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Research Article

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Influence of Bone Implant Contact on Biomechanical Performance of Short Implant Placed in Atrophic Posterior Mandible

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Abstract

In excessive reduced alveolar bone height patients, thickness of cortical bone is less and available bone height for placing implant is limited. Placing conventional long implant may invasive additional bone. To minimize unnecessary bone invasion, short implants is considered to be a good option. However, Crown-to-Implant (CI) ratio remains questionable in success of dental implant at different Bone-to-Implant Contact (BIC) levels. Therefore, biomechanical performance of short implants with suprastructure on the posterior atrophic mandible was then studied for difference of BIC contact and CI ratio. Six three-dimensional (3D) finite element models of a 6 mm short implant with 6 mm and 12 mm crown height represented a CI ratio of 1:1 and 2:1, respectively, with 30%, 60%, and 90% BIC were modeled. Uniform thickness of the cortical bone model was 1 mm covering the trabecular layer. Axial force of 200 N was applied to the occlusal surface. Results revealed that the maximum von Mises stress of bone is relatively low, indicating that low chance of bone resorption occurred. Elastic strain of cortex and trabecular at BIC level 30%, 60% and 90% were almost similar for CI ratios of both 1:1 and 2:1. Magnitude of elastic strain at a 30% BIC level was also in range for physiologic bone remodelling. These findings may help patients who have risk of low osseointegration.

Keywords: Dental implants, Finite element analysis, Short implant, Biomechanical evaluation

1 Introduction

After tooth extraction, surrounding bone begins remodelling process. Without functional tooth, so no occlusal load stimulates the bone remodelling, then bone around extraction site gradually loss and become atrophic (Figure 1). In order to prevent bone loss and atrophic, dentists usually place dental implants and its superstructure to restore the occlusal function.

Dental implants are considered predictable, safe, and effective solutions for edentulous patients. Placing of dental implants requires exposing cortical and tubercular bone layers to make the proper cavity diameter, locating the implant position. Exposure changes bone structure as well as occlusal force pattern. Bone structure then adapts to such new environments.

Dental implant may be categorized as short or long. The length of short dental implant is generally

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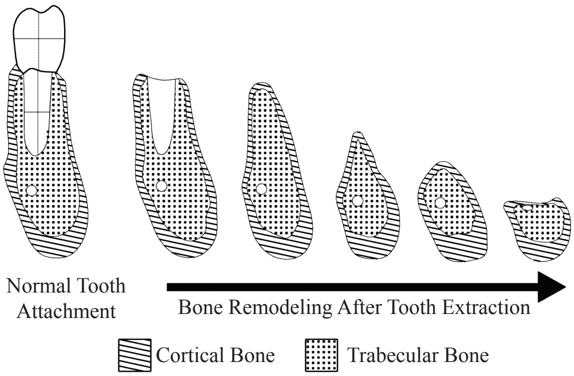

Figure 1: Bone remodelling after tooth extraction.

less than or equal to 8 mm [1]. In excessive reduced alveolar bone height patients, typically thickness of cortical bone is less. Available bone height for placing implant is less than normal patient. Thus, placing long dental implant may invasive additional bone. To minimize the unnecessary bone invasion, short dental implants is considered to be an option for prosthetic restoration in the limited mandible anatomy.

A key factor in the success of teeth replacements with dental implants is the load transfer from implant to the surrounding bone [2]. The level of load transfer depends on Bone to Implant Contact (BIC), which inducing the strain on the surrounding bone. Different strain magnitude responds to bone remodelling differently. Only the proper range of strain induces effective bone regeneration. Table 1 indicates bone response as described in Harold Frost's mechanostat hypothesis [3].

