LINEAR AND VOLUMETRIC RADIOGRAPHIC ASSESSMENT OF PARTICULATE ILIAC BONE GRAFTS FOLLOWING SECONDARY GRAFTING OF UNILATERAL ALVEOLAR CLEFTS

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ABSTRACT

Background: Particulate autogenous bone grafts remain to be the gold standard for reconstruction of alveolar. The success of alveolar bone grafting is assessed clinically and radiographically. Among the radiographic measures of success is the bone bridging across the cleft, maintenance of the bucco-palatal / vertical linear dimensions of the graft and the stability of the total volume of regenerated bridge of bone. Computed tomography (CT) scans provide a better tool for three-dimensional evaluation of the residual bone following the reconstruction procedure.

Aim of the study: This study aimed at assessing the linear (horizontal, vertical) and volumetric changes that occur in particulate iliac bone grafts 6 months after secondary grafting of unilateral alveolar clefts.

Patients and Methods: Six patients with unilateral alveolar clefts who received particulate autogenous iliac crest grafts were included in this study. On a surgical planning software, their immediate and six-months postoperative CT scans were superimposed onto each other using the cranial base as a reference. On the axial cuts, the linear bucco-palatal dimensions of the reconstructed alveolar cleft were recorded, whereas on the coronal cuts the vertical height of the reconstructed alveolar cleft was measured for both scans. The software was also used to calculate the volume of the bone graft on the immediate postoperative CT and that of the remaining bone graft 6 months after. The data was statistically analyzed in the form of means ± standard deviation and paired T-test used to compare the measurements immediately and six-months postoperatively. The percentage change in the alveolar ridge dimensions over the six months follow up period was then calculated.

Results: The horizontal dimension of the grafted alveolar cleft decreased by an average of 24.4% over the six months period. The difference between the means showed a highly statistically significant difference with a P value < 0.01. While for the vertical dimension, the mean decreased by 21.6% over the six months period and the difference between the means was statistically significant with a P value <0.05. The percentage change in volume ranged from -92.4% to +16%.

Conclusions: Radiographic assessment of alveolar cleft reconstruction using CT scans are useful tools, not just for making accurate measurements and better evaluation of the formed bone within the reconstructed alveolar cleft, but also it provides a useful tool for analyzing the outcomes of the secondary alveolar grafting procedure for future correlation and optimization of the whole grafting procedure and expected outcomes.

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INTRODUCTION

Grafting of alveolar clefts is important for maxillary arch stability, closure of the oronasal communication and support eruption of unerupted teeth[1]. Different bone grafts and combination of grafting materials have been reported on, all aiming at achieving the goals of secondary alveolar grafting[2].

Although autogenous bone grafts have been favored for their osteogenic capabilities compared to other types of grafting materials, but their rate of resorption has been a point to consider. Robertson and Jolleys[3] reported that autogenous rib grafts for alveolar grafting mostly resorb and that the remaining bone doesn't support tooth eruption, thereby, does not help in gaining the objectives. While Sindet-Pedersen and Enemark et al[4] reported successfully on mandibular bone grafts harvested through an intraoral approach, reaching a marginal bone level that was comparable to that of anterior iliac bone grafts, with less donor site morbidity. Mixing autogenous grafts with alloplastic material[5] platelet rich plasma[6] or fibrin glue[7] aimed at expanding the autogenous bone graft and decrease its resorption rate.

But still particulate iliac bone grafts are among the most commonly reported on for alveolar grafting[2]. Its particulate nature allows easy eruption of the permanent canine compared to cortical and rib grafts[8].

The success of alveolar bone grafting is assessed clinically and radiographically. Among the radiographic measures of success is the bone bridging across the cleft, not of less importance is the maintenance of the bucco-palatal, vertical and the total volume of that regenerated bridge of bone. Previously, radiographic assessment utilized two dimensional scales for assessing marginal bone level after grafting and amount of bone fill [9-14]. Computed tomography (CT) scans provided a better tool for three dimensional evaluation of the residual bone following the reconstruction procedure.

At the beginning Van der Meij[15] reported on manual tracing of CT axial cuts of immediate and one year postoperative scans, to calculate the residual bone at one postoperative year. But they used a lengthy procedure of printing the axial cuts obtained from a CT scan onto overhead projector slides, and the manually superimposing the immediate post-operative onto the 1year follow-up scans. With the advent of CT softwares and surgical simulation softwares, the accurate measurement of the grafted site in all three dimensions in addition to volumetric analysis and even accurate superimposition of immediate and follow-up CT scans became possible[1, 16, 17, 18]. Having the possibility of performing all needed assessments on a single program, eliminates the error that might arise if more than one software were used for the superimposition, linear and volumetric measurements.

