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Comparison of bioactive glass coated and hydroxyapatite coated titanium dental implants in the human jaw bone

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ABSTRACT

Background: Current trends in clinical dental implant therapy include modification of titanium surfaces for the purpose of improving osseointegration by different additive (bioactive coatings) and subtractive processes (acid etching, grit-blasting). The aim of this study was to evaluate and compare the behaviour of hydroxyapatite and the newly developed bioactive glass coated implants (62 implants) in osseous tissue following implantation in 31 patients.
Methods: Bioactive glass and hydroxyapatite was suitably coated on titanium alloy. Hydroxyapatite coating was applied on the implant surface by air microplasma spray technique and bioactive glass coating was applied by vitreous enamelling technique. The outcome was assessed up to 12 months after prosthetic loading using different clinical and radiological parameters.
Results: Hydroxyapatite and bioactive glass coating materials were non-toxic and biocompatible. Overall results showed that bioactive glass coated implants were as equally successful as hydroxyapatite in achieving osseointegration and supporting final restorations.
Conclusions: The newly developed bioactive glass is a good alternative coating material for dental implants.

Keywords: Bioactive glass, biocompatible, coated implants, hydroxyapatite, osseointegration.

Abbreviations and acronyms: ABL = average marginal bone loss; BG = bioactive glass; GI = gingival index; GR = gingival recession; HA = hydroxyapatite; IFG = interfacial; IOPA = intraoral periapical; MDCT = multi-detector spiral CT scan; PI = plaque index; PPD = probing pocket depth.

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INTRODUCTION

Endosseous dental implants have been used in dentistry for many years to improve the appearance and functional ability of the natural dentition.[1] As bio-inert materials often become encapsulated in fibrous tissue, it is important to develop new biomaterials to ensure the extended lifetime of implants.[2] Bioactive materials such as hydroxyapatite (HA) and bioactive glass (BG) can develop a chemical bond with the bone that is stronger than either the bone or ceramic alone.[3,4] There are some problems with the use of HA as a coating material, such as change in the microstructure of the coating and a very slow osseointegration rate that jeopardizes the long-term stability of implants in bony tissues.[5] It has been established that BG has good mechanical properties and a higher bioactivity in comparison to HA.[5,6] Consequently, the material has become a natural choice for coating on metallic implants. Comparative studies between HA coated and BG coated implants *in vivo* are scant with conflicting results.[6,7] Therefore, the present study was undertaken to evaluate and compare the *in vivo* behaviour of the BG coated and HA coated (control) titanium dental implant in the human jaw bone.

MATERIALS AND METHODS

The study was carried out at the Department of Periodontics, Dr R Ahmed Dental College and Hospital, Kolkata, India in association with the Bioceramic and Coating Division of the Central Glass and Ceramic Research Institute, Kolkata, India. It was approved by the institutional ethical committee of Dr R Ahmed Dental College and Hospital, Kolkata, India. Indigenous bioactive glass [BG: silica (SiO_2) = 43–44 wt.%, decahydrated borax ($Na_2B_4O_7.10H_2O$) = 6–7 wt.%, dry soda ash (Na_2CO_3) = 11–12 wt.%, calcium carbonate ($CaCO_3$) = 29–30 wt.%, di-ammonium hydrogen orthophosphate $(NH_4)_2HPO_4$ = 8–9 wt.%,

titanium oxide (TiO_2)=1–2 wt.%] and hydroxyapatite [HA: derived from calcium hydroxide and phosphoric acid using coprecipitation technique] that was prepared (Central Glass and Ceramic Research Institute, Kolkata, India) and characterized earlier, was also used in the present study.[6,8] Titanium alloy (Ti-6Al-4V) implants (4 mm diameter x 13 mm of length) and coating on titanium (Ti) dental implants (coating thickness 70–90 μm) were fabricated in the laboratory (Central Glass and Ceramic Research Institute, Kolkata, India). HA coating was applied on the implant surface by air microplasma spray technique, using a tabletop microplasma spraying machine (Spraymet, Bangalore, India). BG coating was applied on the implant surface by conventional vitreous enamelling technique at 800–810 °C in an ambient atmosphere. Each component of Ti-6Al-4V dental implants was ultrasonically cleaned and sterilized by gamma radiation after packing.