Table 1: Strain and bone response according to Frost's mechanostat hypothesis [3]

Bone's Threshold	Microstrain	Function
Critical Load	< 200	Bone Resorption
Physiologic Load	1000–1500	Bone modeling with secondary lamellar bone deposition
Overload	1500–3000	Bone modeling with primary lamellar bone deposition
Pathologic Load	> 4000	Bone modeling with primary woven bone deposition
Bone Fracture	25000	Fracture

A hundred percent BIC has been assumed for evaluating the performance of dental implant [4]. Yet that rate is never achieved 100% [5]. Only around 50%–80% BIC is seen in case of clinical success [5]. Patients with osteoporosis, osteomalacia, diabetes or tobacco addiction may have low BIC levels. This can affect dental implant stability, especially for short dental implants. Mandible atrophy has been encountered, with different procedures to solve this condition by prosthetic reconstruction. Aggressive procedures are used for bone blocking, bone grafting, and implanting. In cases of reduced alveolar bone height, short dental implants have recently become available, offering the dentists a ready option for prosthetic restoration. The risk of dental implant failure at a sample of low BIC level was examined here.

In addition, Crown-to-Implant (CI) ratio remains questionable in success or failure of dental implant at different BIC levels. Dental implants at differing BIC contact levels were also biomechanically analyzed.

BIC level analysis by mechanical testing would mean controlling exact BIC levels [6]. Instead, biological performance related to BIC may be studied by Finite Element (FE) method, a useful approach for diverse biomedical problems [2], [7]. Three-dimensional (3D) FE models were then constructed and analyzed in this study.

2 Materials and Methods

Using Computer-Aided Design (CAD) software, a 3D model of a crown, posterior mandibular segment in the molar region with 4.8 mm diameter dental implant with 6 mm length and abutment complex was modeled. The FE analysis was performed using FE software (Patran/Marc Mentat 2005 R2, MSC Software Inc., USA).

FE analysis included six cases with two different CI ratios of 2:1, and 1:1, with BIC levels of 30%, 60%, and 90%

2.1 *3D CAD model geometry*

3D representation of bone layers and short dental implant-abutment complex (abutment, screw, and implant) was created using CAD software (VISI 20, Vero software, UK), first molar crown geometries were derived by direct model scanning using a Chairside Economical Restoration of Esthetis Ceramics (CEREC) digital scanner (Sirona Dental Systems, Inc, USA).

Bone studied was type-3, as described by Lekholm and Zarb [8]. A thin layer of cortical bone surrounded a core of trabecular bone. Thickness of cortical bone was uniformly 1 mm, covering outer surface of the trabecular layer. 3D primitive models of bone were created instead of freeform models derived from bone anatomy to ease of geometric control for definition of Lekholm and Zarb type 3. Many previous publications were also used the primitive models in the FE analysis relating to Lekholm and Zarb bone classification, for example, Winter *et al* [9], Okumura *et al.* [10], Lofaj *et al.* [11], and Li *et al.* [12]. Short dental implants with 4.8 mm diameter and 6 mm length were placed at the bone center to virtually simulate restoration conditions. Two crown models with 6 mm and 12 mm heights were created from scanning data placed over the dental implant abutment complex to simulate analysis conditions for CI ratios 2:1, and 1:1, respectively. The bone-implant models are presented in Figure 2.

2.2 *FE model generation*

Bone and short dental implant CAD models were then divided into elements and nodes for FE analysis. Automatic mesh generation was used to generate 4-node tetrahedron elements. Number of node and element used in analyses was determined by FE convergence test. Models used in FE convergence test included CI ratios of 1:1 and 2:1, with BIC 90%. Implant and bone stresses were monitored as representative parameters in the FE convergence test.

2.3 *Materials properties*

All material properties assigned to FE models were assumed to be linearly elastic, homogenous, and isotropic. Corresponding material properties such as elastic modulus and Poisson’s ratio were determined by literature survey. (Table 2)

Table 2: Mechanical properties of different materials used in the model

Materials	Elastic Modulus (MPa)	Poisson’s Ratio
Crown (Zirconia) [13]	205,000	0.30
Dental Implant-abutment Complex (Ti-6Al-4V) [14]	110,000	0.35
Cortical Bone [14]	14,000	0.30
Trabecular Bone [14]	1,400	0.30
Mucosa [15]	3.45	0.45

