Correlation of Bone Vascularity in the Posterior Mandible and Subsequent Implant Stability: A Preliminary Study

Vladimir Kokovic, DDS, PhD,* Elena Krsljak, DDS, PhD,† Miroslav Andric, DDS, PhD,‡ Bozidar Brkovic, DDS, PhD,‡ Biljana Milicic, DM, PhD,§ Milan Jurisic, DDS, PhD,|| Muhammed Mustahsen Rahman, DDS, PhD,¶ and Christoph H. F. Hämmerle, DMD, PhD#

Objectives: *Bone vascularity is an important factor in process of osseointegration. The aim of this study was to find whether or not blood perfusion of the bone around the prepared implant sites influences subsequent implant stability.*

Methods: *Patients with bilaterally edentulous mandible were treated with dental implants. Bone vascularity in implant sites was previously noted using Laser Doppler Flowmetry (LDF). Implant stability quotient (ISQ) was measured during follow-up period of 26th week. Statistical distribution and correlation between LDF and ISQ values were presented. Other variables (type of implant loading; sex and distance from the apical part of implant sites to the roof of the mandibular canal) were collected and correlated with LDF values.*

Results: *The mean recorded LDF value was 53.05 perfusion unit. Eighteen implants were immediately loaded, and the other 18 were early loaded. In the group of early loaded implants, a statistically significant correlation between mean value of LDF and changing value of resonance frequency analysis ($P < 0.05$) was noted at 5th, 6th, 12th, and 26th weeks. Using Pearson coefficient of correlation, there was no statistically significant relationship between other variables and LDF values.*

Conclusion: *LDF values of implant sites might determine future implant stability. (Implant Dent 2014;23:200–205)*

Key Words: bone vascularity, Laser Doppler Flowmetry, mandible, posterior, implant stability

Some of the crucial factors influencing the process of osseointegration are: material biocompatibility, precision of implant site preparation, traumatic extent of surgical technique, and type of loading protocol. When the prerequisites for successful osseointegration were originally described, implant loading protocols were already considered a crucial factor.[1,2] At the third ITI Consensus Conference in 2003, the original definitions of loading protocol were adapted and modified.[3] In various studies, sufficient bone density has been identified as an important factor for implant survival.[4,5] In accordance with those defined protocols, the posterior mandible presents favorable bone density. Hence, immediate and early loading (EL) of dental implants in the partially edentulous posterior mandible are both viable treatment options.[6]

*Associate Professor, College of Dental Science, Medical Health and Science University, Ras Al Khaimah, United Arab Emirates.
†Professor, Department of Oral Physiology, Faculty of Dentistry, University of Belgrade, Belgrade, Serbia.
‡Associate Professor, Clinic of Oral Surgery, Faculty of Dentistry, University of Belgrade, Belgrade, Serbia.
§Associate Professor, Department of Medical Statistics and Informatics, Faculty of Dentistry, University of Belgrade, Belgrade, Serbia.
||Professor, Clinic of Oral Surgery, Faculty of Dentistry, University of Belgrade, Belgrade, Serbia.
¶Professor, College of Dental Science, Medical Health and Science University, Ras Al Khaimah, United Arab Emirates.
#Professor, Department for Fixed and Removable Prosthodontics, University Zurich, Zurich, Switzerland.

Reprint requests and correspondence to: Vladimir Kokovic, DDS, PhD, College of Dental Science, Medical Health and Science University, PO Box 12973, Ras Al Khaimah, United Arab Emirates, Phone: +971551536346, E-mail: kokovicv@gmail.com

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In the early stages of osseointegration, the degree of bone vascularity and formation of new vascular tissues seem to be important for the formation of contact between bone and implant.[7,8] It has been shown that there is a functional and proportional link between bone remodeling rate and vessel area.[9] After the implant insertion, tissue repair requires the development of a vascular system for the delivery of oxygen and nutrients and to take away cell debris for complete healing process. After the healing, the bone tissue remodeling needs to induce neoangiogenesis.[10] Decrease of blood supply to the bone and soft tissue can compromise bone growth and may increase failures of implant integration.[11] The quality of blood flow in the alveolar bone depends on different factors: the presence of teeth, the age of the patient, degree of resorption, and the presence of systemic disorders.[11–13] In this context, development and maintenance of a good level of osseointegration for dental implants

are certainly related to a well-developed bone vascular network of periimplant bone.[10] The major arterial blood supply to the mandible comes from inferior alveolar artery. Other source of blood supply comes from anastomoses of lingual and facial artery as well as from musculoperiosteal sources.[11] In the elderly and edentulous patients, the central blood supply is compromised, and posterior mandible depends mostly on musculoperiosteal small arteries. Under these circumstances, we might have relative ischemia,[4,5,11,14] and the process of osseointegration in posterior mandible can be seriously affected.