Thirty-one systemically healthy, partially edentulous patients (19 males and 12 females, age range 18–56 years, mean age 36 years) were selected for this study. Sixty-two implants (31 HA coated Ti-6Al-3V and 31 BG coated Ti-6Al-3V implants) were placed. Twenty-eight implants were placed in the anterior maxilla and 34 implants were placed in the anterior mandible. Written consent was obtained from all patients. The period of implant survival was divided into four stages: Stage I (time between surgical placement and surgical uncovering), Stage II (at the point of surgical uncovering), Stage III (time between surgical uncovering and occlusal loading) and Stage IV (time after occlusal loading of implant).

Patients' medical and dental history, clinical examination, oral hygiene habits, anatomic acceptability, and inclusion and exclusion criteria were thoroughly assessed before admission to the study.[9] Each patient received at least two implants of the same diameter and length and of different surface properties (i.e. HA coated + BG coated) in different but identical sites of the particular arch. A panoramic radiograph (OPG) was taken to evaluate the available bone and possible pathologic conditions before implantation. Magnification of the OPG could have been corrected by taking a radiograph with a metallic mesh of known gap (1 mm x 1 mm) adapted over the jaws. An acrylic copy of the planned prosthesis was made, which was perforated to act as a surgical template during the surgical phases. Alveolar ridge width was evaluated using a No. 15 endodontic file with a rubber stopper upon penetrating the soft tissues under local anaesthesia and representing the measured values over a presectioned stone cast. The implant was used to replace a single tooth by implant supported artificial crown or multiple teeth by implant supported fixed bridge that were retained with cement temporarily over implant abutment throughout the study period. None of the implants were splinted to adjacent natural teeth. The permanent restorations were removed during evaluation visits and permanently cemented after completion of the study.[10]

Phase I therapy and oral hygiene instructions were completed at least one month prior to surgery. Two-stage surgery was performed for implant placement (Stage 1 surgery) and exposure of head (Stage 2 surgery) at three-month intervals in aseptic conditions.[9] Standard surgical procedures of implant surgery were followed.[11] After extraoral and intraoral disinfection and local anaesthesia application, crestal incisions were made 1.5 mm short of the gingival margin of the adjacent teeth that was modified at both ends, extending labially and lingually within the confines of the attached gingiva. Full thickness flaps were elevated both labially and lingually to expose the top of the alveolar ridge. A low speed, high torque (850–1250 rpm, 20–50 Ncm) drilling system (i.e. physio-dispenser) with copious normal saline irrigation was used to minimize excessive heat generation and trauma to the bone. A surgical template or stent was placed on the occlusal table of the same arch to direct accurate placement of the implant. A 2.5 mm diameter drill bit (Uniti system, Equinox, Holland) was used to penetrate at least 3–4 mm of crestal bone for all the osteotomy sites. The stent was then removed, and the faciolingual and mesiodistal dimensions of the osteotomy sites were checked by inserting similar diameter guide pins. Keeping the guide pins inserted in the other sites, the same drill bit was used to establish the required depth (i.e. 14 mm for 13 mm implant) of osteotomy sites one by one to ensure accurate parallelism of the two prepared sites. Holes were drilled 1 mm in addition to implant length to ensure the level of implant was at or just below the level of crestal bone as all two-staged osseointegrated implant systems confirm early post-operative crestal bone loss as a result of surgery. Progressively larger diameter drill bits (sequential drilling procedure) were used (i.e. 4 mm for 4 mm implant). All the drilling procedures were accomplished with a steady hand, without wobbling, to minimize funnelling of the coronal portion of the osteotomy sites. Implants were threaded into place without touching its surface, at the level of bone using a hand wrench. Almost all the implants achieved primary stability at the time of placement. After placement, a healing cover screw was threaded over the implants and tension free primary flap closure was obtained to ensure complete sealing of wound edges to prevent saliva contamination and maintain a sterile environment around the implant. Patients were given topical (0.2% chlorhexidine twice daily x 14 days) and oral antimicrobials (500 mg amoxycillin thrice daily x 7 days), analgesic medications (400 mg ibuprofen thrice daily x 3 days with antacids) and routine post-surgical instructions before

