A Novel Approach to Assess and Measure Resorption of Allograft Cancellous Blocks. A Clinical Pilot Study

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ABSTRACT

Aim The aim of this pilot study was to evaluate the feasibility of a novel method in assessing the volumetric changes in block alveolar bone grafts following augmentation.
Methods The study utilised information from pre-surgical cone beam CTs, post-surgical cone beam CTs, and milled allograft blocks to evaluate the volumetric differences in ridge volume, and thus the volumetric resorption of the augmentation block. This process involved reformatting DICOM data to obtain STL files, and 3-dimensional voxel analysis of the aligned STL files.
In addition the study undertook surface mapping to obtain colorimetric maps depicting hotspots with increased resorption.
Results Four cases were assessed in total (with six block grafts). Block volume sizes varied between 614mm3 and 1674mm3. The results obtained suggest a mean block resorption at 4-months post- augmentation of 19.5%. This is comparable to existing published literature which has involved calculation of block resorption using analog means.
In addition, the method described was able to consistently show areas with increased resorption within the block volume at the 4-month timepoint.
Conclusion This novel method may be beneficial to investigate the treatment outcomes from alveolar block grafting with greater accuracy than previous methods, whilst also providing new information on the patterns of resorption within blocks.

KEYWORDS Osseointegration, resorption, block graft, dental implant.

INTRODUCTION

Alveolar bone grafting is a technique that involves using bone graft material to augment tissue volume in the mandible or maxilla. The graft material can be autogenous, allogenic, or xenogenic, and can be sourced from various body sites or donors. The graft material serves as a scaffold for new bone formation, which is initiated by the host cells and progresses through a series of cellular and molecular events. The intended outcome of the grafting procedure is the integration of the new bone with the host bone, leading to a stable and functional bone structure. The stability of the bone graft is essential to achieving a predictable clinical outcome(1–3).
The stability of alveolar bone following grafting has been extensively studied in both animal and human models.(1) The commonly utilised measures of bone graft stability include radiographic analysis,(1,4–6) clinical examination,(5,7,8) and histological evaluation.(5) Radiographic analysis, such as computed tomography (CT) or cone-beam computed tomography (CBCT), provides a quantitative assessment of bone thickness and density. Clinical examination includes the evaluation of the soft tissue contours, the presence of pain or discomfort, and the ability to chew and speak. Histological evaluation involves the examination of tissue samples obtained from the grafted site, which provides insights into the cellular and molecular events of bone regeneration.
Several studies have reported high success rates for alveolar bone grafting, with up to 95% of cases showing stable bone volume and density over a period of 5-10 years(2,9). The success rates vary depending on several factors, including the type of graft material used, the surgical technique,(10–14) the site of grafting(11,15,16), and the patient's systemic health status(17,18).
To date, radiographic analysis techniques have involved quantifying the stability of bone grafting material by manually aligning 2-dimensional cross-sections of radiographs and measuring ridge width and height.

We propose that three-dimensional analysis of block volumes as well as spatial analysis of blocks to determine patterns of resorption will provide useful additional information which may facilitate surgical planning.
As part of this pilot study, a novel technique to analyse the rate and pattern of resorption was used. This involved the alignment of pre- and post-surgical scans following data manipulation. Four patients treated at the Leeds Dental Institute were treated with a total of six allograft blocks.
This study aimed to provide a proof of concept for this technique to guide further research.

METHODS

Patient selection

For the purposes of this pilot study patients were selected consecutively. All patients for whom milled Allograft blocks would provide an alternative to autogenous block grafts for augmenting the alveolar ridge were approached for inclusion.
All patients were non-smokers. None of the patients had a history of bisphosphonate or anti-resorptive therapy, radiotherapy, or steroid use.

