

Original Research Article

Quantum of cortico-cancellous bone safe for harvest from anterior iliac wing of pediatric patients: a finite element analysis with clinical correlation

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ABSTRACT

Background: Objective was to assess the maximum quantum of cortico-cancellous bone that can be harvested from the Anterior Iliac Wing (AIW) of paediatric population.

Methods: All patients reporting to the unit for the correction of bilateral cleft alveolus were included. A Computed Tomogram (CT) of the hip was recorded and the volume of cancellous bone available for harvest was assessed. Finite element model of the hip was generated using D2P and Geomagic Free form software and the impact of bone harvest on stress distribution along the anterior iliac wing was assessed by substituting the muscle forces (hip abductors and sartorius group) and was clinically correlated to volume harvested and donor site morbidities.

Results: 10 patients were enrolled, 5 patients were excluded. CT volumetric evaluation revealed an average 0.5 cc to 4.7 cc of cancellous bone and 6.7 cc to 11 cc of cortical bone was available for harvest. Harvest of 50% of available graft volume was safe with minimal stress distributed along the line joining the tuberosity to the area between Antero Superior and Inferior spines (4.2 MPa at rest and 18.5 MPa at stance). The stress levels increased with increase in volume of bone harvested. Intra operatively 1.9 cc to 6.2 cc of cortico cancellous graft was harvested, which was equivalent to 60% of the graft available with no long-term morbidities.

Conclusions: The volume of bone graft harvest should be restricted (up to 6 cc) to avoid long term morbidities.

Keywords: Anterior iliac wing, Bone graft, Cancellous bone graft, Finite element analysis, Pediatric pelvis

INTRODUCTION

Osseous maxillofacial reconstruction is extremely demanding due to its pivotal role in facial aesthetics and function of the stomatognathic system.¹ Reconstructive options often range from free bone grafts to microvascular free flaps.² Autogenous bone graft are considered the gold standard reconstruction for small maxillofacial defects.³ The anatomical variations, quantum of graft available, complication rates are the primary factors that determine choice of donor site. Anterior iliac wing (AIW) has received greater popularity for maxillofacial reconstruction considering the quantum of bone graft available and low complication rates.⁴

However pediatric population needs special addressal, considering the varied anatomy that restricts the quantum of bone that can be harvested. Apart from this, the cartilagenous apophyses act as areas of weakness which can undergo spontaneous fractures under the influence of physiologic muscle contraction.⁵⁻⁸ Harvest of bone graft in this population may further weakens the cortical shell that may interfere with the transmission of load to the axial skeleton leading to chronic complications. Thus it is essential to understand the anatomical constraints of paediatric hip bone in relation to the surrounding muscular anatomy to assess the safe volume of bone that can be harvested with minimal morbidity in these patients. The aim of the study was to evaluate the

quantum of cortico-cancellous bone that can be harvested from the paediatric (AIW) by Finite element analysis (FEA) with clinical correlation.

METHODS

A prospective study was conducted in the department of Maxillofacial Surgery SRMDC Chennai including all the patients who reported to us for bilateral cleft alveolar bone grafting from December 2016 to December 2017 with informed consent of their parents. The approval for the study was obtained from the Institutional Review Board (SRMDC/IRB/2017/MDS/NO.408). Adult patients, patients with unilateral cleft alveolus, patients with medical co-morbidities and noncompliant were excluded.

Pre-operative orthopantomogram (OPG) and maxillary occlusal radiograph were recorded to assess the extent of the alveolar defect. A pre-operative CT pelvis was performed (0.6 mm thickness, 128 slice with Siemens AS plus CT machine) to assess the volume of the bone graft available for harvest.

Volumetric evaluation of the graft available in the AIW within the following boundaries: 1 cm inferior to iliac tuberosity superiorly, 1 cm superior to anterior superior iliac spine(ASIS) inferiorly, point of fusion of medial and lateral cortices posteriorly, lower border of the cartilaginous cap anteriorly, medial cortex medially and lateral cortex was assessed. FEM evaluation of hip bone was performed after substitution of the muscle forces (The Hip Abductor Muscle (HAM) and sartorius-semi-tendineous group). The FEM process involved conversion of DICOM CT Images to printable (Steriolithographic STL) format using D2P software (Figure 1) where in segmentation of the cortical and cancellous bone was done (Figure 2).

