jaecques, S.V. (2010a) Influence of implant connection type on the biomechanical environment of immediately placed implants – ct-based nonlinear, three-dimensional finite element analysis. *Clinical Implant Dentistry and Related Research* **12**: 219–234.

Pessoa, R.S., Vaz, L.G., Marcantonio, E. Jr, Vander Sloten, J., Duyck, J. & Jaecques, S.V. (2010b) Biomechanical evaluation of platform switching in different implant protocols: computed tomography-based three-dimensional finite element analysis. *International Journal of Oral and Maxillofacial Implants* **25**: 911–919.

Reliasoft (2011) The weibull distribution and beta, Available at: http://www.reliasoft.com/newsletter/1q2001/beta.htm.

Ritter, J.E. (1995) Predicting lifetimes of materials and material structures. *Dental Materials* **11**: 142–146.

Shin, Y.K., Han, C.H., Heo, S.J., Kim, S. & Chun, H.J. (2006) Radiographic evaluation of marginal bone level around implants with different neck designs after 1 year. *International Journal of Oral and Maxillofacial Implants* **21**: 789–794.

Silva, N.R., Bonfante, E.A., Zavanelli, R.A., Thompson, V.P., Ferencz, J.L. & Coelho, P.G. (2010) Reliability of metalloceramic and zirconia-based ceramic crowns. *Journal of Dental Research* **89**: 1051–1056.