The Laser Doppler Flowmetry (LDF) represents a noninvasive technique for monitoring tissue blood perfusion expressed in perfusion units (PU). The technique is based on measuring the Doppler shift induced by moving red blood cells to the illuminating coherent light.[15,16] This method has been widely used in the field of dentistry for the assessment of blood flow in mucosal tissues underneath dentures and for the blood perfusion in the pulp.[17,18] In addition, LDF has been used to register gingival blood flow changes during periodontal surgical procedures and to assess the recovery of the gingival blood flow during the subsequent healing period.[19–21] Furthermore, experimental findings suggest that the LDF can successfully be used for studying blood perfusion of mucoperiosteal flaps in guided tissue regeneration procedures[22] and for detecting blood flow in sinus bone grafts.[23] LDF has been shown to be a reliable method for measuring intraosseous blood flow.[24,25] Recently, it has also been shown that LDF can successfully be used to assess bone vascularity during implant insertion in humans.[26]

The purpose of this study was to measure the association of bone vascularity at the time of implant site preparation as assessed using LDF and implant stability measured using implant stability quotient (ISQ) score. The investigators hypothesize that higher bone vascularity assessed by LDF during implant insertion is associated with increased implant stability. The specific aims of the study were: (a) to measure bone vascularity at the time of implant placement using LDF scores; (b) to measure implant stability (after implant insertion, 1st, 2nd, 3rd, 4th, 5th, 6th, 12th, and 26th week of study) using ISQ scores; (c) to estimate the association between LDF score and ISQ score adjusted for clinically relevant variable such as loading status, local anatomical structures (mandibular canal), and sex.

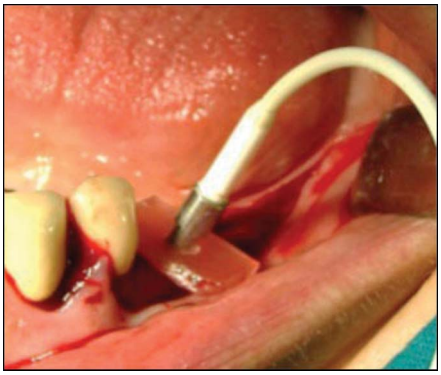

Fig. 1. Measurement of blood perfusion in implants' sites. A measuring device for laser Doppler flowmetry has been inserted into the implant site bed 35.

MATERIALS AND METHODS

Study Design and Sample

To address the research purpose, the investigators designed and implemented prospective cohort study. This clinical study included patients requiring implant treatment in the partially edentulous mandible bilaterally. The study was performed at the Clinic of Oral Surgery, Faculty of Dentistry, University of Belgrade, Belgrade, Serbia in the period between June 2010 and January 2011. Ethical approval was obtained from the local Ethics Committee at the Faculty of Dentistry (Nr. 165/2, 2004), and participants gave informed consent. Patients included in this study represent a part of a comparative clinical trial of immediate and early loaded short tapered effect implants. To be included in the study sample, patients had to:

a. Belong to the ASA I group (American Society of Anesthesiology patient classification, ie, normal healthy patients)
b. Have bilateral terminal edentulous spaces distal to the 1st premolar in the lower jaw (Kennedy class I)
c. Have natural teeth or prosthetic rehabilitation in the posterior maxilla to provide occlusal contact with prosthetic appliances on the implants in the mandible
d. Have the same type of antagonists on both sides in the maxilla
e. Have surgical sites with bone density type 1, 2, and 3 according to the classification by Lekholm and Zarb[27]
f. Have adequate buccal-lingual bone dimensions (≥6 mm) to have at least 1 mm of bone around our implants
g. Have inserted dental implants with primary stability value ≥60 ISQ.[28]

Patients were excluded as study subjects if they:

a. Had systemic disease likely to compromise implant surgery
b. Had oral parafunctions (bruxism)
c. Were smokers
d. Had inadequate oral hygiene
e. Had implants with value of primary stability <60 ISQ.