release from the clinic. Two weeks after Stage 1 surgery, the sutures were removed and the patients were instructed to gently brush the area with an ultra soft bristle toothbrush. Stage 2 surgery was performed to expose implant heads under local anaesthesia and a gingival healing cuff was screwed into the implant body to facilitate gingival healing around it. Similar to Stage 1 surgery, routine post-surgical instructions and medications were given to the patients. After two weeks of Stage 2 surgery, gingiva former was unscrewed and the abutment screw was screwed into the implant to receive temporary prosthesis. Patients were then recalled after one week to receive permanent restoration. From the date of prosthetic attachment (baseline), patients were evaluated for one year at six-monthly intervals. The clinical parameters were recorded to the nearest millimetre with the help of a University of North Carolina (UNC-15) probe (Hu-Friedy Inc., Chicago, USA) for each implant site. The implant-soft tissue interface was evaluated by plaque index (PI), gingival index (GI), probing pocket depth (PPD) and gingival recession (GR). All the clinical parameters were measured at the following positions: mesial, distal, labial and lingual (palatal). The highest score of PI, GI, PPD and GR for each implant was used to determine the respective score of that implant in a particular visit.

The implant-hard tissue interface was evaluated by measurement of marginal bone loss by intraoral periapical (IOPA) x-ray. Measurements taken directly and/or from the radiographs at implant uncovering were used as the baseline for radiographs taken at subsequent follow-up evaluations (Fig 1B). In determining actual bone loss, radiographic measurements of bone level were calibrated using a divider and caliper with 1/10 mm gradation. Formulas used for calibration of actual average bone loss of each implant appear in Fig 2.

Axial CT scan view was also used to evaluate the implant interface for detection of any possible gap persisting between the surrounding bone and implant

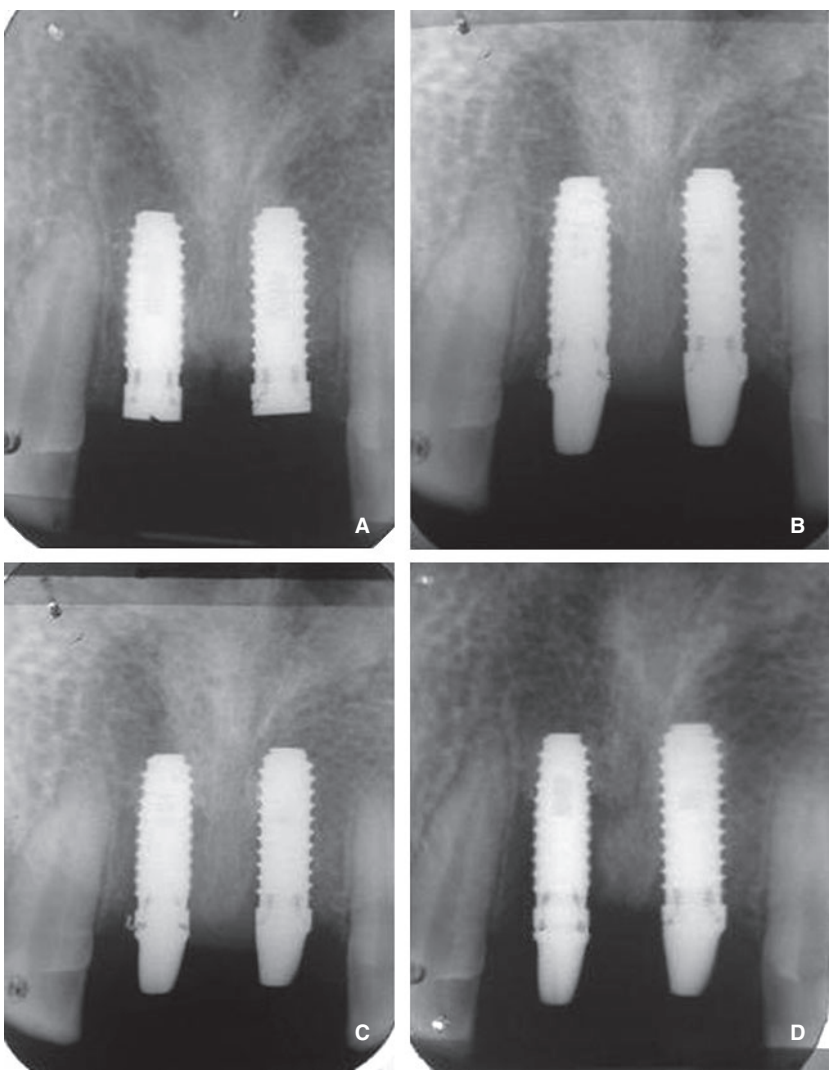

Fig 1. IOPA x-ray at immediate postoperative period (A), baseline (B), six months (C) and 12 months (D) after permanent prosthetic attachment.

