Computer-Aided Design Evaluation of Harvestable Mandibular Bone Volume: A Clinical and Tomographic Human Study

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ABSTRACT

Purpose: To evaluate and compare the volume of bone graft material that can be safely harvested from the mandibular symphysis and rami using a computer-aided design (CAD) software program.

Materials and Methods: Preoperative computerized tomography scans from 40 patients undergoing bone augmentation procedures were analyzed. Symphysis and rami cross sections were mapped using a CAD software program (AutoCAD®, Autodesk, Inc., San Rafael, CA, USA) to evaluate the bone volume that can be safely harvested. CAD calculations were contrasted to intrasurgical measurements in a subgroup of 20 individuals.

Results: CAD calculations yielded a safe harvestable osseous volume of 1.44 $cm^3 \pm 0.49$ for the symphysis and 0.82 $cm^3 \pm 0.21$ for each ramus ($p < .0001$, confidence interval [CI] 95%: 0.47–0.78). These measurements were significantly lower ($p < .0001$) than the bone volumes harvested intrasurgically for both symphysis and ramus, respectively (2.40 $cm^3 \pm 0.50$ vs. 2.65 $cm^3 \pm 0.45$). CAD calculations of harvestable symphysis and ramus bone translated into an average of 2.40 $cm^3 \pm 0.50$ (range: 1.80–3.10 cm^3) and 2.65 $cm^3 \pm 0.45$ (range: 1.90–3.50) of particulate bone graft intrasurgically, respectively. Ramus cortical was significantly thicker than the symphysis cortical, 2.9 ± 0.4 mm versus 2.19 mm $\pm$ 0.4 mm ($p < .0001$, CI 95%: 0.45–1.03).

Conclusion: The symphysis and rami are good harvesting sources to obtain dense corticocancellous bone. The significant volumetric CAD differences between the symphysis and ramus seem to balance out intrasurgically and may be due to the greater cortical bone volume at the ramus area. It is plausible to harvest an average of 7.70 cm^3 from the symphysis and rami alone. The use of a CAD software program can enhance surgical treatment planning prior to bone transplantation.

KEY WORDS: bone graft, bone regeneration, bone transplantation, computer-aided design, mandible, volumetric computed tomography

INTRODUCTION

Patients seeking implant rehabilitation of edentulous areas frequently present with deficient ridges and pneumatized sinuses. In such cases, hard and soft tissue reconstruction and sinus augmentation are often necessary for functional and esthetic implant rehabilitation. A variety of materials are available for bone grafting, including the following: intraoral and extraoral autologous bone, and bone substitutes such as allografts, xenografts, and alloplast.[1–3]

Intramembranous autologous bone transplants are considered the gold standard because they contain the proper concentration of specific growth factors for that particular individual.[4–6] Intraoral bone autografts present several advantages such as minimal resorption, good volume maintenance, and high concentration of bone morphogenetic proteins.[4–7] The most frequently utilized sources of such bone harvesting are the mandibular ramus and symphysis.[7–9] Both provide a dense cortical bone and high concentration of promoter proteins.

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Cone beam computerized tomography (CT) scans are an invaluable tool in diagnosis and treatment planning for bone harvesting, assessing donor site repair, and dental implant therapy.[8–14] CT scans are also a very accurate means of assessing long-term healing and osseous volume stability of autografts after implant therapy.[12–14]

The aim of the present study was to quantitate and compare the preoperative volume of mandibular ramus and symphysis bone graft available for harvesting, after entering CT scan cross sections into a computer-aided design (CAD) software program. Moreover, this study aimed at comparing the above presurgical volume measurements with those taken intrasurgically.