Table 1. Vascularity of Implant Sites in the Posterior Mandible Expressed in PU for the Immediate Loaded and Early Loaded Groups

		Site/PU					
Patient No.	Gender	35	36	37	45	46	47
1	M	97.37	50.64	33.21	17.52	25.33	70.81
2	M	35.6	41.32	47.48	52.06	130.66	43.76
3	F	30.68	26.79	58.44	40.76	51.88	72.01
4	F	32.11	48.5	95.29	58.41	40.88	44.26
5	M	39.2	82.57	82.53	58.41	57.84	41.58
6	F	51.5	39.34	60.04	51.56	47.53	27.45
Mean		47.74	48.19	58.89	46.45	59.02	54.63
SD		25.43	18.82	23.01	15.57	36.82	20.32

Table 2. Mean, Ranges, and SDs LDF Values (Expressed in PU) for Immediate and Early Loaded Implants

Parameters		IL	EL	*P*
LDF	PU, mean ± SD	54.84 ± 28.73	49.72 ± 15.81	0.513
	95% confidence interval for mean	40.55–69.13	41.86–57.59	
	≤60 PU	12 (66.7%)	16 (88.9%)	0.228
	≤50 PU	9 (50%)	10 (55.6%)	0.999
	≤40 PU	7 (38.9%)	3 (16.7%)	0.264

Assessment of Blood Pressure Values During Procedure

Blood pressure measurements have been performed before applying of local anesthesia and before measurement of blood perfusion by noninvasive measurement technique.

Clinical Procedures and Assessment of Bone Vascularity

To be able to measure the vascularity of the implanted area, operations were done using a local anesthetic without a vasoconstrictor (0.75% ropivacaine, Naropine; AstraZeneca, Sodertalje, Sweden). Mid-crestal incisions and buccal extensions were performed in both edentulous sides of the mandible. Implant sites were prepared using the surgical guide according to the manufacturer's recommendations. After bilateral preparation of implant beds with a pilot drill Ø 2.2 mm at the position of the 2nd premolar, first, and second molar, measurement of blood perfusion in the mandible was performed with LDF (Periflux System; Perimed, Jarfalla, Sweden).

Measurements of Blood Perfusion

The LDF module was calibrated according to the manufacturer's instructions and emitted laser light of 780 nm. This light was transduced to the implant site by a special optical fiber probe (PF 407) with a diameter of 2.0 mm (Fig. 1). The fiber probe was inserted into the implant sites at a standard depth of 8 mm. The probe was fixed with a sterile wax plate, and the cable was set so that it did not touch the surrounding soft tissue. The LDF module was connected to a personal computer for capturing the recordings. The magnitude of signal and frequency changes was directly related to the relative number.

It has previously been shown that light penetrates into bone tissue to approximately 3 mm from the bone surface.[26,29] In this way, blood perfusion has been measured in the whole horizontal dimension of alveolar bone. The gap between the probe and bone at the implants site was 0.2 mm. To avoid contamination, implant sites were rinsed with saline before the probe was placed and to avoid patient movements during blood flow recordings, the patients sat in a relaxed manner in a semi-reclined position in a dental chair. The LDF probe was placed directed perpendicular to the mesial, distal, buccal, and lingual aspects of the walls of the implant bed. Within a few seconds after insertion of the probe, the recorded value of PU stabilized and remained stable during the recording period. A noise-free period of 20 seconds was chosen for a stable and reliable recording session. Four recordings were carried out at every implant site.