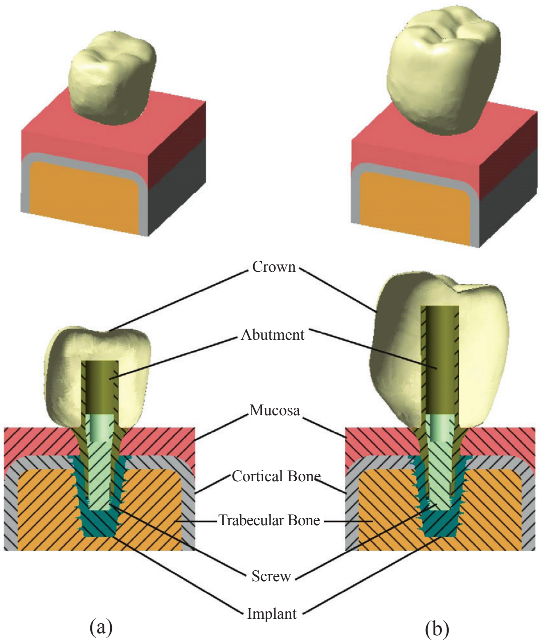

Figure 2: Model of bone-implant model, (a) CI ratio 1:1, and (b) CI ratio 2:1.

2.4 *Contact conditions*

All models of dental implant abutment complex were assigned relative displacement conditions. Crown contact to abutment and mucosa were set at no relative displacement and relative displacement conditions, respectively. Cortical bone and trabecular bone layers were also set at no relative displacement. Bone-implant interface was assumed to be perfect, simulating complete osseointegration [16]. BIC levels depended on assumption of elemental quantity of implant contact to bone. Higher contact element numbers presents higher BICs. As shown in Figure 3, pink color indicates elemental region presenting bone osseointegration to implant, whereas black color indicates elemental regions presenting non-bone osseointegration. Larger area of the pink corresponds to higher BICs.

2.4 *Boundary conditions*

A 200 N of axial force was applied vertically to the occlusal surface [16]. Since, the model presents distal half of mandible. Generally, fix-displacement constrains are applied on the distal end surface of cortical

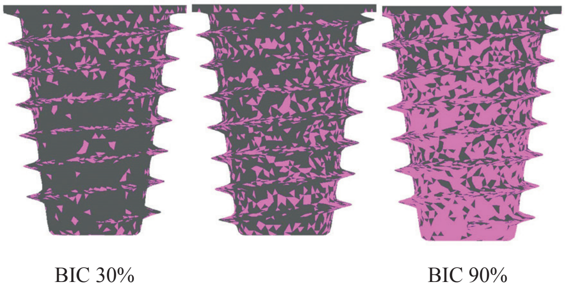

Figure 3: BIC levels corresponding to numbers of contact element.

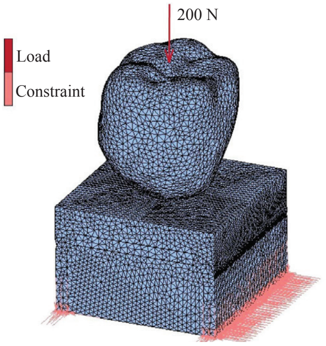

Figure 4: FE model with boundary conditions.