MATERIALS AND METHODS

A total of 40 consecutive patients, 17 males and 23 females, undergoing bone augmentation procedures and no osseous pathologies associated (age range 31–82 years) entered this study. Enrolment took place between January 2007 and December 2010. All patients had unremarkable medical history. The present study was conducted in accordance with the Helsinki Declaration of 1975, as revised in 2000, and all subjects provided informed consents prior to therapy. CT scans of the mandibular ramus and symphysis were analyzed using a design software program (AutoCAD®, version 16.0, Autodesk, Inc., San Rafael, CA, USA). AutoCAD is a CAD software application used in architecture, construction, and manufacturing. The method has been explained elsewhere.[8,9,11] Briefly, cross-sectional images were imported into the software program file (Figure 1, A–C). Each 1-mm cut was mapped by a polyline (see Figure 1, B and C). For the mandibular symphysis, 5-mm safety margins were outlined caudal to the apices of the anterior teeth, cephalad to the inferior border of the mandible, and anterior to both mental foramens. For the ramus, the measurements extended from the midaspect of the first mandibular molar (external

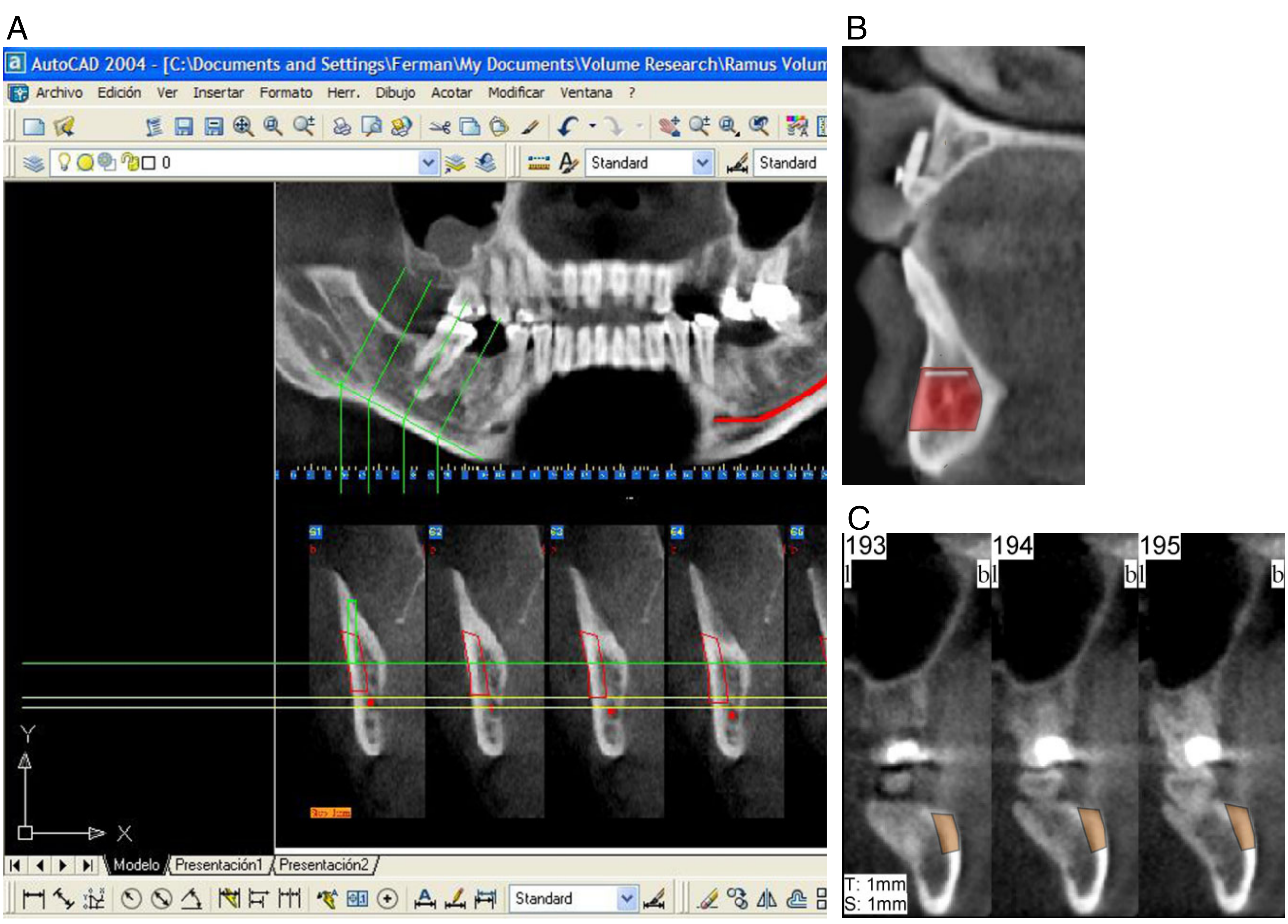


Figure 1 *A*, AutoCAD calculations after entering computerized tomography scan cross sections into the software program. *B*, Symphysis donor site cross section: area of interest demarcated in red. *C*, Ramus donor site cross sections: area of interest demarcated in brown.