According to previously published recommendations, recordings were taken in different directions to determine the average alveolar bone vascularity around one site.[30,31] The blood

Table 3. Distance From the Bottom of the Implant Site to the Roof the Mandibular Canal

Groups	No. of Implant Sites	Mean ± SD (mm)	Range
IL	18	3.97 ± 1.12	2.67–6.00
EL	18	3.75 ± 1.33	2.00–6.15
Total	36	3.86 ± 1.27	2.00–6.15

Table 4. Implant Stability Over Time Expressed in ISQ Values in the Immediately and Early Loaded Groups

		RFA (ISQ) X ± SD								
Groups	Number	Primary Stability	1st Wk	2nd Wk	3rd Wk	4th Wk	5th Wk	6th Wk	12th Wk	26th Wk
IL	18	80.06 ± 4.505	80.56 ± 4.190	79.56 ± 4.422	78.72 ± 5.737	79.17 ± 5.639	79.83 ± 5.813	80.00 ± 6.010	81.89 ± 4.351	82.50 ± 4.134
EL	18	80.17 ± 6.032	80.61 ± 5.089	80.28 ± 4.812	79.28 ± 5.211	77.89* ± 6.694	78.61 ± 5.952	78.50 ± 6.308	81.17* ± 4.190	82.22 ± 3.282

Table 5. Correlation Between Mean Value of LDF and Changing Values of RFA During the Follow-up Period (Pearson Correlation)

Group			RFA0	RFA1	RFA2	RFA3	RFA4	RFA5	RFA6	RFA12	RFA26
IL	LDF	r	–0.033	–0.050	0.002	0.099	0.064	0.066	0.049	0.140	0.081
		P	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05
EL	LDF	r	0.243	0.400	0.323	0.315	0.416	0.556*	0.520*	0.530*	0.554*
		P	>0.05	>0.05	>0.05	>0.05	>0.05	0.016	0.027	0.024	0.017

*Correlation has been noted in these time points.

perfusion has not been measured after preparation of implant beds with pilot drills Ø2.8 and Ø3.5. Larger gap between the probe and implant sites has been filed with blood during the recording resulting in inadequate value measurements.

Thereafter, the implants (4.8/4.1 mm Straumann dental implant system, SLActive, TE; Basel, Switzerland) used in this investigation were inserted according to standard clinical protocols.

Measurements of Implant Stability

To determine implant stability at the time of insertion and stability changes during the healing period, resonance frequency analysis (RFA) was performed (Osstell Mentor; Integration Diagnostics AB, Gothenburg, Sweden). After implant insertion, the ISQ was measured weekly during the 1st 6 weeks, as well as at the 12th and 26th week of the study. Measurements were performed from 2 different directions using a smart peg (type 4), which was hand screwed into the implant. Recent data indicate that primary implant stability between 60 and 65 ISQ is prerequisite for the load immediately after installation.[28] This was the reason why implants with primary stability value <60 ISQ have not been included in this study.

Loading Protocol

The loading protocol for the implants was randomized using sealed envelopes. The envelopes were opened after the provisional restorations had been fabricated for both groups. One side of the mandible was thus randomly determined to be the immediate loading (IL) group and the other one to be the EL group. In the IL group, the temporary restoration was then inserted and fixed, whereas in the EL group, the temporary restoration was set aside and inserted 3 weeks later.

Measurements of Bone Dimension

Preoperative assessment included the fabrication of a study cast and a cone-beam computed tomographic radiograph (3D Accuitomo; J. Morita Manufacturing Corp., Osaka, Japan) for the evaluation of the available bone volume. Fabrication of surgical and prosthetic guides was also part of the preoperative protocol. Cone-beam computed tomography was used preoperatively to determine the distance from the top of the alveolar crest to the roof of the mandibular canal in the area of the planned implant placement. In addition, another cone-beam computed tomography was taken immediately after implant placement to measure the distance from the apex of the implant to the roof of the mandibular canal.

Statistical Analysis

Descriptive statistical parameters were applied to the data. Correlation coefficients were assessed to determine the degree of association between different variables. The Mann-Whitney and the Kolmogorov-Smirnov tests were applied to detect the differences between different time points of measurements. Pearson coefficient of correlation was used to assess the relationship between vascularity and implant stability. A *P*-value of 0.05 was chosen as the level of significance for all comparisons.

RESULTS

All 6 patients (3 women and 3 men; mean age, 48.87 ± 1.99 years) completed the study. There were no implant failures in either of the investigated groups. It has not been noted statistically significant difference of the blood pressure values between 2 observed time points ($P < 0.05$).