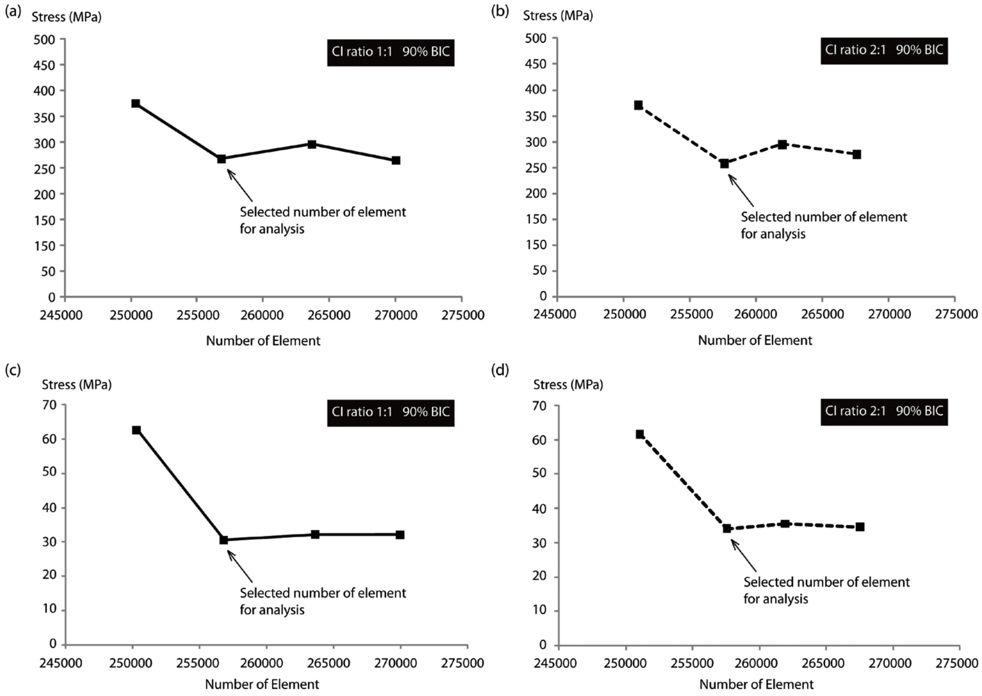

Figure 5: FE Convergence Analysis: (a), (b) stress exhibited on implant and (c), (d) stress exhibited on cortical bone.

and trabecular bones of the FE model for the case of healthy bone [17]. In the bone atrophy, thickness of cortical bone is thin. The trabecular bone has a chance to be moved distalward when a load is applied. Thus, constrain was only applied on distal end surface of cortical layer. An example FE model with boundary conditions is shown in Figure 4.

3 Results

As shown in Figure 5, the FE convergence test shows the selected number of element for analysis for CI ratio 1:1 and 2:1. Greater number of element beyond the selected number affected the FE result slightly. This can be considered that number of element beyond the selected number is independent to the FE result. Therefore, second points shown in Figure 5 were selected as optimal number of element for analysis which was 256,802 elements with corresponding number of node of 62,628 nodes for CI ratio 1:1 and 259,641 elements with corresponding number of node of 63,156 nodes for CI ratio 2:1.

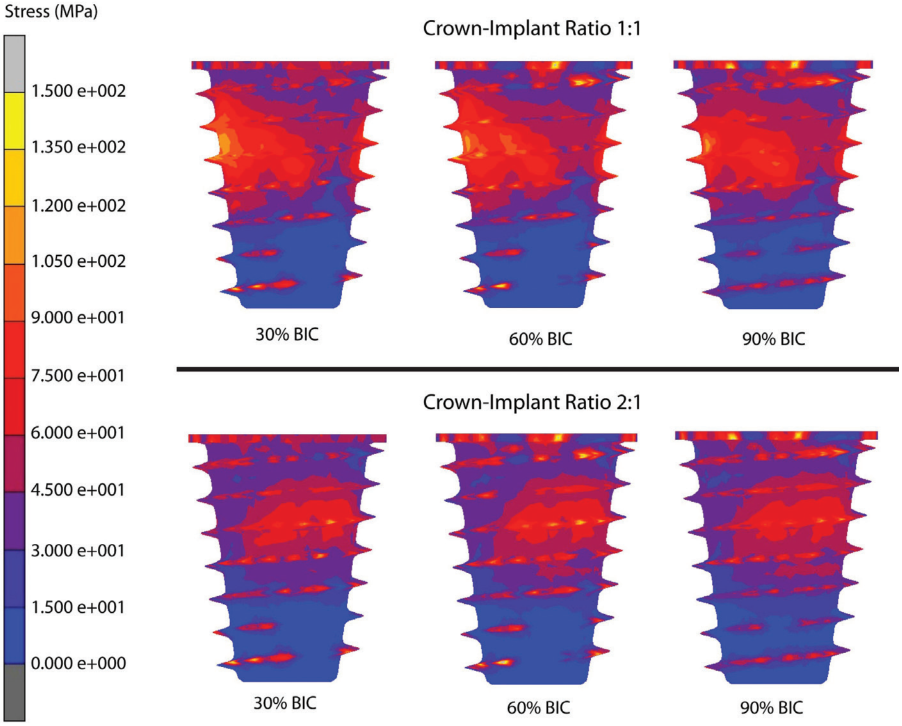

Figure 6: Stress distribution on implant.