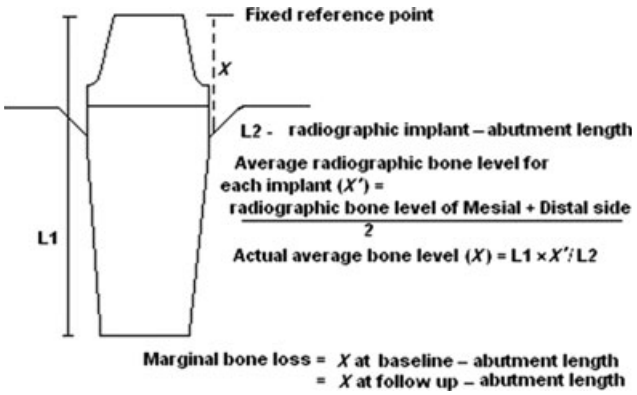

Fig 2. Formula used for calibration of actual average marginal bone loss of each implant.

surface.[12] Considering the high radiation exposure, a single sitting CT scan consisting of one scout view and two or three axial slices were taken for evaluation. CT scan view was taken six months after prosthetic loading in 10 patients of both groups in the maxilla and mandible (Fig 3). A specific multi-detector spiral CT scan (MDCT) unit (GE Hi-Speed, GE Health Care, Boston, USA) was used to evaluate the interface gap for all patients with 1.5x magnification.

Success/failure criteria

For the one year follow-up period, a successful implant was considered to be one that met the success/failure criteria. An implant was considered as failed if one or more of the following conditions were identified: clinical mobility (>1 mm), unresolved chronic pain, implant loss, radiolucency around implant, unresolved infection with the use of antibiotics or local treatment which had recurred more than three times, and marginal bone loss no greater than one-third of the height of the implant.[9,13] Failures of implants were documented as implant location, type of implant, stage of treatment at removal and reason for removal.

Statistical analysis was employed to compare the study results using a software programme (SPSS Version 11, SPSS Inc., Chicago, USA). To determine differences between the coated titanium implants, study results were analysed using paired samples; t-test for intra-group comparison, and ANOVA and *post hoc* test for inter-group comparison. For each outcome measurement, at least 95% confidence limit was estimated. No analytical comparison was performed between the maxilla and mandible. The implantation sites were divided into two groups: Group I [(control) – osteotomy sites received HA coated Ti implants] and Group II [osteotomy sites received BG coated Ti implants].

RESULTS

The coated implants of each group (BG and HA) were fabricated under identical conditions in order to minimize any experimental error. HA coating was applied by air microplasma spraying technique which enables minimum structural change in composition as compared to conventional air plasma spray. The *in vitro* studies of these coatings were reported earlier.[6,8,14]

It was found that healing was in general uneventful for all groups. There was almost no sign of infection or untoward allergic and foreign-body type of reactions postoperatively among the samples studied. All the implants achieved primary stability at the time of Stage 1 surgery except two. The results of the different clinical and radiological parameters evaluated throughout the study period are presented in Tables 1–3 and Figs 1, 3 and 4. Evidence of suppuration, resorption of almost entire areas of HA coating was observed with one HA coated implant in the lower jaw at Stage I. But coating resorption or suppuration was not observed with any BG coated implants at Stage I failure, although partial resorption was observed with one failed BG coated implant at Stage III. Among the implant types, the implant failure rates of the maxilla and mandible are shown in Table 3.

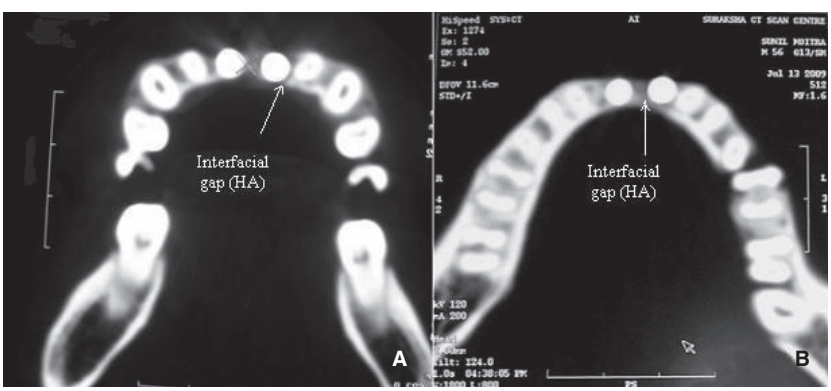

Fig 3. Interfacial gap around a HA coated implant at axial CT scan view in (A) maxilla and (B) mandible.

