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Accuracy of both virtual and printed 3-dimensional models for volumetric measurement of alveolar clefts before grafting with alveolar bone compared with a validated algorithm: a preliminary investigation

C.P. Kasaven, G.T. McIntyre *, P.A. Mossey

University of Dundee Dental Hospital, 2 Park Place, Dundee DD1 4HR, UK

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Abstract

Our objective was to assess the accuracy of virtual and printed 3-dimensional models derived from cone-beam computed tomographic (CT) scans to measure the volume of alveolar clefts before bone grafting. Fifteen subjects with unilateral cleft lip and palate had i-CAT cone-beam CT scans recorded at 0.2 mm voxel and sectioned transversely into slices 0.2 mm thick using i-CAT Vision. Volumes of alveolar clefts were calculated using first a validated algorithm; secondly, commercially-available virtual 3-dimensional model software; and finally 3-dimensional printed models, which were scanned with microCT and analysed using 3-dimensional software. For inter-observer reliability, a two-way mixed model intraclass correlation coefficient (ICC) was used to evaluate the reproducibility of identification of the cranial and caudal limits of the clefts among three observers. We used a Friedman test to assess the significance of differences among the methods, and probabilities of less than 0.05 were accepted as significant. Inter-observer reliability was almost perfect (ICC = 0.987). There were no significant differences among the three methods. Virtual and printed 3-dimensional models were as precise as the validated computer algorithm in the calculation of volumes of the alveolar cleft before bone grafting, but virtual 3-dimensional models were the most accurate with the smallest 95% CI and, subject to further investigation, could be a useful adjunct in clinical practice.

Keywords: bone grafting; 3D; CAD-CAM models; micro-CT; volumetric assessment

Introduction

Oral clefts result from failure of fusion of the facial process at different stages of dentofacial development, and are one of the most common congenital defects worldwide. They affect about 9.92 babies/10 000, with sixfold and threefold variations in the prevalence of cleft lip and palate, and isolated cleft palate, respectively.[1]

Where movement of teeth is precluded by the dimensions of the cleft, alveolar bone grafting is an integral component of treatment.[2] During bone grafting the alveolar defect is firmly packed with chips of cancellous bone to reconstruct the height of the alveolar crest from donor sites (including the anterior iliac crest,[2] the tibia,[3] and the mandibular symphysis,[4]) or with recombinant human bone morphogenetic protein (rhBMP), an osteoinductive cytokine.[5] Bone is packed under the alar base to ensure good nasal symmetry.[2]

* Corresponding author at: Orthodontic Department, University of Dundee Dental Hospital, 2 Park Place, Dundee, DD1 4HR, UK.
Tel.: +44 1382 635964.
E-mail address: grant.mcintyre@nhs.net (G.T. McIntyre).

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All protocols for alveolar bone grafting involve initial imaging to assess the need for grafting and the eruption status of adjacent teeth, and to assess the need for preoperative orthodontic expansion (where necessary) to manoeuvre adjacent dental crowns and roots away from the cleft. Immediate preoperative imaging is also needed to assess the size of the defect, and postoperative imaging to evaluate the success of the procedure. While 2-dimensional dental, occlusal, or panoramic radiographs before and after operation have traditionally been used to estimate "bone-fill", interest in the use of 3-dimensional imaging to quantify the success of alveolar bone grafting has been growing over the last 15 years. With 3-dimensional imaging it is possible to quantify the volume of the cleft and the volume of bone retained after consolidation, which is important in assessing the degree of success and, ultimately, if sufficient bone is available for eruption of canines and orthodontic movement of teeth. Higher success rates (around 72%–95%) have been reported when alveolar bone grafts have been assessed using 2-dimensional radiographs,[2,6–8] compared with the success rates of 16%–55% with 3-dimensional imaging.[9,10] This is because 2-dimensional radiographs are subject to such limitations as enlargement of images, distortion, structural overlap, limited identifiable landmarks, positioning problems, and the effects of these on the quality of subsequent images, which results in an overestimation of success rates by around 17%–25%.[11,12]

