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Comparative radiopacity of bone graft materials

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A B S T R A C T

The aim of this study was to investigate the radiopacity of bone graft materials (BGMs) in comparison with bovine mandibular cortical bone and human dentine. Eight samples of each material (8 mm in diameter and 3 mm in thickness) were prepared from Dexabone® (DB), Bio – Oss® (BO), 4BONE SBS (4B), KASIOS® TCP (KA), S.C. PONETI (PO), and Apatite–Wollastonite (AW). The optical densities of each material, along with one tooth section (human canine tooth 1 mm slice), bovine mandibular cortical bone (BC) samples, and an aluminum step wedge, were measured from radiographic images using a transmission densitometer. The data were analyzed by nonparametric one-way ANOVA (Kruskal–Wallis) and Duncan's multiple range tests for post hoc comparison ($\alpha = 0.05$). BC and AW had statistically lower optical density values than BO, 4B and human dentine ($p < 0.05$). Among BGMs, AW (3.681 ± 0.409 mm eq Al) had the highest radiopacity values whereas BO (1.925 ± 0.176 mm eq Al) had the lowest one. The radiopacity values of DB and KA did not reveal a statistically significant difference when compared with other materials ($p > 0.05$). The radiopacity of all BGMs investigated seemed to be too low to be detected radiographically when placed in the mandibular cortical bone.

1. Introduction

Bone grafts are often necessary to provide support, fill voids, and enhance biologic repair of skeletal defects (Parikh, 2002). Various bone graft materials (BGMs) to promote healthy and rapid bony healing are being studied in the field of oral surgery practice (Hardin, 1994). Autograft, allograft, xenograft, synthetic materials and biological derivatives have been used as bone substitutes for a long time (Hou et al., 2007; Nolff et al., 2010). Experiments to find the best bone graft material (BGM) still continue.

In order to ascertain the healing attributes of various graft materials, the authors evaluated the resorption and rate of conversion to native bone of the graft materials using different methods (Johnson et al., 1996; Feichtinger et al., 2006; Nolff et al., 2010). Johnson et al. (1996), evaluated the abilities of the bone graft substitutes to heal a 2.5 cm defect in canine radii at two time intervals (12 weeks and 24 weeks). They compared the radiodensitometric values with biomechanical results.

Radiographic evaluation of the graft materials has been carried out in various studies. After sinus lift procedures, clinical and radiographic outcomes of grafted sites have been studied for various periods of up to 5 years (Buchmann et al., 1999; Raghoebar et al., 2001). Hatano et al. (2004), evaluated sinus graft procedures radiographically with panoramic radiographs for up to 108 months to determine the changes in the graft height.

Photo-densitometry was first used to assess bone structures by Morgan et al. (1967a), in 1967. In radiographic absorptiometry (RA), a standardized hand radiograph is taken with an aluminum step wedge placed on the film and analyzed using an optical densitometer. The bone mineral density is determined by comparing it with the defined density of the aluminum (Al) step wedge. The results are expressed in Al equivalent values or arbitrary units (Cosman et al., 1991; Matsumoto et al., 1994; Njeh et al., 1999). RA is a low cost and readily accessible technique (Njeh et al., 1999). As well as the soft tissue overlying the bone, physical factors that influence the radiographic image such as fluctuation in beam quality, instability of X-ray source, film response, processing conditions, radiation scattering and beam hardening effects also have adverse effects on the precision and accuracy of RA. Hence, RA implementation was initially characterized by significant precision errors of about $9 \pm 10\%$ (Morgan et al., 1967b; Njeh et al., 1999).

BGMs have not been tested for their radiopacity, so this study is important for investigating the radiopacity of the graft materials. The aim of this study is to evaluate Dexabone® (DB), Bio – Oss® (BO), 4BONE SBS (4B), KASIOS® TCP (KA), S.C. PONETI (PO), Apatite–Wollastonite (AW) (Kokubo et al., 1985; Kokubo et al., 1986), human dentine and bovine mandibular cortical bone.

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2. Materials and methods

In this study, the radiopacity levels of six different BGMs were tested. The materials, as well as the manufacturers and the compositions for the materials used in this study are listed in Tables 1 and 2. Human canine dentine (HD), bovine mandibular cortical bone (BC) and an Al step wedge were used as references.

Wax patterns (Pinnacle standard modeling wax; Dentsply Ltd., Addlestone, UK) of 3 mm in thickness, 3 cm in width and 5 cm in length were prepared. On these wax patterns, six holes, 8 mm in diameter were made. A glass slide 0.9 mm in thickness, 3 cm in width and 8 cm in length was used as a base. The wax patterns were attached to these glass slides so that molds were prepared for filling with the BGMs. Each BGM was filled into the wax molds to the brim and pressed with a thin glass cover. Eight samples of each material were prepared.