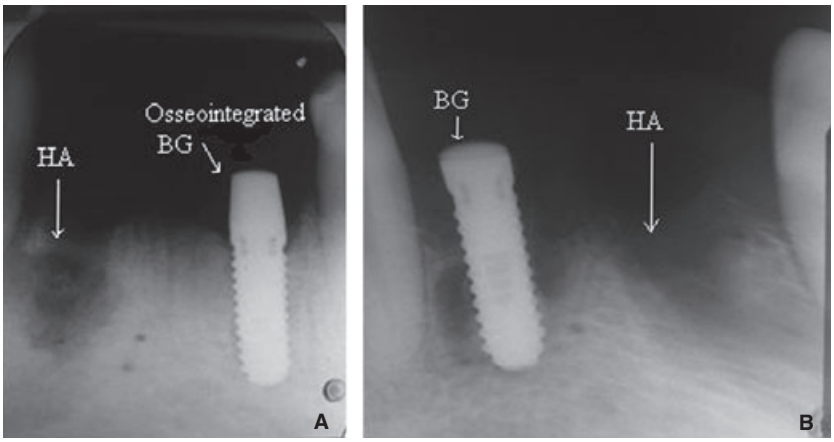

Fig 4. IOPA x-ray of failed HA coated and BG coated implants from mandibular sites at Stage I.

Table 1. Mean and standard deviation values of Group I (HA) and Group II (BG) at specific time intervals in both jaws for PI, GI, PPD, ABL and GR. Interfacial gap around implants (CT view) of both jaws at six months also presented

Parameters	HA group (Group I, control)			Bioactive glass group (Group II)		
Maxilla	Baseline	6 months	12 months	Baseline	6 months	12 months
PI	0.83 ± 0.40	0.92 ± 0.30	0.82 ± 0.40	0.85 ± 0.36	0.93 ± 0.26	0.78 ± 0.42
GI	0.53 ± 0.52	0.36 ± 0.50	0.27 ± 0.46	0.52 ± 0.51	0.43 ± 0.51	0.21 ± 0.43
PPD (mm)	3.25 ± 0.50	3.50 ± 0.58	3.25 ± 0.50	3.30 ± 0.52	3.50 ± 0.55	3.17 ± 0.40
ABL (mm)	1.13 ± 0.17	1.83 ± 0.10	1.92 ± 0.10	1.12 ± 0.17	1.77 ± 0.18	1.81 ± 0.15
GR (mm)	0.09 ± 0.30	0.18 ± 0.40	0.18 ± 0.40	0.00 ± 0.00	0.11 ± 0.33	0.22 ± 0.44
Interfacial gap in CT scan	–	3 implants	–	–	1 implant	–
Mandible						
PI	0.80 ± 0.40	0.92 ± 0.30	0.81 ± 0.41	0.78 ± 0.44	0.89 ± 0.33	0.67 ± 0.50
GI	0.56 ± 0.52	0.38 ± 0.50	0.27 ± 0.46	0.52 ± 0.51	0.44 ± 0.51	0.25 ± 0.43
PPD (mm)	3.00 ± 0.00	2.86 ± 0.38	2.71 ± 0.48	3.00 ± 0.00	2.75 ± 0.46	2.62 ± 0.52
ABL (mm)	1.09 ± 0.12	1.69 ± 0.09	1.73 ± 0.09	1.06 ± 0.12	1.56 ± 0.09	1.60 ± 0.09
GR (mm)	0.09 ± 0.30	0.18 ± 0.40	0.18 ± 0.40	0.07 ± 0.26	0.21 ± 0.42	0.21 ± 0.42
Interfacial gap in CT scan	–	1 implant	–	–	1 implant	–

PI = plaque index; GI = gingival index; PPD = probing pocket depth; ABL = average marginal bone loss; GR = gingival recession.