Therefore the aim of our study was to assess the linear (horizontal, vertical) and volumetric changes that occur in particulate iliac bone grafts 6 months after secondary grafting of unilateral alveolar clefts.

PATIENTS AND METHODS

Six patients with unilateral alveolar cleft presenting for early secondary alveolar cleft reconstruction were enrolled in this study. All patients were grafted with particulate anterior iliac crest bone graft. For each patient an immediate and a 6 months postoperative CT scan were requested.

The DICOM files of the immediate postoperative CT scan were imported into a surgical planning software (*Mimics, Materialise inc., Leuven, Belgium*). The DICOM data were segmented to highlight only bony tissues from the CT and further manipulated to select only the area of interest. A 3D reconstruction of the selected area then followed. The same process was carried out on the six months postoperative CT scan using the same parameters to ensure comparability of both 3D reconstructed volumes.

The six months postoperative 3D volume was then superimposed onto the immediate postoperative one utilizing a point-based registration system; where a number of points on the skull base common between both volumes were used as landmarks to superimpose both skulls onto each other (figure 1).

On the axial cuts, the horizontal (bucco-palatal) dimension of the grafted alveolar cleft was measured at three different axial levels ; nearest to the elevated nasal floor, midway between the nasal floor and the alveolar crest and nearest to the alveolar crest (figure 2). An average of the recorded measurements was then calculated. While on the coronal cut, the vertical distance between the highest and the lowest

points of the bone graft was recorded midway between the buccal and palatal walls on both scans.

For volumetric assessment of the grafted alveolar defect, firstly the bone graft was outlined on the immediate postoperative CT on a slice by slice basis (figure 3). After the bone graft has been outlined along its entire length, a 3D volume was generated, and its volume recorded (labelled Y). Secondly, on the superimposed CT scans (immediate and 6 months postoperative), the area of interest was highlighted and isolated using a series of cutting planes (figures 4 and 5). The volume of the consolidated bone graft at six months was then calculated according to the following equations:
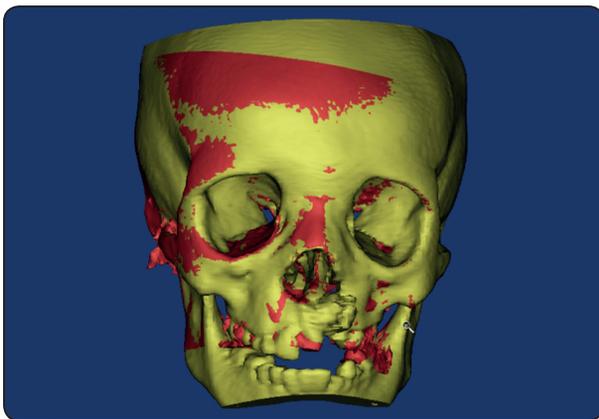

Fig. (1) Superimposition of the immediately and six months postoperative volumes based on cranial base landmarks
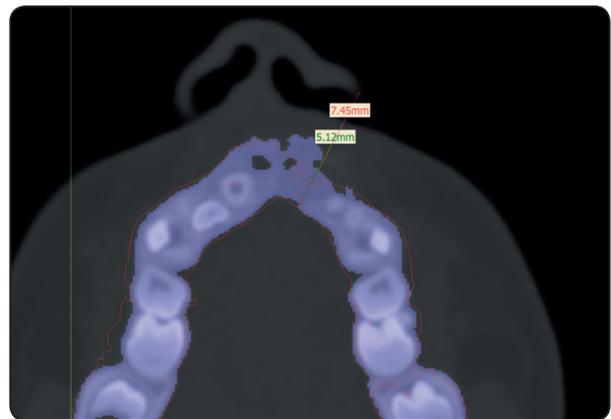

Fig. (2) Axial CT scan showing measurement of the horizontal (bucco-palatal) dimensions of the grafted area on the immediate postoperative (purple) and six months postoperative (red outline) CT scans.
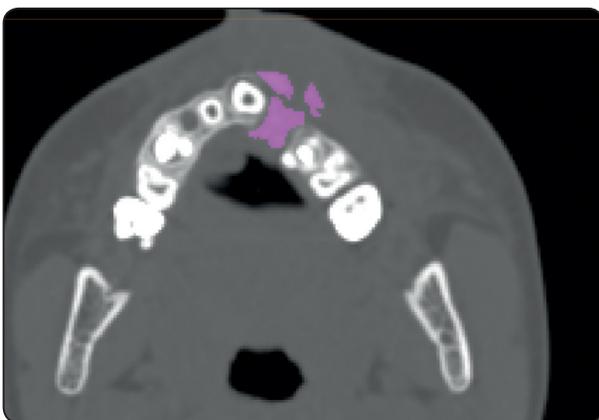