Longitudinal sections of human permanent canine teeth were prepared 1 mm in thickness using a micro-slicing device (Accutom, Struers Co, Copenhagen, Denmark) ($n = 8$). Bovine mandibular bone, obtained from a freshly sacrificed animal, was used for the cortical bone specimen preparation. Buccal cortical bone was extracted from the bovine mandible using chisels after cutting with burs. Eight disc shaped cortical bone specimens were prepared, each of which was 3 mm in thickness and approximately 8 mm in diameter. An Al step wedge (Alu-Keil; PEHA Med. Geräte GmbH, Sulzbach, Germany) was prepared. The step wedges maximum thickness was 8 mm; each step had a thickness of 1 mm, length of 5 mm, and width of 14 mm. A glass slide with a wax mold and the specimens on it, one tooth section, the bovine cortical bone specimen and an Al step wedge were positioned side by side on occlusal D speed radiographic film (Kodak Ultra-speed; Eastman Kodak Company, Rochester, NY). A special holder was mounted to ensure a fixed focus/film distance. The films were exposed for 0.38 s with a dental X-ray system (Trophy; Vincennes, France) at 70 kV and 8 mA; the object-to-film distance was 30 cm. All films were processed immediately in a standard automatic processor (Velopex Extra-X; Medivance, Harlesden, UK) using fresh developer and fixer (Velopex Ready Mixed Developer and Fixer; Hexagon International (GB) Ltd, UK).

The optical density of the radiographic images was measured with a transmission densitometer (Pehamed Denso-Dent Densitometer; PEHA Med. Geräte GmbH) (mean of at least three readings per specimen) with an aperture size of 3 mm (DIN 6868/55). Following the method of El-Mowafy and Benmergui (1994), the optical density data for the Al step were entered into a computer and the best possible exponential fit was used for curves of Al optical density. A graph was plotted to illustrate the relationship between step wedge thickness and optical density values (ODVs) with the following equation: [$y = -0.3675\mathrm{Ln}(x) + 1.4231$] (Fig. 1). From that graph, ODVs of the specimens were used to determine the equivalent Al thickness (eq Al) values. One-way analysis of variance (ANOVA) (Kruskal–Wallis) and Duncan's multiple range tests were conducted to statistically analyze the ODVs and eq Al values of the materials.

Table 1
The compositions of the materials used in this study.

Dexabone®	(DB)	is a bovine origin graft material which has high porosity
Bio – Oss®	(BO)	bone graft material which is a natural bone substitute material obtained from the mineral portion of bovine bone
4BONE SBS	(4B)	is a fully synthetic bone substitute made of synthesized 60% hydroxyapatite and 40% beta tricalcium phosphate which has 70% macroporosity for promoting the invasion of osteogenic cells
KASIOS® TCP	(KA)	is a synthetic bone substitute made of 99.9% beta tricalcium phosphate
S.C. PONETI®	(PO)	Hydroxyapatite
Apatite–Wollastonite	(AW)	Bioactive glass ceramic ($MgO–CaO–SiO_2–P_2O_5–F$ system)

Table 2
Materials used in the study.

Materials	Manufacturer and batch numbers	Grain size
Dexabone® (DB)	Aap Biomaterials GmbH & Co. KG, Dieburg, Germany (N023)	1.0–2.0 mm
Bio – Oss® (BO)	Geistlich Pharma AG, Wolhusen, Switzerland (070453)	1.0–2.0 mm
4BONE SBS (4B)	BIOMATLANTE SARL, Vigneux de Bretagne, France (0403E107)	0.5–1 mm
KASIOS® TCP (KA)	Kasios®, ZI La Croix, Launaguet, France (407/07.030)	0.5–1 mm
S.C. PONETI (PO)	Poneti srl, Bucharest, Romania (10000304)	0.5–1 mm
Apatite–Wollastonite (AW)	Manufactured according to formula of Kokubo et al., 1985 and Kokubo et al., 1986.	0.5–1 mm
Bovine mandibular cortical bone (BC)	–	–
Human canine dentin (HD)	–	–

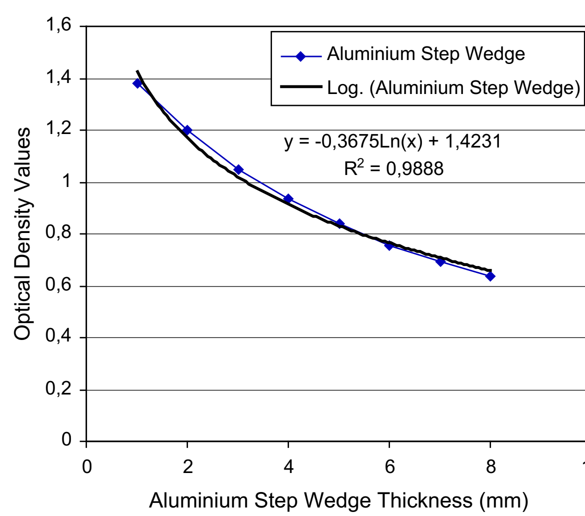

Fig. 1. Optical density calibration curves for Al step wedge.

3. Results

Table 3 records the means and standard deviations of ODVs and eq Al values for all tested materials. The Kruskal–Wallis test indicated significant differences between the ODVs and eq Al values of the materials ($p < 0.0001$).

The Duncan's multiple range tests revealed BC and AW to have ODVs significantly lower than the other materials, except DB, KA, and PO. HD, BO and 4B had the highest ODVs among the materials tested, and were significantly higher than the materials BC and AW ($p < 0.05$). Lower values represent greater radiopacity.

Duncan's multiple range tests showed AW and BC to have the highest eq Al values (3.681 ± 0.409 and 3.432 ± 0.323 mm eq Al, respectively), whereas HD and BO had the lowest eq Al values (1.697 ± 0.221 and 1.925 ± 0.176 mm eq Al, respectively).

4. Discussion

Johnson et al. (1996), emphasized that degradation of the material would occur only after sufficient ossification had occurred