DISCUSSION

This study was a short term, bi-centre, prospective clinical study with an identified control (HA coated Ti-6Al-4V dental implant). The study design permitted comparison of HA coated and BG coated Ti-6Al-4V dental implant in each subject. To facilitate comparison, location of implant, bone quality type and area basis load distribution to intraoral forces were kept very much near to identical. Also, all patients did not receive any long-span fixed prosthesis or combined implant-tooth supported prosthesis. These types of studies prevent bias in evaluating clinical success. The present study has not focused on prosthesis failure but on the success of implants themselves supporting the prosthesis. No significant changes were observed with mean PI, mean GI, mean PPD and mean GR scores throughout the study period for both coated types in the upper and lower arches (Tables 1 and 2). This finding was similar to the observations of Jeffcoat *et al.*[9] who suggested that a low level of plaque did not interfere with the healing processes of any particular group. Low GI scores suggested that all the coating materials were biocompatible, non-toxic, did not elicit any inflammatory and/or foreign body responses to the tissues. There was also no apparent retardation of normal bone healing processes around implants that claimed to be primary requisites for osseointegration.[15] PPD alone might have limited value in providing any comparable results because it might be changed with alteration in the position of the gingival margin.[16]

Crestal and peri-implant bone levels could be best determined by regular accurate radiographic evaluation.[17] The mean average marginal bone loss (ABL) of the two groups from baseline to 12 months after prosthetic attachment showed higher values in the upper arch than the lower arch (Table 1). This might be due to poorer bone quality in the anterior maxillary region.[18] Statistically significant ABL was found only in the interval between implant uncovering and six

Table 2. Paired t-values (intra-group comparisons) and results of inter-group comparisons (ANOVA and *post hoc* test) of Group I and Group II at baseline, six months and 12 months after prosthetic attachment in both jaws for PI, GI, PPD, ABL and GR

Parameters	HA group (Group I, control)			Bioactive glass group (Group II)			Inter-group comparison
Maxilla	Baseline to 6 months (paired t-value)	6 months to 12 months (paired t-value)	Baseline to 12 months (paired t-value)	Baseline to 6 months (paired t-value)	6 months to 12 months (paired t-value)	Baseline to 12 months (paired t-value)	ANOVA and *post hoc* test
PI	−0.55 p > 0.05	0.55 p > 0.05	0.50 p > 0.05	−0.56 p > 0.05	1.00 p > 0.05	0.56 p > 0.05	p > 0.05 NS
GI	0.80 p > 0.05	0.43 p > 0.05	1.93 p > 0.05	0.36 p > 0.05	1.14 p > 0.05	1.75 p > 0.05	p > 0.05 NS
PPD	−1.00 p > 0.05	1.00 p > 0.05	0.00 p > 0.05	−1.00 p > 0.05	1.58 p > 0.05	1.00 p > 0.05	p > 0.05 NS
ABL	−9.89 p < 0.05	0.00 p > 0.05	−11.31 p < 0.05	−19.03 p < 0.05	−2.24 p > 0.05	−15.65 p < 0.05	p > 0.05 NS
GR	−1.00 p > 0.05	0.00 p > 0.05	−1.00 p > 0.05	−1.47 p > 0.05	0.00 p > 0.05	−1.47 p > 0.05	p > 0.05 NS
Mandible							
PI	−0.55 p > 0.05	0.55 p > 0.05	0.58 p > 0.05	−0.56 p > 0.05	1.00 p > 0.05	0.56 p > 0.05	p > 0.05 NS
GI	0.78 p > 0.05	0.46 p > 0.05	1.90 p > 0.05	0.35 p > 0.05	1.16 p > 0.05	1.76 p > 0.05	p > 0.05 NS
PPD	1.00 p > 0.05	1.00 p > 0.05	1.55 p > 0.05	1.53 p > 0.05	1.00 p > 0.05	2.05 p > 0.05	p > 0.05 NS
ABL	−13.74 p < 0.05	−2.12 p > 0.05	−12.17 p < 0.05	−26.45 p < 0.05	−2.05 p > 0.05	−29.37 p < 0.05	p > 0.05 NS
GR	−1.00 p > 0.05	0.00 p > 0.05	−1.00 p > 0.05	−1.47 p > 0.05	0.00 p > 0.05	−1.47 p > 0.05	p > 0.05 NS

NS = not significant; GR = gingival recession; PI = plaque index; ABL = average marginal bone loss; PPD = probing pocket depth; GI = gingival index.