oblique ridge) toward the ascending ramus (midway between the third molar area and the mandibular foramen); apically, they extended 5 mm before reaching the inferior alveolar canal. First, the surface area of each mapped polyline (see Figure 1, B and C) and then the volume of each 1-mm-thick cross section were measured. The total harvestable volume was calculated by adding the consecutive cuts. Moreover, linear measurements of cortical thickness were taken at the symphysis, parasymphysis (midline and canine areas), and ramus/external oblique ridge area (second molar area/ascending ramus). Measurements were performed by the same calibrated examiner (R.S.M.). The examiner underwent a period of repetitive training to achieve a reproducibility of measurements of 98%.

In a subgroup of 20 individuals, the volumes of harvested bone were measured intrasurgically using a sterile graduated cylinder (Figure 2) with 0.5-cm^3 markings. One cubic centimeter of saline solution was added into the cylinder to fill in the particle voids and thereafter, subtracted from the final volume following the principle of displacement volumetry.[15]

Preoperative and intrasurgical bone volume values were analyzed and compared.

Figure 2 Calibrated cylinder used to measure particulate bone after harvesting.

Statistical Analysis

Descriptive analysis of data was expressed as mean ± standard deviation. A commercially available software program (SPSS®, version 14.0, SPSS Inc., Chicago, IL, USA) was used to evaluate volumetric differences between the symphysis and ramus harvesting areas. Box plot graphics were drawn to compare mean volume values. The Student's *t*-test was used for paired observations to assess volumes of harvestable bone. Statistical significance was set at $p < .05$.

RESULTS

A total of 40 consecutive CT scans were analyzed. Patients' mean age was 47 years (range: 31–82 years) and comprised 17 males and 23 females.

Mean harvestable symphysis bone volume (Tables 1 and 2) calculated from preoperative CT scans and excluding the lingual cortex was 1.44 cm^3 ± 0.49 (range: 0.53–2.84 cm^3). If the 5-mm safety margins were included in the calculations, the bone volume increased to 2.3 cm^3 ± 0.70, range: 0.8 to 4.4 cm^3 ($p < .0001$). For the ramus area, the mean harvestable bone was 0.82 cm^3 ± 0.21 (range: 0.42–1.31) per side or a total of 1.64 cm^3 for both rami. The volume difference between chin and ramus donor sites (1.44 vs. 0.82 cm^3) was statistically significant ($p < .0001$). Figure 3A shows the symmetric distribution for both groups.

CAD calculations of harvestable symphysis and ramus bone (1.44 vs. 0.82 cm^3, see Table 1) translated into an average of 2.40 cm^3 ± 0.50 (range: 1.80–3.10 cm^3) and 2.65 cm^3 ± 0.45 (range: 1.90–3.50) of particulate bone graft intrasurgically, respectively ($p = .21$).

The buccal cortical thickness at the second molar/ramus area averaged 2.9 mm ± 0.4 (range: 2.1–4.3 mm). The mean buccal cortical thickness at the midline symphysis area was 2.19 mm ± 0.4 (range: 1.1–3.0 mm). The mean buccal cortical thickness at the canine parasymphysis area was 2.10 mm ± 0.4 (range: 1.7–3.1 mm). The differences in cortical thickness (see Figure 3B) between the second molar/ramus area and the symphysis/parasymphysis area were statistically significant ($p < .0001$).