Surgical protocol

Patients underwent a pre-surgical cone beam CT scan before surgery, for implant planning. The resulting voxel data (DICOM) was processed, and 3D planning software was used to digitally design cancellous allograft blocks. These were harvested from the femoral heads of adult humans undergoing hip replacement surgery. They underwent the Allotec® process (Botiss, Cells+Tissuebank, Austria) which includes defatting, sterilisation and lyophilization. The bone blocks were milled using the computer-aided design described above.
The following surgical protocol was implemented:

- Augmentation bed preparation.
- Milled allograft block affixed to a recipient site with fixation screws.
- Minimally guided bone regeneration (GBR) with deproteinised bovine bone mineral (Geistlich BioOss®) at peripheries, if required. This was combined with a porcine pericardium-derived membrane (Jason® membrane, Botiss biomaterials).
- Periosteal release, buccal advancement and closure with non-resorbable sutures.

This protocol is clinically documented in Figure 1.
Loading of the grafts was avoided to prevent wound breakdown. This was removed by utilising temporary removable prostheses that did not impinge on the tissues, and by minimising prosthesis wearing. This involved relieving dentures to prevent compression of tissues at the grafted site. A risk of resorption is present if implant placement is not performed within 4 months(19). A post-surgical CBCT scan was completed 3 months following surgery.

Method of analysis

A novel approach was used to assess volumetric changes in the block. DICOM CBCT data from the pre-surgical and post-surgical scans was processed to remove extraneous scan information more than 1cm distant from the graft site. Scan windowing was completed using a standardised format to evaluate bone (cortical and cancellous). The DICOM data was converted to binary STLs and repaired to resolve non-manifold edges. STL data was imported into a custom software package to evaluate volumetric change as outlined below, and in Figure 2:

- CBCT STLs pre- and post-surgery were aligned using a verified and published best-fit algorithm(20).
- Accuracy of alignment was assessed manually by visually assessing the alignment of anatomy.
- The exported STL files were voxelised by creating image stacks (voxel size 25µm) using custom software written with OpenCV.
- Alignment was reassessed by evaluating the percentage of 25µm voxels which were aligned. More than 95% alignment was required to proceed(21).
- All scans aligned within the required accuracy (95%).
- Volumetric change was assessed using a per-voxel analysis.
- This volumetric change was compared to the initial block volume size (based on CAD planning).

RESULTS

Four cases were assessed in total (with six block grafts). Block volume sizes varied between 614mm3 to 1674mm 3. 50% of blocks had soft tissue breakdown at the wound edge during healing. This may be attributed to

FIG. 1 A) Recipient site preparation with a round bur prior to receiving a custom milled allograft block affixed with screws B) Positioning and fixation of bone block C) Primary soft tissue closure