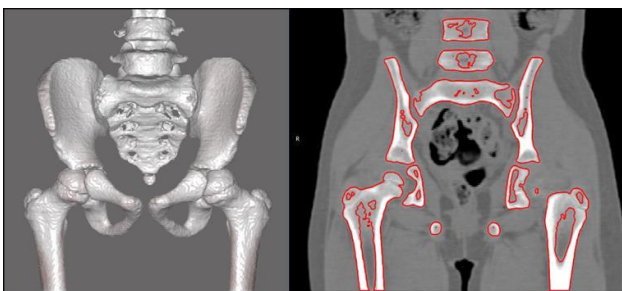


Figure 1: DICOM to STL model.

The STL model (stereo lithographic) was then imported into geomagic freeform software with haptic device to calculate the volume of bone in the AIW within the foresaid boundaries. Multiple planes were created to mimic the harvest pattern (mono cortical with cancellous (50% harvest and 100% harvest) and bicortical). The model was then divided into small element for finite element analysis, a process is called discretization. Element size of 0.8 mm with the 10 node tetrahedral

element type was applied with total number of 22, 86, 302 nodes in all the 3 axis (Figure 3).

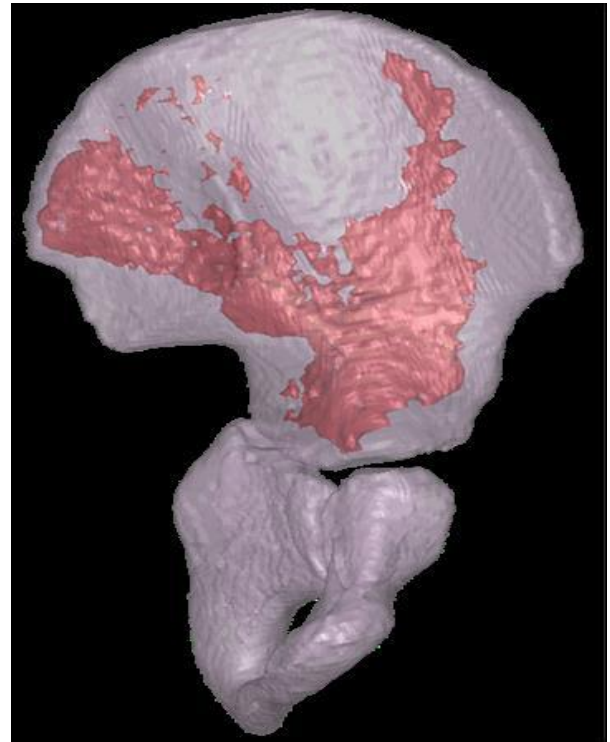


Figure 2: Cancellous and cortical segmentation.

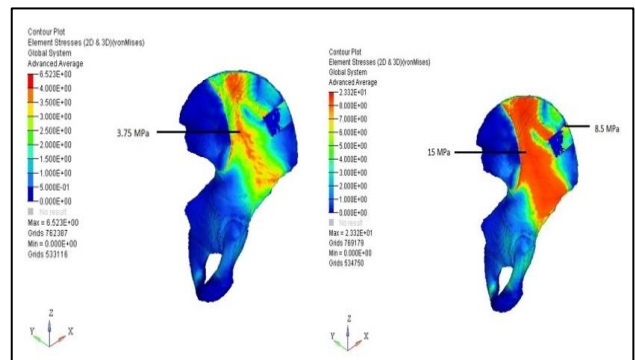


Figure 3: Load case 1: 50% corticocancellous bone harvest at rest and activation.