DISCUSSION

The present study aimed at measuring and comparing the preoperative volume of mandibular ramus and symphysis bone graft available for harvesting purposes in a group of 40 patients undergoing augmentation

TABLE 1 CAD Calculations of Harvestable Bone Volume: Symphysis versus Ramus Donor Sites

	Chin Volume 1	Ramus Volume	Chin Volume 2
1 M	1.75	1.11	2.75
2 F	0.53	0.63	0.86
3 M	1.44	1.16	1.97
4 F	1.35	0.58	1.76
5 F	1.34	0.77	1.99
6 F	1.38	0.59	1.92
7 F	1.54	0.67	2.27
8 F	1.36	0.98	1.94
9 M	0.82	1.31	1.59
10 F	1.25	0.65	1.74
11 F	1.04	0.97	1.88
12 M	2.15	0.96	3.72
13 F	1.12	0.86	1.75
14 M	2.18	0.79	3.65
15 M	1.56	0.65	1.97
16 F	1.45	0.89	2.14
17 F	0.68	0.98	1.25
18 F	1.08	0.78	1.54
19 F	1.32	0.67	2.24
20 F	1.45	0.57	2.84
21 F	1.06	0.74	1.68
22 M	0.68	0.67	1.92
23 F	1.98	1.16	2.83
24 M	1.2	0.91	1.85
25 M	1.07	0.94	1.68
26 M	1.59	0.88	2.54
27 M	1.68	0.42	2.75
28 F	0.95	0.76	1.62
29 M	0.8	1.05	2.73
30 M	1.71	0.65	2.58
31 M	1.69	1.17	2.49
32 F	2.43	0.86	3.62
33 F	1.48	0.59	2.47
34 F	2.43	0.75	3.73
35 M	1.62	0.51	2.54
36 M	1.69	0.67	2.53
3 M	2.84	1.25	4.43
38 F	1.35	0.79	2.04
39 F	1.57	0.77	2.83
40 F	1.09	0.74	1.51
Mean*	1.44	0.82	2.30

*Volumes are in cubic centimeter. Volume 2 = 5-mm safety margins included.
Differences between volumes were statistically significant ($p < .0001$).
CAD = computer-aided design; F = female; M = male.

procedures. It, moreover, aimed at comparing the above volumetric preoperative calculations with those taken intrasurgically. Preoperative measurements were performed by combining CT scan cross sections and a CAD software program (AutoCAD).

CAD calculations yielded a safe harvestable bone volume of $1.44\ cm^3 \pm 0.49$ for the symphysis and $0.82\ cm^3 \pm 0.21$ for each ramus ($p < .0001$). The above calculations were significantly lower ($p < .0001$) than the volumes harvested intrasurgically for both the symphysis ($2.40\ cm^3 \pm 0.50$) and ramus ($2.65\ cm^3 \pm 0.45$). The above data should be taken into consideration in treatment planning sinus or ridge augmentation procedures. Moreover, CAD calculations showed that buccal ramus cortical plates (see Figure 3B; Figure 4A) were significantly thicker than symphysis cortical plates (see Figure 4B), 2.9 ± 0.4 mm versus 2.19 mm ± 0.4 mm, respectively ($p < .0001$). Thicker cortical ramus plates seemed to compensate for the lower tomographic volume. Invariably, volumetric CAD software programs seem to underestimate the amount of particulate graft material available from intraoral donor sites for augmentation purposes.

Cone beam CT (CBCT) scans seem to be reliable diagnostic tools to evaluate linear and volumetric measurements.[16,17] A recent systematic review found CBCT devices to be accurate and reliable to perform three-dimensional analysis of the upper airway.[17] However, the present study used a combination of both CBCT and CAD (AutoCAD) to calculate presurgical volumes.[8,9] Measurement accuracy seems to be more operator dependent when using CBCT devices.[16] In the present study, measurements were performed by the same calibrated examiner who underwent a period of repetitive training to achieve a high reproducibility rate of 98%.