LDF values of all 36 implant sites in all patients are presented in Table 1. Individual LDF values of particular implant sites in the same patient differed greatly in some cases, for example in patients 1 and 2. In addition, a large variability of values was found between patients. The measured PU values ranged from 17.5 to 130.7 with a mean of 53.05. LDF >60 PU was measured at 8 implants sites, LDF <60 and ≥40 PU at 18 sites, and LDF <40 PU at 10 sites (Table 2). There were no statistically significant differences between mean values of the left and right sides of the mandibles as well as between different implants positions. There was no statistically significant difference in vascularity between men (53.3) and women (51.5).

The mean LDF value was greater in the IL group than in the EL group but not to a significant degree (Table 2).

The mean distance from the apex of the implant to the roof of the mandibular canal is presented in Table 3. More than 3 mm between the apex of the implant and the roof of the mandibular canal was noted at 73.68% of sites. The remaining sites showed a distance of <3 mm but >2 mm. Using Pearson coefficient of correlation, there was no statistically significant relationship between LDF values and the distance from the apex of the implant site to the roof of mandibular canal.

The RFA results showed that overall changes in implant stability were nonsignificant during the follow-up period of 26 weeks in the IL group (Table 4). However, in the EL group, statistical analysis indicated a significant decrease of implant stability between the 3rd and 4th week (which corresponds to the 1st week of loading). Furthermore, a significant increase of implant stability was noted between the 6th and 12th week.

Correlating mean values of LDF and RFA values in subsequent weeks of the follow-up period (Table 5),

a statistically significant correlation ($P < 0.05$) was observed in the EL group only. In detail, initially high PU values correlated with a strong increase of RFA values during weeks 5 to 26 (in the 5th, 6th, 12th, and 26th weeks), whereas low initial PU values correlated with a small increase of RFA values during this same time period.

DISCUSSION

This study confirmed previous observations that LDF can be used as a method of assessing alveolar bone vascularity in implant sites before implant insertion. The result of this clinical study indicates a correlation between initial PU values and implant stability changes during healing. Hence, in the EL group, initially high PU values correlated with a higher increase in RFA values than with initially low PU values. A large variability of PU readings was found between individuals and between sites in single individuals.

In our study, the mean LDF value at 36 implant sites located in the posterior part of the mandible was 53.04 PU. This value differs considerably from values previously found[26] in the anterior part of mandible (25.8 PU). This may be explained by variations in bone density and arterial supply of the mandible.[32–34] Also differences in the results obtained can be explained by the different age of the individuals included in the various studies.[13] The average age of patients in this study was 48.9 years, whereas in a previous study reporting lower values, the mean age was 63.6 years.[26]

Since the proximity of the mandibular canal to the implant site could possibly influence blood perfusion around the implant, the distance of the canal to the apical part of the implant site was measured in all patients. Nevertheless, the results obtained indicate that the proximity of the mandibular canal does not directly influence the vascularity of the cancellous bone around implant sites when distance is greater than 2 mm.

No statistically significant difference in the LDF was noted between the patients of different gender. Individual LDF values between patients and of particular implant sites within the same patient differed greatly in the majority cases, which results in the wide standard deviance.

In this study, 2 different loading protocols were clinically analyzed for the same type of implants. The results showed high values of primary implant stability and subsequent secondary implant stability over time regardless of the loading protocol (ISQ >80 in both analyzed groups). This indicates successful transformation from mechanical to biological bone integration. It is also interesting to note that the decrease of implant stability found at the 4th week in the EL group corresponded well with the previously described biological bone remodeling process during this time.[35]

It has previously been stated that bone vascularity at an implant site could influence implant osseointegration.[26] Hence, it was especially interesting to investigate whether perfusion of the implant site could be important for subsequent implant stability. Only in the EL group, a significant correlation between initial PU values and later RFA values was found. One possible explanation for this result may be found in the fact that in most implant sites (88.9%) from the EL group, the recorded value of LDF was ≤ 60 PU. In the IL group, 33.3% of implant sites showed an LDF value of >60 PU, and oscillations of implant stability were not obvious. Therefore, a statistically significant correlation between mean LDF and changing value of RFA was noted at 5, 6, 12, and 26 weeks in the EL. In the literature, different clinical studies have described the changes in implant stability values during the early healing period.[36,37]

The development of new probe designs is recommended to provide more accurate blood perfusion measurements correlating to the different diameters of the 1st osteotomy pilot drills.