At the same time as 3-dimensional imaging has been developing, virtual models produced with CAD-CAM software and 3-dimensional printing hardware have opened up a range of opportunities in education, science, technology, healthcare, and industry. CAD-CAM models are useful for both surgical planning and for communication between members of the surgical team and patients.[13] Three-dimensional printing has also been used to provide implant-supported cutting guides for mandibular reconstruction,[14] orthodontic appliances such as Andresen appliances, sleep apnoea appliances,[15] aligners,[16] and orthognathic surgical splints.[17] Virtual and printed 3-dimensional models have the potential to be useful for preoperative planning and intraoperative harvesting of bone for alveolar bone grafting.

The aim of this study was to compare the accuracy of virtual and printed 3-dimensional models with a validated method for the quantification of the volume of alveolar clefts in vivo from cone-beam computed tomographic (CT) scans.[18] Our null hypothesis was that there is no measurable difference in dimension between virtual and printed 3-dimensional models derived from cone-beam CT scans when the volume of alveolar clefts is estimated, compared with the gold standard computational algorithm method.

Material and methods

The Tayside Committee on Medical Research Ethics and Tayside Medical Science Centre confirmed that neither ethics committee approval nor the approval of the Caldicott Guardian were required, as anonymised cone-beam CT scans were to be used. The Tayside Medical Science Centre and Greater Glasgow & Clyde NHS Board gave research and development approval. Cone-beam CT scans from 15 subjects with unilateral cleft lip and palate were identified from a consecutive series at Glasgow Dental Hospital after those with movement, beam hardening, and aliasing artefacts had been excluded. Subjects were scanned using an i-CAT cone-beam CT scanner (Imaging Sciences International, Hatfield, Pennsylvania, USA) with the following settings: 0.2 mm resolution, 120 kV, 37.07 mAs, acquisition time 26.9 seconds, field of view 65 × 65 mm,and rotation 360°. Each scan was sectioned transversely into 2-dimensional slices 0.2 mm thick. The cranial and caudal limits of the alveolar cleft were then assessed by three observers (one dental student and two faculty orthodontists with considerable experience in the care of patients with clefts) to test inter-observer reliability. The cranial boundary corresponded to the first appearance of a measureable alveolar defect and the caudal boundary was the bifurcation of the first permanent molars on the side of the cleft.

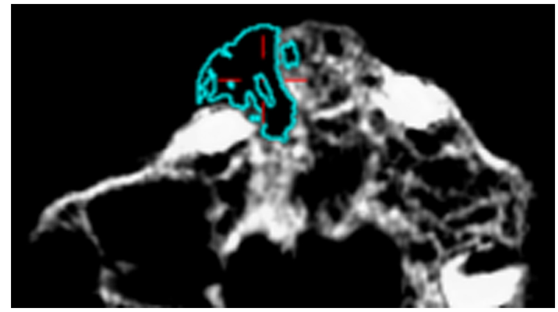

Fig. 1. Region growing tool to segment the alveolar cleft.

The volumes of the alveolar clefts were then calculated using first a validated computer algorithm (MATLAB®, The Mathworks Inc, Natik, Massachusetts), then commercially available 3-dimensional virtual model software (Volume Graphics Studio Max 2.2, Volume Graphics, Heidelberg, Germany) and finally 3-dimensional printed models, which were scanned with microCT and analysed using Volume Graphics Studio Max 2.2.

Validated computer algorithm (MATLAB®)

Using the protocol devised by Kasaven et al[18] each 2-dimensional slice was converted from DICOM to Portable Network Graphics (PNG) format. The Matrix Laboratory algorithm[18] was applied to each axial slice and summed to calculate the volume of each alveolar cleft. These data were used as the gold standard for comparison.