There seems to be a tendency toward obtaining higher particulate osseous volume when a thicker cortical plate is present. This is particularly true for the mandibular ramus.[8,9] Rajchel and colleagues examined cross sections of 45 adult dried undamaged mandibles with no absent teeth.[18] The thickest buccal cortical plate reported was 2.3 mm ± 0.7 for the second molar area at the level of the inferior alveolar canal. They did not report the crestal cortical thickness. The present study has shown thicker cortical plates at the crestal portion of the ramus/external oblique ridge area as compared with the more apical portion of the inferior alveolar canal reported by Rajchel and colleagues.[18] Clinically, ramus/

TABLE 2 CAD versus Intrasurgical Calculations of Harvestable Bone Volume and Cortical Thickness at Donor Sites: Symphysis versus Ramus

	Symphysis	Ramus	*p* Value
CAD Vol 1	1.44 $cm^3 \pm 0.49$	0.82 $cm^3 \pm 0.21$	$p < .0001$
CAD Vol 2	2.3 $cm^3 \pm 0.70$	N/A	N/A
Particulate*	2.40 $cm^3 \pm 0.50$	2.65 $cm^3 \pm 0.45$	$p = .21$
Cortical thickness	2.19 mm ± 0.4	2.9 mm ± 0.4	$p < .0001$

*Particulate = intrasurgical bone volume.
CAD Vol = computer-aided design software program bone volume; N/A = not applicable; Vol 1 = volume of harvestable bone excluding the safety margins; Vol 2 = volume of harvestable bone including the 5-mm safety margins.

external oblique ridge grafts present significantly thicker buccal cortical plates than the symphysis area that has more cancellous bone (see Figure 4, A and B).

A morphometric analysis of implant-related anatomy reported a volumetric outcome for the symphysis donor site similar to the present study.[19] The aforementioned study used 22 dry skulls and performed osteotomies at the symphysis area to harvest two separate blocks, preserving the midline cortical. The average volume for both blocks was 1.7 cm^3; CT scan analysis or panoramic radiography, which was used to locate anatomical landmarks, was not reported. The present study is also in agreement with previous volumetric CT scan calculations for the ramus/external oblique area, yielding an average of 0.80 to 0.85 cm^3.[9,10]

Age could be a potential factor affecting osseous density and cortical thickness.[20] Bone density seems to have great interindividual variability and research has shown that mandibular apparent bone density is significantly increased with age and dentate status.[20] Moreover, mandibular density values seem to be significantly higher than postcranial sites (iliac crest, lumbar area, and femoral neck) and should not be used to extrapolate and generalize bone density status in elderly humans.[21]

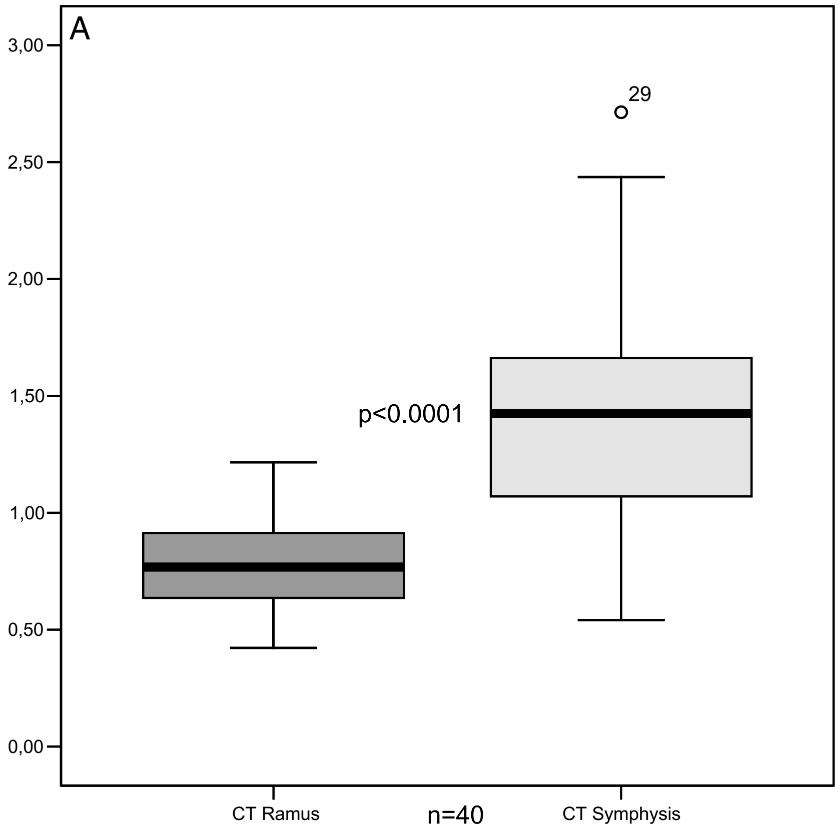
In terms of osseous healing, a recent study showed no significant differences in bone fill between patients older than 50 years and younger ones.[11] The aforementioned study population had an average age of 42.6 years and a range of 20 to 70.[11] A different study has shown that patients older than 33 years had less favorable mandibular osseous healing and poorer bone density at 12 months after cyst removal.[22]