Fig. (3) Isolation of the bone graft on a slice by slice basis on the immediately postoperative CT scan.
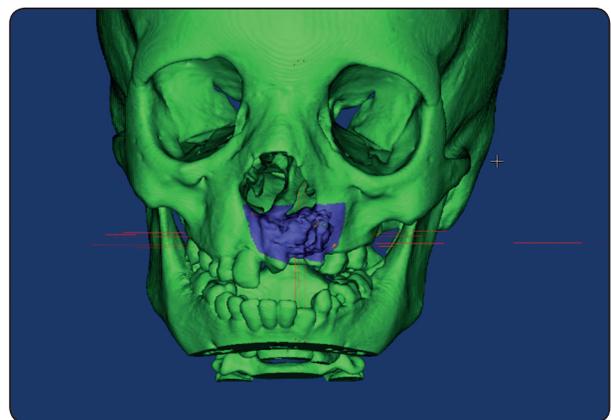

Fig. (4) Isolation of the volume of interest (blue) on the reconstructed 3D volume.
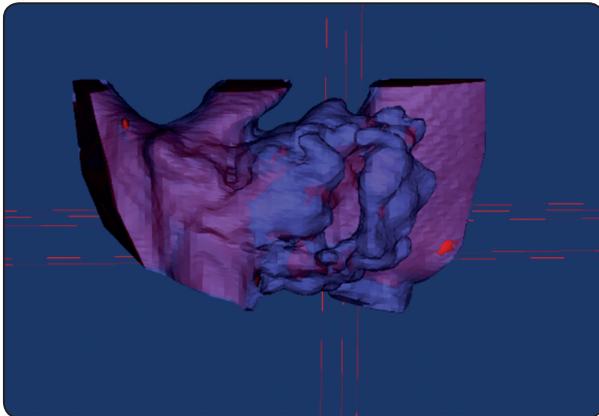
Fig. (5) The isolated 3D volumes of interest of the immediate (blue) and six months (purple) postoperative CT scans superimposed on to each other.

Volume of the native bone in the selected and isolated area (this is common between both scans) = Total volume of the selected area on the immediate postoperative scan – Volume of the bone graft (Y)

Volume of the consolidated bone at 6 months = Total volume of the selected area on the six months postoperative scan – Volume of the native bone (calculated by the previous equation)

The recorded volumes were then tabulated and the percentage change in the bone graft volume between the immediate and six months postoperative CT scans calculated (Table 2).

Statistical Analysis:

Statistical analysis was carried out to compare the horizontal and vertical dimensions of the reconstructed alveolar cleft immediately and six months postoperatively. The calculated means were first tested for normality using Shapiro-Wilk test. Accordingly, the data were statistically analyzed using paired t-test with a confidence level of 95%. The null hypothesis was that no significant difference existed between the immediate and six months postoperative horizontal and vertical alveolar ridge measurements. The percentage change in the alveolar ridge dimensions over the six months follow up period was then calculated.

TABLE (1) Immediate and six months post-operative bone graft linear measurements (Horizontal and Vertical) and the mean values of those measurements:

Patient		Immediate Postoperative (cm)		6 months postoperative (cm)	
		Mean		Mean	
1	H	1.329 1.301 1.213	1.281	1.068 1.058 0.887	1.004
	V	1.146		0.989	
2	H	1.228 1.538 1.085	1.284	1.051 1.074 0.781	0.969
	V	1.367		1.170	
3	H	1.856 1.502 1.858	1.739	1.308 1.17 1.108	1.195
	V	1.046		0.857	
4	H	1.168 1.069 0.745	0.994	0.928 0.830 0.512	0.757
	V	1.383		0.876	
5	H	1.248 1.167 0.943	1.12	1.075 0.984 0.724	0.928
	V	1.089		0.832	
6	H	1.52 1.338 1.113	1.324	1.646 1.479 1.224	1.450
	V	1.309		1.395	

H, Horizontal; V, Vertical

RESULTS

Our sample included 6 patients, four males and 2 females, of ages ranging from 9-11 years of age. Three of them had a previously operated palatal cleft with no remaining anterior palatal fistulas requiring further closure.