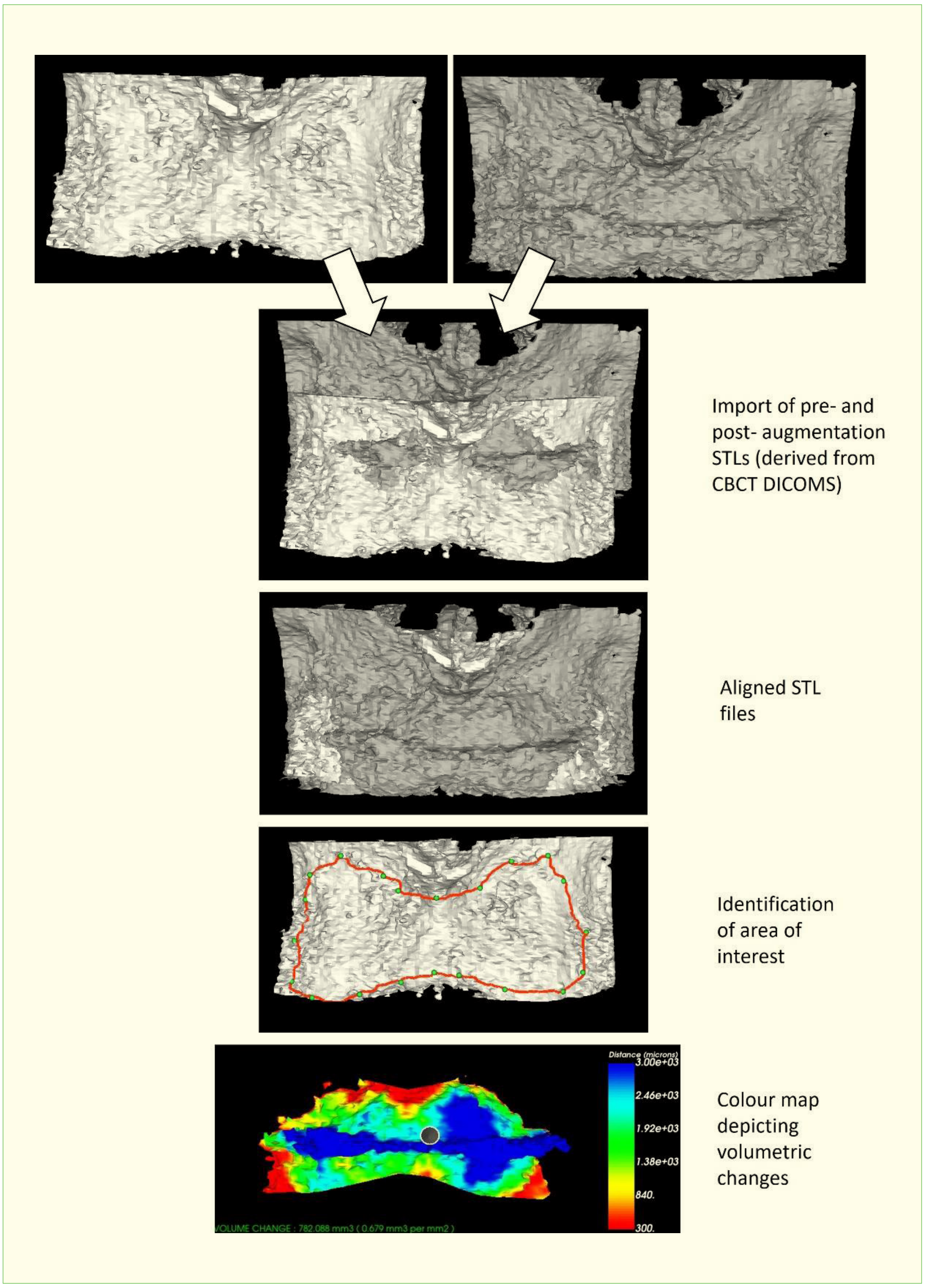

FIG. 2
Depiciting the method of importing pre- and post-augmentation STLs, alignment, identification of the area of interest, and graphical depiction of the volumetric changes in block volume.

the extent of augmentation required and the challenges associated with achieving adequate periosteal release. Soft tissue breakdown in all cases was managed with chlorhexidine irrigation and monitoring. The use of adjunctive antimicrobials involved one case. As a result of soft tissue breakdown, all cases affected required a delay in implant planning. Mean block resorption at implant planning (mean time between block placement and implant planning = 5 months) was 19.5%. This is concordant with published literature on the resorption and soft tissue complications following allogenic block grafts(22,23).

Qualitative evaluation of block resorption suggests that the pattern of resorption was complex in nature. Greater resorption was typically observed over the central and largest part of the block, which may correspond to the distance furthest from a vascular supply. This variation can be seen in the case depicted in Figure 3.

The percentage resorption data are summarised in Table 1.