Stress level indicated risk of material failure. Figure 6 shows stress distribution on implants. Table 3 shows maximum von Mises stresses exhibited on cortical bone, trabecular bone, and implant. It can be seen that maximum stresses on cortical bone with a 2:1 exceeded for a 1:1 CI ratio by 1% to 12%. Similar trends were observed in stresses found on trabecular bone, with greater differences between 1:1 and 2:1 CI ratios.

Table 3: Von Mises stress

CI Ratio	BIC	Cortical Bone (MPa)	Trabecular Bone (MPa)	Implant (MPa)
1:1	30	33.4	7.8	297.4
	60	35.8	9.1	280.3
	90	30.6	6.3	268.4
2:1	30	37.4	8.5	328.3
	60	38.3	11.1	295.4
	90	30.9	7.8	258.5

Elastic strain was used to evaluate bone response to occlusal load. Some range of elastic strain may lead to bone remodelling and bone resorption, as presented in Table 1.

According to Table 4, elastic strain on surrounding bone differed slightly for a 1:1 and 2:1 CI ratio. 90% BIC presented the lowest magnitude among all BIC levels under consideration for both 1:1 and 2:1 CI ratios. BIC level was considered as a key factor influencing elastic strain on cortical bone. Elastic strain on trabecular bones was higher than on cortical bone, as noted in Figure 7 and 8.

Table 4: Elastic stain in bone

CI Ratio	BIC (%)	Surrounding Bone Strain ($\mu\varepsilon$)
1:1	30	1,341.1
	60	1,367.8
	90	1,297.1
2:1	30	1,306.4
	60	1,350.3
	90	1,271.2

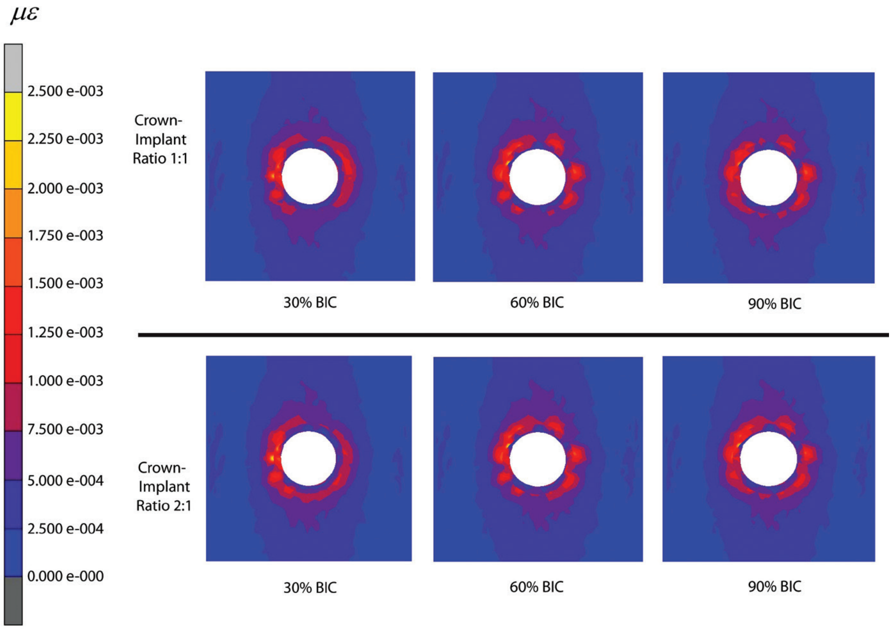

Figure 7: Elastic strain around magical cortical bone.