Osseous transplants of ectomesenchymal origin, such as the mandibular symphysis or ramus, seem to have enhanced potential for intraoral adjustment due to the biochemical similarity in the protocollagen component of the donor and recipient areas.[23,24] Moreover, their cortical nature and micro-architecture is associated with improved transplant survival and superior maintenance of their volume.[25,26]

Intramembranous ossification is characterized by the formation of osseous tissue without the intermediate stage of cartilage formation.[6,27,28] Experimental studies suggest that bone transplants from intramembranous ossification and ectomesenchymal origin (maxillofacial skeleton) are associated with less resorption than those from endochondral ossification (long bones).[23,24]

From an osteoinductive point of view, autologous osseous transplants are the gold standard in the reconstruction of dento-alveolar ridge deficiencies.[4–6,27,28] In vitro studies using multipotent progenitor cells, osteoprogenitor cells, osteoblasts, chondroblast, and osteosarcomatic cells have shown that bone morphogenetic proteins induce or inhibit cell proliferation depending on cell types and culture conditions.[4,5] The highest concentration of promoter proteins (bone morphogenetic proteins or osteogenin), which induce the transformation of pluripotent mesenchymal stem cells into osteoblasts during the transplant healing process of osteoinduction, is found in dense intramembranous cortical bone from the mandibular symphysis, ramus, and calvaria.[4,5]

CT scan analysis prior to bone harvesting from the symphysis or ramus areas can prevent potential damage to vital structures such as the inferior alveolar nerve or apices of anterior teeth. Severing the blood supply of these teeth, the mental or incisal nerve will lead to neurosensory disturbances, paresthesias, and/or pulp necrosis. The most common adverse events reported are temporary hypoesthesia and altered sensation for a particular stimulus after block harvesting.[29,30] Perforating