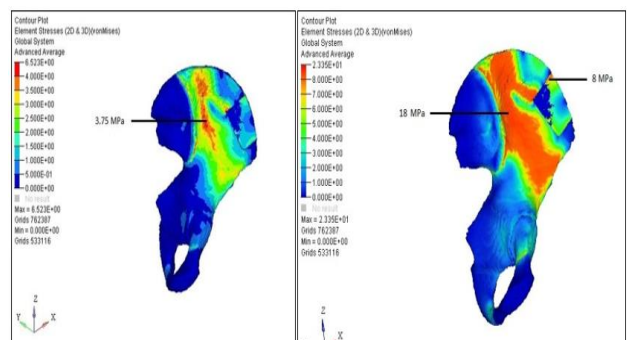


Figure 4: Load case 3: 100% cortico-cancellous bone removal at rest and activation.

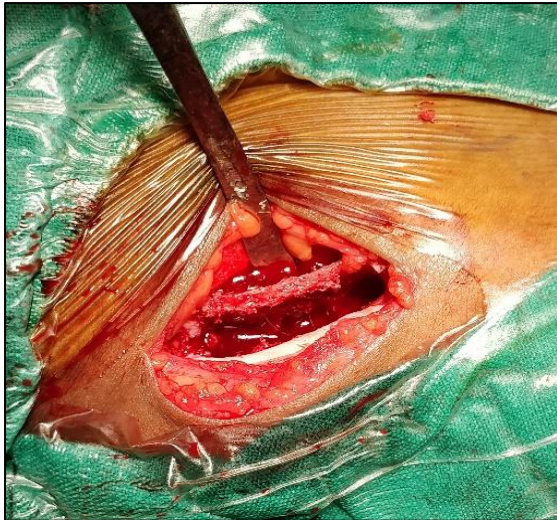


Figure 5: Graft harvest-donor site.



Figure 6: Graft harvest-recipient site.

he force of HAM group acting on the crest and lateral cortex that form the external moment arm were generated based on the individual body weight using Donald A. Neumann’s method and forces acting on the ASIS by Sartorius and Semitendinous were substituted.^{9,10} The pattern of stress that developed in the pediatric AIW at

rest and activity at 50% and 100% harvest of graft was assessed (Figure 4-6). This was correlated with the volume of graft harvested intra-operatively and post-operative complications were recorded.⁸

RESULTS

A total number of 10 patients were enrolled. 5 patients were excluded from the study based on the exclusion criteria. 5 patients (4 male and 1 female) within the age group of 7 to 14 years were included in the study. The average weight of the patients was 25 kg to 39 kgs. The volume of cancellous bone available within the foresaid landmarks was 0.5 cc to 4.72 cc. The volume of cortical bone (medial cortex) amongst these patients ranged between 6.7 cc to 11 cc. The average depth of fusion of the medial and the lateral cortices from the cartilaginous margin of the crest ranged between 23mm to 36 mm. These results are tabulated in Table 1.

Forces produced by Sartorius-semitendineous group and HAM were substituted in the FEM model. The average quantum of force (HAM) acting on the intact AIW at rest ranged between 288-445 N and this increased to 953-1469 N on stance with uniform stress distributed across the iliac wing which was transmitted to sacroiliac joint and the pubic symphysis.

Harvest of 50% of the available cortico-cancellous bone lead to the increase in stress along a tangential line joining the ASIS to the iliac tuberosity with maximum stress between the ASIS and the AIIS (load case 1: average 4.2 MPa (range 3 MPa to 4.8 MPa). This stress level increased to an average of 18.5MPa at stance (Load case 2: range 14.45 to 19.8 MPa). Harvest of the 100% available cortico-cancellous bone volume (mono cortical) (at rest-Load case 3) increased the stress to 5.4 MPa (Load case 3: range-3 MPa to 10 MPa) which increased to 19.6 MPa (Load case 4: range 15 to 28 MPa) during stance (Table 2). Maximum stress distribution was noticed to extend from the superior margin of harvest to ASIS (Table 2).

Harvest of bicortical graft lead to increase in the stress along the same region from 22-23 MPa at rest to 51-54 MPa on activation (Table 2).

Table 1: Illustration of the volume of bone available and harvested from anterior ilium.