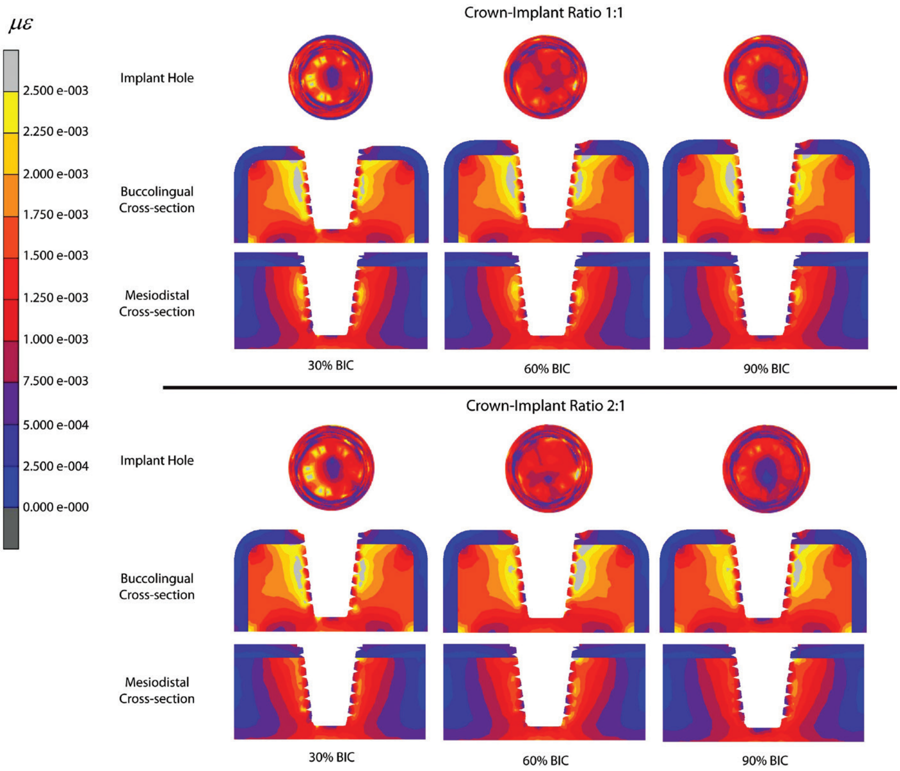

Figure 8: Elastic strain in bone cavity, buccolingual plane and mesiodistal plane.

4 Discussions

Findings indicate that Von Mises stress found on implants was lower than yield stress of Ti-6Al-4V titanium alloy, which is 800–900 MPa [18]. This shows a low risk of implant breakage under a 200 N occlusal load. For all cases, Von Mises stress on cortical bone was below tensile strength of cortical bone, which is 100–150 MPa [19]. As a result, bone stress was not in critical level, thereby reducing marginal bone resorption.

Loading mechanism of dental implant is an axial load. Implant surface slides besides the bone cavity surface, generating the strain on cortical bone along the implant. Axial load applied at the occlusal surface transfers directly from crown to implant. The implant then distributes the load to surrounding bone. Since, the occlusal surface is located at crush of tooth; its position is not co-centric to center of implant (Position is more in buccul direction), the stress distribution of implant is then more crowed in one side. In addition, strain distribution pattern is higher in buccul-lingual direction which is also affected from the vertical loading applied position on occlusal surface of the tooth.

Elastic strain exhibited in the trabecular bone is greater than in the cortical bone, as noted in Figure 8. Lower elastic strain on the cortical bone is useful for stimulating bone remodelling. FE results affirm the finding of various reports [5], [20]–[24] that wide range of BIC (50%–80%) offers good clinical success.

Patients with metabolic dysfunctions, osteoporosis, osteomalacia, diabetes or tobacco addiction, and similar complaints usually present decreasing of osteoblast function leading to suppress bone formation. Suppressing bone formation decreases BIC level. Suitability of short dental implant restoration for such patients may be judged by elastic strain. Bone elastic strain at 30% BIC is sufficient to stimulate bone remodelling.