From a clinical perspective, it would be interesting to assess if certain magnitudes of PU values can be used as important factors in the decision process regarding loading protocols. Based on the preliminary finding of this study, new clinical trials can be designed to answer some of these pertinent questions.

CONCLUSION

Based on the results of this preliminary study, it can be concluded that a certain relationship exists between PU values and increasing RFA values. This study failed to determine a threshold above which osseointegration of implants predictably occurs and below which implants are not osseointegrated by the surrounding bone. It would, however, be of great clinical benefit if such a threshold could be determined. Further research in this area is necessary taking into account a larger number of investigated implant sites located in different regions of the maxilla and the mandible.

DISCLOSURE

The authors claim to have no financial interest, either directly or indirectly, in the products or information listed in the article.

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REFERENCES

1. Albrektsson T, Brånemark PI, Hansson HA, et al. Osseointegrated titanium implants: Requirements for ensuring a long-lasting, direct bone to implant anchorage in man. *Acta Orthop Scand.* 1981;52:155–170.

2. Ericson RA, Albrektsson T. The effect of heat on bone regeneration: An experimental study in the rabbit using the bone growth chamber. *J Oral Maxillofac Surg.* 1984;42:705–711.

3. Cochran DL, Morton D, Weber HP. Consensus statements and recommended clinical procedures regarding loading protocols for endosseous dental implants. *Int J Oral Maxillofac Implants.* 2004;19 (suppl):109–113.

4. Norton MR, Gamble C. Bone classification: An objective scale of bone density using the computerized tomography scan. *Clin Oral Implants Res.* 2001;12:79–84.

5. Molly L. Bone density and primary stability in implant therapy. *Clin Oral Implants Res.* 2006;17:124–135.

6. Cordaro L, Torsello F, Roccuzzo M. Implant loading protocols for the partially edentulous posterior mandible. *Int J Oral Maxillofac Implants* 2009;24(suppl): 158–168.

7. Cooper LF. Biologic determinates of bone formation for osseointegration: Clues for future clinical improvements. *J Prosthet Dent.* 1998;80:439–449.

8. Berglundh T, Abrahamsson IA, Lang NP, et al. De novo alveolar bone formation adjacent to endosseous implants. A model study in the dog. *Clin Oral Implants Res.* 2003;14:251–262.

9. Barou O, Mekraldi S, Vico L, et al. Relationship between trabecular bone remodeling and bone vascularization: A quantitative study. *Bone.* 2002;30:604–612.

10. Traini T, Assenza B, Roman FS, et al. Bone microvascular pattern around loaded dental implants in a canine model. *Clin Oral Invest.* 2006;10:151–156.

11. Tolstunov L. Implant zones of the jaws: Implant location and related success rate. *J Oral Implantol.* 2007;33:211–220.

12. Chanavaz M. Anatomy and histophysiology of the periosteum: Quantification of the periosteal blood supply to the adjacent bone with 85Sr and gamma spectrometry. *J Oral Implantol.* 1995;21: 214–219.

13. Eiseman B, Johnson LR, Coll JR. Ultrasound measurement of mandibular arterial blood supply: Techniques for defining ischemia in the pathogenesis of alveolar ridges atrophy and tooth loss in the elderly? *J Oral Maxillofac Surg.* 2005;63:28–35.

14. Bradley JC. The clinical significance of age changes in the vascular supply to the mandible. *Int J Oral Surg.* 1981; 10(suppl 1):71–76.

15. Bollinger A, Partsch H. Christian Doppler is 200 years young. *Vasa*. 2003; 32:225–233.

16. Rajan V, Varghese B, van Leeuwen TG, et al. Review of methodological developments in laser Doppler flowmetry. *Lasers Med Sci.* 2009;24:269–283.

17. Kocabalkan E, Turgut M. Variation in blood flow of supporting tissue during use of mandibular complete dentures with hard acrylic resin base and soft relining: A preliminary study. *Int J Prosthodont.* 2005; 18:210–213.

18. Firestone AR, Wheatley AM, Thüer UW. Measurement of blood perfusion in the dental pulp with laser Doppler flowmetry. *Int J Microcirc Clin Exp.* 1997;17:298–304.