S. no	Age of patients (years)	Patient weight (in Kg)	Depth of fusion of the medial and lateral cortices from the iliac crest (mm)	Volume of cancellous bone available (cc)	Volume of cortical bone available (cc)	Volume harvested from anterior ilium for simultaneous ABG intra operatively (corticocancellous) (cc)
1	12	31	26	2.05	11.19	2.5
2	15	39	36	1.51	18.85	3.9
3	14	39	33	4.72	6.71	6.2
4	11	27	25	2.17	11.14	4.98
5	7	25	23.5	0.50	7.12	1.9

Table 2: HAM forces and pattern of stress distribution.

Patient	HAM force at rest	HAM force on activation	Stress distribution at rest 50%	Stress distribution at rest 100%	Activation after 50% bone harvest	Activation after 100% bone harvest
1	385.02 N	1270.5 N	3.75 MPa	3.75 MPa	15 MPa	18 MPa
2	420.3 N	1387 N	6 MPa	10 MPa	25 MPa	28 MPa
3	288.9 N	953.6 N	22 MPa	23 MPa	51 MPa	54 MPa
4	288.9 N	953.5 N	4.88 MPa	4.85 MPa	19.85 MPa	17.5 MPa
5	445.19 N	1469 N	3 MPa	3 MPa	14.45 MPa	15 MPa

Clinical correlation

The volume of cancellous bone available was inadequate hence cortico-cancellous (with medial cortex) bone of 1.9 to 6.2 cc was harvested in all cases (Table 1). This was equivalent to almost 60% of the total quantum of graft available within the pediatric AIW. Mild gait disturbances in the form of limping were noted on the first post-operative day that settled to normal gait by post-operative day 4. Patients reported pain on the first three post-operative days that was addressed with NSAIDS. None of the patients reported chronic pain or gait disturbances.

DISCUSSION

AIW is considered the workhorse for maxillofacial reconstruction due to the technical ease. However it is also associated with untoward post-operative sequel that may range from chronic pain to permanent gait disturbances however, the causes of these have seldom been discussed in the literature.¹¹⁻¹⁵ Unusual complications in the form of fracture of ASIS, crestal apophysis also have been reported after the harvest of graft from AIW.^{13,14} This was attributed to the forceful contraction of the muscle groups abutting the weakened AIW.¹⁵

Assessment of the stresses that develop on the AIW after the graft harvest will provide a baseline evidence to the foresaid hypothesis and will aid in understanding the response of AIW to the graft harvest. FEM study by Louis et al and Kureria et al on adult pelvis reveal that physiologic load during rest and stance is primarily transmitted by intact cortical shell to the sacro-iliac joint and pubic symphysis.¹⁶⁻¹⁷ Disruption of the integrity of cortical shell interferes with the load transmission to the pelvic buttresses. This was supported by Schmitz et al who reported that harvest sub-crestal bicortical grafts in adults lead to increase in the stress between the ASIS and the anterior edge of the harvest site with lack of normal pattern of stress distribution to the posterior iliac wing.¹⁸

Pediatric AIW may behave differently under similar circumstances considering the anatomical variations.¹⁹ This is obvious from our study as harvest of bicortical grafts in contrary to adults leads to increase in the stress to 54 MPa which is beyond the threshold of transverse

load bearing ability of the intact cortex as described by Herman et al.²⁰ This may predispose the crestal fractures as described previously.⁵

Considering the foresaid discussion it is certain that harvest of graft in pediatric population essentially weakens the residual bone. We hypothesized that the chronic pain that has been described in the literature may be the response of muscle guarding in relation to the quantum of bone harvested. This can be supported by a study by Rendenbach et al who reported that harvest of DCIA flaps may lead to restricted mobility of the hip joint in all the three planes secondary to the muscle guarding.²¹ Hence it is essential to restrict the quantum of graft harvest to avoid untoward complications in paediatric population. Restricting the quantum of graft harvest to 50% of the volume available by preoperative CT evaluation, respecting the anatomical constraints of the Pediatric hip bone, maintaining the integrity of the cortical shell are essential to avoid these untoward complications.

Future studies to aim at correlating the post-operative complications of bone harvest from the (pediatric/ adult) AIW with the quantum of harvest, the approach used and the anatomical/physiological considerations of the pediatric AIW to minimize the morbidity associated with graft harvest.

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Conflict of interest: None declared

Ethical approval: The study was approved by the Institutional Ethics Committee

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