1:1 and 2:1 CI ratios had similar biomechanical performance for bone remodelling, since elastic strains do not significantly differ. Therefore, 1:1 or 2:1 CI ratio can be both applied. In addition, short implant should be one of alternatives treatment for atrophic mandible tooth replacement.

5 Conclusions

FE analysis shows that stress distribution on surrounding bone was in low magnitude, indicating low risk of bone resorption. Low BIC presents physiologic elastic strain around bone for remodelling. Elastic strain, biomechanical performance at 30% and 60% BIC did not differ nor was CI ratio affected. In addition, 30% BIC optimally maintained elastic strain range for physiologic bone remodelling. At 90% BIC, elastic strain level reduced to lower magnitude for both 1:1 and 2:1 CI ratios. Short implant with 1:1 or 2:1 CI ratio can be one of alternatives for atrophic mandible tooth replacement.

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References

[1] C. A. Lemos, M. L. Alves, R. Okamoto, M. R. Mendonça, and E. P. Pellizzer, “Short dental implants versus standard dental implants placed in the posterior jaws: A systematic review and meta-analysis,” *Journal of Dentistry*, vol. 47, pp. 8–17, Apr. 2016.

[2] J. P. Geng, K. B. Tan, and G. R. Lui, “Application of finite element analysis in implant dentistry: A review of literature,” *The Journal of Prosthetic Dentistry*, vol. 85, no.6, pp. 585–598, Dec. 2003.

[3] H. M. Forst, “Perspective: bone’s mechanical usage windows,” *Bone and Mineral*, vol. 19, no. 3, pp. 257–271, Dec. 1992.

[4] V. Giuseppe and S. Gianpaolo, “Comparative evaluation of osseointegrated dental implants based on platform-switching concept: Influence of diameter, length, thread shape, and in-bone positioning depth on stress-based performance,” *Computational and Mathematical Methods in*

Medicine, vol. 2013, pp. 1–14, May 2013.

[5] Z. Lian, H. Guan, S. Ivanovski, Y. C. Loo, N. W. Johnson, and H. Zhang, "Effect of bone to implant contact percentage on bone remodelling surrounding a dental implant," *International Journal of Oral and Maxillofacial Surgery*, vol. 39, no. 7, pp. 690–698, Jul. 2010.

[6] R. Bernhardt, E. Kuhlisch, M. C. Schulz, U. Eckelt, and B. Stadlinger, "Comparison of bone-implant contact and bone-implant volume between 2D-histological sections and 3D-SRμCT slices," *European Cells and Materials*, vol. 10, no. 23, pp. 237247, Apr. 2012.

[7] F. Ramos Verri, J. F. Santiago Junior, D. A. de Faria Almeida, G. B. de Oliveira, V. E. de Souza Batista, H. Marques Honório, P. Y. Noritomi, and E. P. Pellizzer, "Biomechanical influence of crown-to-implant ratio on stress distribution over internal hexagon short implant: 3-D finite element analysis with statistical test," *Journal of Biomechanics*, vol. 48, no.1, pp. 138–145, Jan. 2015.

[8] U. Lekholm and G. A. Zarb, "Patient selection and preparation," in *Tissue-integrated Prostheses: Osseointegration in Clinical Dentistry*, ed. Chicago: Quintessence, 1985, pp. 199–209.

[9] W. Winter, T. Krafft, P. Steinmann, and M. Karl, "Quality of alveolar bone—Structure-dependent material properties and design of a novel measurement technique," *Journal of the Mechanical Behavior of Biomedical Materials*, vol. 4, no. 4, pp. 541–548, May 2011.

[10] N. Okumura, R. Stegaroiu, E. Kitamura, K. Kurokawa, and S. Nomura, "Influence of maxillary cortical bone thickness, implant design and implant diameter on stress around implants: A three-dimensional finite element analysis," *Journal of Prosthodontic Research*, vol. 54, no. 3, pp.133–142, Jul. 2010.