19. Baab D, Oberg P, Holloway G. Gingival blood flow measured with a laser Doppler flowmeter. *J Periodontal Res.* 1986;21:73–85.

20. Donos N, D'Aiuto F, Retzepi M, et al. Evaluation of gingival blood flow by the use of laser Doppler flowmetry following periodontal surgery. A pilot study. *J Periodontal Res.* 2005;40:129–137.

21. Retzepi M, Tonetti M, Donos N. Comparison of gingival blood flow during healing of simplified papilla preservation and modified Widman flap surgery: Clinical trial using laser Doppler flowmetry. *J Clin Periodontol.* 2007;34:903–911.

22. Retzepi M, Tonetti M, Donos N. Gingival blood flow changes following periodontal access flap surgery using laser Doppler flowmetry. *J Clin Periodontol.* 2007;34:437–443.

23. Wong K. Laser Doppler flowmetry for clinical detection of blood flow as a measure of vitality in sinus bone grafts. *Implant Dent.* 2000;9:133–142.

24. Hobbs CM, Watkins PE. Evaluation of the viability of bone fragments: An experimental study using laser Doppler flowmetry. *J Bone Joint Surg Br.* 2000;82-B:130–133.

25. Nötzli HP, Siebenrock KA, Hempfing A, et al. Perfusion of the femoral head during surgical dislocation of the hip. Monitoring by laser Doppler flowmetry. *J Bone Joint Surg Br.* 2002;84-B:300–304.

26. Verdonck HWD, Meijer GJ, Kessler P, et al. Assessment of bone vascularity in the anterior mandible using laser Doppler flowmetry. *Clin Oral Implants Res.* 2009; 20:140–144.

27. Misch CE, Judy KW. Classification of partially edentulous arches for implant dentistry. *Int J Oral Implantol.* 1987;4:7–13.

28. Glauser R, Sennerbay L, Meredith N, et al. Resonance frequency analysis of implants subjected to immediate or early functional occlusal loading. Successful vs. failing implants. *Clin Oral Impl Res.* 2004; 15:428–434.

29. Nötzli HP, Swiontkowsi MF, Thaxer ST, et al. Laser Doppler flowmetry for bone blood flow measurements: Helium-neon laser light attenuation and depth of perfusion assessment. *J Orthop Res.* 1989;7: 413–424.

30. Verdonck HWD, Merijer GJ, Thorsten L, et al. Assessment of vascularity in irradiated and non-irradiated maxillary and mandibular minipig alveolar bone using laser Doppler flowmetry. *Int J Oral Maxillofac Implants.* 2007;22:774–778.

31. Ahn H, Johansson K, Lundgren O, et al. In vivo evaluation of signal processors for laser Doppler tissue flowmeters. *Med Biol Eng Comput.* 1987; 25:207–211.

32. Turkyilmaz I, Tözüm TF, Tumer C. Bone density assessments of oral implant sites using computerized tomography. *J Oral Rehabil.* 2007;34:267–272.

33. Loukas M, Kinsella CR, Kapos T, et al. Anatomical variation in arterial supply of the mandible with special regard to implant placement. *Int J Oral Maxillofac Surg.* 2008;37:367–371.

34. Toyoshima T, Wagner W, Klein MO, et al. Primary stability of hybrid self-tapping implant compared to a cylindrical non self-tapping implant with respect to drilling protocols in an ex vivo model. *Clin Implant Dent Relat Res.* 2011;13: 71–78.

35. Brånemark R, Ohrnell LO, Skalak R, et al. Biomechanical characterization of osseointegration: an experimental in vivo investigation in the beagle dog. *J Orthop Res.* 1998;16:61–69.

36. Bischof M, Nedir R, Szmukler-Moncler S, et al. Implant stability measurement of delayed and immediately loaded implants during healing. A clinical resonance-frequency analysis study with sandblasted-and-etched ITI implants. *Clin Oral Implants Res.* 2004;15:529–539.

37. Huwiler MA, Pjetursson BE, Bosshardt DD, et al. Resonance frequency analysis in relation to jawbone characteristics and during early healing of implant installation. *Clin Oral Implants Res.* 2007; 18:275–280.