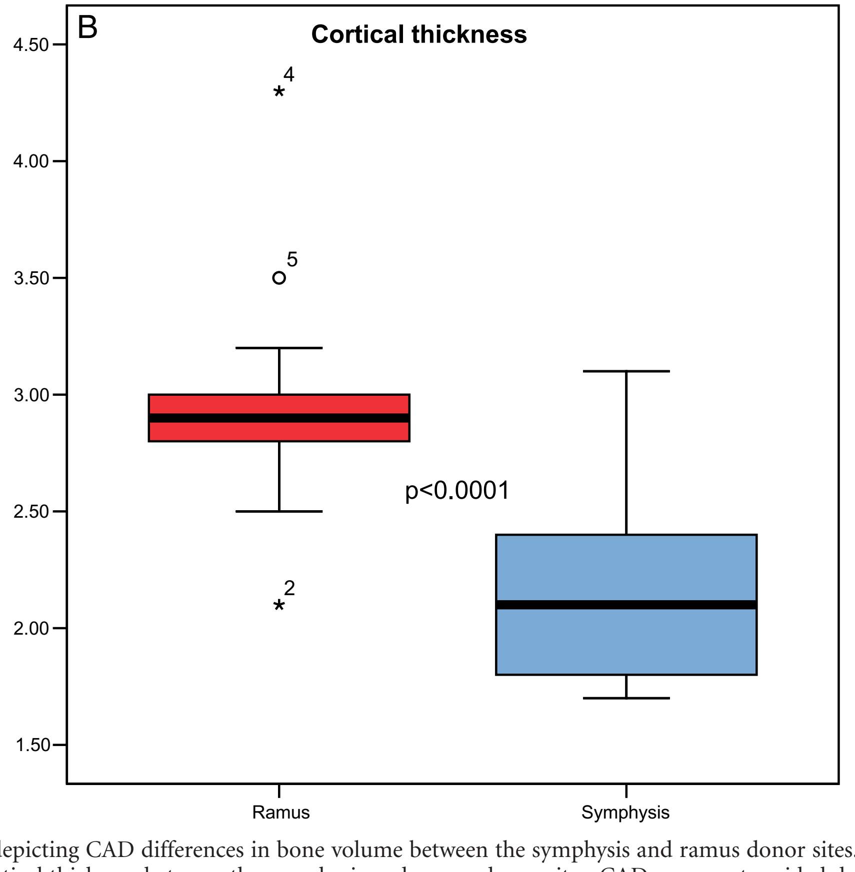


Figure 3 *A*, Box plot depicting CAD differences in bone volume between the symphysis and ramus donor sites. *B*, Box plot depicting CAD differences in cortical thickness between the symphysis and ramus donor sites. CAD = computer-aided design; CT = computerized tomography.

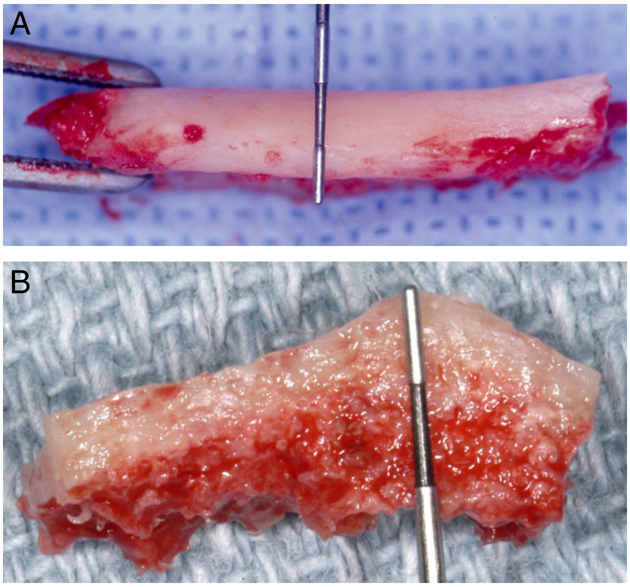


Figure 4 *A*, Ramus block after harvesting. *B*, Symphysis block after harvesting.

the lingual cortex and entering the sublingual spaces are other potential complications that could occur if the correct buccolingual symphysis width is unknown. A preoperative CT scan analysis will aid in anticipating the amount of bone volume that can be harvested and in avoiding the aforementioned complications.

Clavero and Lundgren[29] followed a pool of 53 patients who underwent symphysis or ramus graft surgery. Fifteen (52%) of the 29 symphysis graft subjects still presented decreased sensitivity and had permanent altered sensation at 18 months. A recent long-term retrospective study showed postoperative sensitivity of the lip, teeth, and gingiva after symphysis block harvesting.[30] Only 7.6% of the patients developed impaired tactility and sensitivity of the soft tissues and 1% apical pathology. The radiographic donor site evaluation using lateral cephalograms in a subgroup of 45 patients showed good remineralization in 42 of the sites (93.3%). The authors concluded that the rate of subjective symptoms seemed to be higher than the clinical findings and did not affect the patient's daily life.[30] In the present study population, paresthesias were associated to those cases where incisions were performed on alveolar mucosa, apical to the mucogingival line. No apical pathology around the mandibular teeth has been observed at 14 months.

The outcome data from the present research should be interpreted with caution due to the small sample size (40 patients) of the study population. Further volumetric research, using larger numbers of individuals and comparing potential age differences, is granted.

CONCLUSIONS

The mandibular symphysis and ramus/external oblique ridge are good harvesting sources to obtain dense corticocancellous bone. Thicker cortical ramus plates seem to compensate for lower tomographic volumes. The significant volumetric CAD differences between the symphysis and ramus balance out intrasurgically. Volumetric CAD software programs underestimate the amount of particulate graft material available from intraoral donor sites for sinus or ridge augmentation. It is plausible to harvest an average of 7.70 cm^3 from the symphysis and rami alone. The use of a CAD software program may improve surgical treatment planning prior to bone transplantation.

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