[11] F. Lofaj, J. Kučera, D. Németh, and L. Kvetková , "Finite element analysis of stress distributions in mono- and bi-cortical dental implants," *Materials Science & Engineering. C, Materials for Biological Applications*, vol. 50, pp. 85–96, May 2015.

[12] T. Li, X. Yang, D. Zhang, H. Zhou, J. Shao, Y. Ding, and L. Kong, "Analysis of the biomechanical feasibility of a wide implant in moderately atrophic maxillary sinus region with finite element method," *Oral Surgery, Oral Medicine, Oral Pathology and Oral Radiology*, vol. 114, no. 2, pp. e1–e8, Aug. 2012.

[13] C. B. Tanaka, H. Harisha, M. Baldassarri, M. S. Wolff, H. Tong, J. B. C. Meira, and Y. Zhang, "Experimental and finite element study of residual thermal stresses in veneered Y-TZP structures," *Ceramics International*, vol. 42, no.7, pp. 9214–9221, May 2016.

[14] S. Inglam, S. Suebnukarn, W. Tharanon, T. Apatananon, and K. Sitthiseripratip, "Influence of graft quality and marginal bone loss on implants placed in maxillary grafted sinus: A finite element study," *Medical and Biological Engineering & Computing*, vol. 48, no.7, pp. 681–689, Jul. 2010.

[15] M. Z. Bendjaballah, "The effect of non-contact conditions in a splinted fixed partial denture on the load sharing mechanism: A finite element study," *Journal of Bionic Engineering*, vol. 9, no. 3, pp. 336–342, Sep. 2012.

[16] P. Rungsiyakull, "*Effects of cusp inclination and occlusal table dimensions on the loading on implant systems and simulated bone*," M.S. thesis, Faculty of Dentistry, The University of Sydney, New South Wales, AU, 2008.

[17] A. Dorogoy, D. Rittel, K. Shemtov-Yona, and R. Korabi, "Modeling dental implant insertion," *Journal of the Mechanical Behavior of Biomedical Materials*, vol. 68, pp. 42-50, Jan. 2017.

[18] N. Chantarapanich, K. Sitthiseripratip, B. Mahaisavariya, and P. Siribodhi, "Biomechanical performance of retrograde nail for supracondylar fractures stabilization," *Medical and Biological Engineering & Computing*, vol. 54, no.6, pp. 939–952, Jan. 2016.

[19] J. B. Brunski, D. A. Puleo, and A. Nanci, "Biomaterials and biomechanics of oral and maxillofacial implants: Current status and future developments," *The International Journal of Oral and Maxillofacial Implants*, vol. 15, no. 1, pp. 15–46, 2000.

[20] M. S. Block, I. M. Finger, M. G. Fontenot, and J. N. Kent, "Loaded hydroxylapatite-coated and grit-blasted titanium implants in dogs," *The International Journal of Oral and Maxillofacial Implants*, vol. 4, no. 3, pp. 219–225, 1989.

[21] G. Papavasiliou, P. Kamposiora, S. C. Bayne, and D. A. Felton, "3D-FEA of osseointegration

percentages and patterns on implant-bone interfacial stresses," *Journal of Dentistry*, vol. 25, no. 6, pp. 485–491, Nov. 1997.

[22] W. E. Roberts, "Bone tissue interface," *Journal of Dental Education*, vol. 52, no.12, pp. 804–809, Dec. 1988.

[23] P. D. Ledermann, R. K. Schenk, and D. Buser, "Long-lasting osseointegration of immediately loaded, bar-connected TPS screws after 12 years of function: a histologic case report of a 95-year-old patient," *The International Journal of Periodontics and Restorative Dentistry*, vol. 18, no.6, pp. 552–563, Dec. 1998.

[24] S. J. Froum, H. Simon, S. C. Cho, N. Elian, M. D. Rohrer, and D. P. Tarnow, "Histologic evaluation of bone-implant contact of immediately loaded transitional implants after 6 to 27 months," *The International Journal of Oral and Maxillofacial Implants*, vol. 20, no. 1, pp. 54–60, 2005.