The raw data of all recorded measurements can be found in table 1. Patient number 6 showed some results dissimilar to the pattern of the other five patients and therefore was excluded from statistical analysis. Patient number 6 showed an increase in the linear (horizontal, vertical) and volumetric measurements.

The means of the horizontal and vertical dimensions of the bone-grafted alveolar cleft both immediately and six months postoperatively showed normal distribution according to Shapiro Wilk test. Accordingly, paired t test was used to compare the means of the immediate and six months postoperative CT alveolar dimensions.

For the horizontal (bucco-palatal) dimension: The overall mean obtained from immediately postoperative CT was 1.284 ± 0.282 cm compared to 0.971 ± 0.157 cm at six months postoperatively.

The horizontal dimension of the grafted alveolar cleft decreased by an average of 24.4% over the six months period. The difference between the means showed a highly statistically significant difference with a p value < 0.01.

As regards the vertical dimension of the grafted alveolar cleft, the overall mean obtained immediately postoperative was 1.206 ± 0.158 cm compared to 0.945 ± 0.139 cm six months postoperatively. The vertical dimension of the grafted alveolar cleft decreased by an average of 21.6% over the six months period. The difference between the means showed a statistically significant difference where p value was < 0.05.

Descriptive data of the volumetric measurements of the bone graft immediately and six months postoperatively could be found in table 2. Percentage change in volume ranged from -92.4% to +16%.

TABLE (2) Immediate and six months post-operative bone graft volumes and the percentage of volume changes seen within the particulate iliac crest bone grafts:

Patient	Bone Graft Volume Immediately Postoperative (cm³)	Consolidated Bone Graft Volume 6 months Postoperative (cm³)	Percentage Change in Graft Volume
1	1.418	0.107	-92.4 %
2	2.366	1.823	-22.9 %
3	1.812	0.983	-45.8 %
4	1.615	0.975	-39.6 %
5	1.982	1.248	-37 %
6	0.945	1.097	+16 %
Mean of All cases	1.690	1.039	-37.0%
Mean of 1st 5 cases	**1.839**	**1.027**	**-47.5%**

DISCUSSION

Different radiographic tools and methods have been used for assessment of reconstructed alveolar clefts using autogenous bone grafts. In the past years, reports shifted from the 2D methods of evaluation to the more sophisticated three dimensional ones, as it has been reported that intraoral (dental) radiographs could give over-estimated values for the actually formed bone that could reach 25% more bone formation than that measured using CT scans[11]. The same findings were published by Lee et al [14], who also mentioned the over-estimated bone formation of bone graft volume evaluated using intraoral radiographs.

Many studies in the literature included 2D assessment scales, among which are the Enemark grading system and the Bergland system [4, 10, 12, 13]. The former depends on assessing the marginal bone level between teeth on both sides of the grafted cleft while the latter on occlusal radiographs for recording the amount of bone fill. Being dependent on the erupted dentition, these couldn't have been applied to our sample as it necessitates the eruption of the sound erupted permanent teeth which is an ideal scenario not always available in our sample.

Different methods of 3D volumetric assessments were proven reliable[18]. Van der Meij[15] et al were among the first to quantitatively assess the volumetric changes seen on CT scans and the amount of resorption that took place, but using the lengthy manual procedure explained before. Tai et al[1], used the volumetric calculation tool in CT scan software, which allows only limited actions to be performed. While Feichtinger et al[16] utilized the navigation tool that is although accurate but might not be available for use in many institutions. The use of a third party surgical simulation softwares further enhanced the accuracy of assessment and is convenient and time saving, that's why it was chosen for the current study. Super-imposition and registration of the immediate postoperative CT scan onto the follow-up CT scan allows the operator visualize the outlines of 2D windows of both CT scans at the time and hence measuring the exact change in the bucco-palatal and vertical dimensions in the same cuts.

The volume needed for grafting the early secondary alveolar clefts in the current study ranged from 0.945 to 2.366 cm^3 with a mean of 1.039 cm^3. Similarly Feichtinger et al[15] reorted a needed volume of 0.7-1.7 cm^3 with a mean of 1.2 ± 0.34 cm^3. Janssen et al[17] reported the need for less bone of a mean of 0.83cm^3.