DISCUSSION

The outcome of bone grafting procedures has been largely investigated with 2-dimensional measurements of bone thickness and height.(1) Whilst this technique has the potential to provide a good overview of the resorption process, it is challenging to perform accurate region-specific analysis using this method. It is also challenging

Case	Months between block placement and implant planning CBCT	Initial block volume / mm^3	Post-resorption block volume /mm^3	Percentage resorption
1	3.6	961.8	779.0	19.0%
2	8.2	1119.1	861.7	23.0%
3	8.2	614.8	504.1	18.0%
4	3.0	629.0	515.8	18.0%
5	3.0	651.1	546.9	16.0%
6	4.5	1674.1	1289.0	23.0%
Mean	5.1	941.7	749.4	19.5%

TABLE 1 Showing the mean allograft block resorption as calculated using 3-dimensional analysis

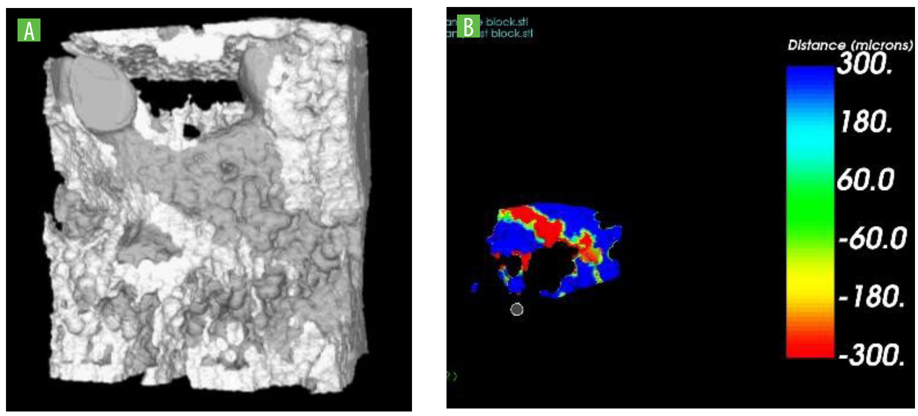

FIG. 3 A) Pre- and post- block grafting CBCTs aligned B) Heatmap in isolation showing the horizontal resorption of graft

to visualise the pattern of resorption. In addition, the traditional method of measuring resorption is time-intensive and prone to human error as it requires multiple measurements to be made manually following the alignment of successive CBCTs.

We have presented a novel technique for evaluating bone block resorption following augmentation procedures in the oral cavity. This new technique enables the calculation of the percentage of bone resorption, which has previously been estimated based on 2-dimensional measurements. The percentage resorption calculated is concordant with the literature reporting on percentage bone loss calculated from multiple 2-dimensional measurements. Further research is required to validate our technique with a larger patient cohort and the use of multiple measurement techniques per case. The proposed technique utilises automation to align scans. Following verification of this alignment, assessment of changes in volume is software-driven rather than being calculated manually. Furthermore, the use of post-alignment verification minimises the risk of error. This pilot has identified differing patterns of resorption, with more resorption in the central portion of the block graft. Information regarding the pattern of resorption may provide insights into regions where bone grafting procedures may be prone to increased block resorption or soft tissue complications. Additionally, this may support further advancement in bone block design. Whilst this requires further investigation with a study carrying sufficient statistical power, such findings may guide the development of improved bone grafting techniques and materials with improved graft stability and reduced complication rates.

This protocol will require validation against pre-existing techniques, and ratification from multiple centres prior to considering implementation in a wider research context.

CONCLUSION

This novel method of analysis, in the pilot phase, has demonstrated an ability to assess the resorption patterns of bone grafts. This technique may facilitate further analysis of the factors influencing the success of, and resorption related to, bone grafting procedures. Information regarding the pattern of resorption with different bone grafting biomaterials, surgical techniques and block sizes may be beneficial in ascertaining the optimal treatment strategy beyond the simplistic information associated with block thickness and augmentation dimension (horizontal and vertical).

Further testing of this technique is required on a larger scale to validate the proof of concept.

Contributions

J.P.: Research concept, design, oversight of clinical methods, statistical and digital analyses, manuscript preparation.
A.S., N.P., S.B.: Manuscript preparation, clinical treatment.

A.K.: Digital analysis and software production, manuscript preparation.

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