Table 3. Number of failures in Group I and Group II in maxilla and mandible at different time intervals

Parameters	HA group (Group I, control)				Bioactive glass group (Group II)			
Maxilla total-28 implants	Stage I	Stage II	Stage III	Stage IV	Stage I	Stage II	Stage III	Stage IV
No. of failure	1	–	–	1	–	–	1	–
Failure rate	14.28% (of 14 implants)				7.14% (of 14 implants)			
Mandible total-34 implants								
No. of failure	2	–	–	–	1	–	–	–
Failure rate	11.76% (of 17 implants)				5.88% (of 17 implants)			

months after prosthetic loading for the two groups in both jaws (Table 2), apparently due to the initial load application on healing implants compared to the unloaded condition.[18] Changes of mean ABL values from baseline to 12 months after prosthetic attachment in both upper and lower jaws were less for the BG coated group (Table 2) compared to the HA group, which suggests that the osteostimulatory property of bioactive glass might change the remodelling responses of bone.[19] All the values of mean bone level changes observed in the present study were in the direction of bone loss, although bone gain around different types of implants would certainly be possible.[18]

Evaluation of bone-implant interface around the metallic implant with CT scan was documented previously.[12] An increased number of interfacial gaps (IFG) (four) in the anterior maxilla were found (Table 1, Fig 3) compared to the anterior mandible (two), and suggests that more rapid and mature bone formation resulted in greater bone to implant body contact in the anterior mandible.[20] Least IFG with BG coated implants indicated early implant stabilization and load bearing capacity in poor quality bone compared to HA group, as also observed by Ghosh *et al.* in animal models.[6] However, gaps shown in the CT scan view were not true gaps because radiodensity in all IFG regions were greater than 400 Hounsfield units. It suggests that immature osteoid containing interface regions are likely to appear as radiolucent gaps, although simultaneous use of CT scan and

histological analysis in an animal model may eventually elucidate the actual aetiology of such interface radiolucency.

One HA coated implant failed (Table 3) at Stage I, which might be due to encroachment of the incisive canal by the implant during surgical placement that resulted in a proliferation of entrapped epithelium (peri-implant radiolucency).[21] One HA coated implant also failed at Stage IV in the maxilla (Table 3) due to increased mobility as a consequence of intraoral load but the BG coated implant was firmly fixed to bone on the other side of the restoration. In the upper jaw, one BG coated implant failed at Stage III due to increased mobility. Therefore, the chances of failure were less with BG coated implant types in poor quality bone compared to HA coated implants in both non-loaded and loaded condition. In the lower jaw, one of each coated implant type failed at Stage I (Fig 4B), probably due to the reduced ability of high density alveolar bone (anterior mandible) to cope with inaccurate surgical technique. Evidence of suppuration and almost entire resorption of HA coating after surgical removal was observed with one HA coated implant in the lower jaw at Stage I, possibly due to the resorption of HA coating at the local acidic environment in abscessed osteotomy sites.[22] Absence of suppuration and intact BG coating on a failed implant in the lower jaw demonstrated that BG produce an alkaline medium around the implant through dissolution of alkali ions that might prevent coating resorption upon failure. The antimicrobial properties of BG might also have some role in preventing infection.[23] Among the implant types, the implant failure rates of BG coated implants were less than HA coated implants in both arches (Table 3). For implant failure occurring at Stage I, the rate of failure was increased as bone density increased. For implant failure discovered in Stage III and Stage IV, the rate of failure was increased as bone density decreased.

CONCLUSIONS

A total of 62 implants in 31 patients were investigated, of which six implants failed and the rest were successful. Overall results showed that BG coated implants are as equally successful as HA coated implants in achieving osseointegration and to support final restorations under the present experimental conditions. Equally important was the fact that it did not cause extra biological complications and therefore is safe to be used in humans. As the sample size of the present study is small, further similar studies are required to throw more light on the observations made in this study and to come to a definite conclusion. The comparative evaluation of the *in vivo* performance of coating on metallic dental implants (HA coating by microplasma technique and BG coating by enamelling technique) in the human body is in agreement with the *in vitro* evaluation and comparative animal study results reported earlier.

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