Tai et al[1] used between 0.9 to 3.6cm^3 of anterior iliac bone graft in his population which included bilateral cases in addition to unilateral cases all of which performed orthodontic maxillary expansion prior to the surgery, which may explain the higher mean of bone graft used in their cases. Both studies included immediate postoperative CT scans as a start for the follow-up period, while Watanabe et al[12] utilized a preoperative CT scan to calculate the amount of the needed graft to be harvested from the tibia, which was deemed unnecessary in our study, as secondary alveolar cleft patients usually have enough bone to be harvested from the anterior iliac crest for unilateral alveolar clefts. In the literature, presentation of 3D volumetric measurements following alveolar cleft reconstruction had been either in the form of the percentage of bone loss or the percentage of bone fill in the grafted cleft. The volumetric measurements in the current study revealed a 22.9- 92.4% bone loss of the actual bone graft, with a mean percentage loss of 47.5%, which is quite close to Tai et al[1] reporting a 43.1%, both evaluated 6 months postoperative . While Janssen et al[17] showed similar results presented differently, as they reported a 61% bone fill of the grafted clefts, which means that the percentage loss was 39.9% of the original graft volume, but this involved mandibular symphyseal bone grafts evaluated after one year of the surgical intervention.

Van der Meij[15] had less bone loss (30%) while Feichtinger et al[16] and Segura-Castillo et al[7] had higher values of bone resorption of 64% and 62.5% bone loss, respectively, although the follow-up period of the latter was 3 months.

Feichtinger et al[16] concluded that the outcome of alveolar bone resorption did not correlate to the severity of the case but due to the lack of functional physiological loading of the bone graft. This explanation sounded logical as the same finding we had, as the case which showed the maximal resorption was a simple case with no palatal cleft previously operated on, which makes the defect bounded by palatal bone. Perhaps if we have adopted longer follow up periods better chances of volume preservation due to eruption of the permanent canine teeth as proposed by Feichtinger et al[16] would have occurred.

As far to our knowledge, the only 2 clinical studies including linear measurements taken from post-operative CT scans, are that of Tai et al[1] and Marukawa et al[6] , but in contrast to the current study neither of the previous studies superimposed the CT scans to ensure that the taken measurements from which the change in dimensions is calculated is unified. As for the current study, the mean immediate postoperative horizontal dimension (bucco-palatal) was 1.28 ± 0.28 cm reaching 0.97±0.15 cm at 6 months with a 24.4% total loss, which was very close to that reported by Marukawa et al[6], where the horizontal loss was 24±1.41%, while that reported by Tai et al[1] was 0.9-2.7 cm with a mean of 1.17cm, and at the end of their follow-up period it reached 0.7-1.5cm with a mean of 1.17cm i.e there was a 29.9% loss in this dimension. The slight differences between the former 2 studies and the latter one, may owe to the longer follow-up period adopted by Tai et al[1] which was 12 months versus 6 months in the other study.

As regards the measurements of the vertical height, only a single coronal cut which lied in the middle of the graft was used with 3 adjacent measurements, from which the calculated mean mentioned in table 1 was driven. The reason why no other coronal cuts were used is that, the severe sloping of the nasal floor in the palatal dimension and the narrowing of the cleft would have affected the perception and interpretation of data. Vertical measurements of the bone grafts revealed a mean of 1.206 ± 0 .158 cm immediate post-operatively compared to 0.945 ± 0.139 cm six months postoperatively with a 21.6% decrease in the vertical measurements. Tai et al[1] on the other hand reported a mean of maximal bone heights of 1.1-2.5cm with a mean of 1.68cm in the immediate post-operative CT falling to 1.0-2.1 after 1 year, giving an average of 17.9% loss of height. The main factor that might have raised the mean heights in their sample is that their patients ranged from 6-16 years while our sample involved a younger age group of 9-11 years.

In our study the only excluded case was a case where there was an overall increase in all measurements (+16% in the bone volume, +0.11 cm in the horizontal and +0.09 cm in the vertical dimension) at 6 months post-operative. We owe this phenomenon to the maxillary growth spurt that could have happened, though it's a measure of success, as the graft was not just incorporated but also grew with the growth of the maxilla. The reason why we decided to exclude it is that it was considered an odd value that could have affected the mean percentage loss in our study. Honma et al[19] had similar findings and patients in which the formed bone exceeded the amount of bone graft were included in their results giving a mean volume change of 199% and 185% of the initial volume by 3 and 12 months post-operative successively.

Reports evaluating alveolar cleft patients vary greatly in the age range of the population enrolled in the studies, the type of graft used and the method of evaluation, this results in a great variation in the results one can face.

CONCLUSION

Radiographic assessment of alveolar cleft reconstruction using CT scans are useful tools, not just for making accurate measurements and better evaluation of the formed bone within the reconstructed alveolar cleft, but also it provides a useful tool for analyzing the outcomes of the secondary alveolar grafting procedure for future correlation and optimization of the whole grafting procedure and expected outcomes.

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