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Research Article

3D-CT assessment of mandibular widths in young subjects with different underlying vertical facial patterns

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ABSTRACT

Aim: This study was undertaken to evaluate the relationships among dental arch widths, mandibular bone widths, and masseter muscle dimensions in growing children with different underlying vertical facial patterns using three-dimensional computed tomography (3D-CT).
Method: Fifty-eight young subjects (32 male and 26 female) with a mean age of 13.27 (±1.59) years had undergone cranial CT examinations as part of medical diagnosis. 3D-CT images were reconstructed for the assessment of various mandibular dental and bone widths in relation to the vertical facial pattern and masseter muscle dimensions.
Results: The cross-sectional area and volume of the masseter muscle, mandibular plane angle, total posterior face height and lower posterior face height were significantly different among the vertical pattern groups. There were a number of significant positive and negative correlations among the muscular dimensions and the dental and bone widths with the different vertical patterns.
Conclusions: Dolichofacials are likely to have relatively smaller masseter cross-sectional areas and volumes than brachyfacials, and vice versa. There is likely to be a close association between mandibular intermolar width and the corresponding widths at the apical and lower border levels. There is not likely to be the same association between the intercanine width and the corresponding lower border width. Brachyfacials are likely to have a greater width of buccal cancellous bone through which the canines can potentially be expanded laterally.

1. Introduction

The so-called “bone-growing” theory was first advocated by Angle [1]. This theory was used to support his nonextraction approach to the relief of dental crowding. Some years later, Lundström [2] proposed the apical base concept, separating the dentoalveolus and the apical base at the level of the root apices. He advocated that the size and shape of the supporting basal bone are largely under genetic control and would determine the limit to which the dental arch might be expanded. He warned that attempted movement beyond this limit would result in instability after alignment, as well as future periodontal problems. Later, Tweed [3] and Riedel [4] strongly suggested that alignment is more likely to be stable if the teeth have been positioned over basal bone. Others, still, have recommended that there should be some balance between the teeth and the surrounding orofacial musculature [5,6].

Although many previous workers have attempted to assess the relationship between stability and the maintenance or otherwise of various interdental widths, there is still no real evidence to set guidelines for sound attempts to expand arches in individual orthodontic patients. Some of those workers have attempted to determine various pretreatment measurements that might help clinicians decide whether a particular mandibular arch should be expanded or not. These have included the depth of incisal overbite [7], Angle’s molar classification [8], and the amount of pretreatment crowding [7]. More recently, the interaction between the underlying vertical facial pattern, the size and orientation of the masseter and other mandibular muscles, and individual craniofacial proportions has been highlighted [9–11]. An inverse relationship between the mandibular plane angle and various transverse arch dimensions has also been reported [12].

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Although an association between mandibular cortical bone thickness and vertical facial pattern has been found [13], little if any computed tomography (CT) imaging has been used to assess the range of mandibular bone transverse widths in the different vertical patterns. There is also the question of whether this imaging technique might provide a novel approach to examining interactions that might exist between the height and width of the mandibular dentoalveolus and the dimensions of the underlying basal bone. With all this in mind, this study was undertaken 1) to confirm whether volume and cross-sectional area of the masseter muscle are directly related to the vertical facial pattern; 2) to determine if transverse mandibular dentoalveolar widths are directly related to the vertical facial pattern; and 3) to determine if transverse mandibular basal bone widths are directly related to dental arch dimensions.

2. Materials and methods

2.1. Sample selection

The gathered sample consisted of three-dimensional (3D) cranial CT images of 32 male and 26 female subjects with a mean age of 13.27 (±1.59) years, all of whom had undergone cranial CT examinations for various medical diagnostic reasons, over approximately an 8-year period. The existence of the records originally became known to the authors by chance. The sample includes some of the patient records assessed in a previous study [11]. All patient families had previously signed institutional informed-consent documents for diagnostic 3D-CT imaging to be undertaken. Approval for the subsequent anonymous use of these historical images and the data gathered from them for this study was given by the Royal Melbourne Hospital Research Ethics Committee. Most subjects would still have been growing when the images were taken and had no documented facial malformations. All had either late mixed or permanent dentitions, with erupted first permanent molars. The only formal inclusion criterion then was the need for both mandibular permanent canines to have erupted. At this stage, the range of individual vertical facial patterns was not yet known.

2.2. CT imaging technique

The SOMATOM Sensation 16 (Siemens Medical Solutions AG, Erlangen, Germany), a multislice helical CT scanner, had been used for all radiographic examinations. The technique was described to the authors, as follows. Anatomically, the region extending from below the inferior border of the anterior mandible to the level of the anterior cranial base had been scanned. Similar to the needs of orthodontic or orthognathic surgery assessment, each subject lay in a supine position with the head positioned so that vertical contiguous slices could be performed (i.e., parallel to the orthodontic Frankfort horizontal plane). The slice thickness of each axial image was 2 mm with 1.5-mm overlap. For this study, multiplanar reconstructions of 3D-CT images were then recreated using Amira, version 5.2.0 imaging software (Thermo Fisher Scientific, Waltham, Massachusetts, USA).

2.3. Assessment of the vertical facial pattern, gonial angle and muscle orientation

Using the Amira program, the right lateral profile of the patient was viewed and analyzed. With the viewing modality preselected to view osseous structures, the 3D craniofacial image was manipulated, as necessary, to orient it to the Frankfort horizontal plane, so that the head posture would be bilaterally symmetrical relative to the sagittal and coronal planes. The mandibular plane angle, gonial angle and facial heights were then recorded for each subject. From these first measurements, it was obvious that there was a wide range of individual vertical patterns. The total sample was therefore divided into three vertical subgroups based on the measured mandibular plane angle: brachyfacial (<22°), mesofacial (22 to 29°), and dolichofacial (>29°). All measurements made in this study are listed in Table 1.

2.4. Assessment of the cross-sectional area and volume of the masseter muscle

The cross-sectional area (CSA) of the right superficial masseter muscle was also assessed with the use of the Amira program. The CSA of the masseter muscle was calculated perpendicular to its mean fiber direction. The default window level for analysis was modified when deemed appropriate, to gain the most accurate representation of the muscle outline. The cross-section of the right-side muscle was then traced digitally and analyzed. The mean of three repeated CSA measurements taken from the same axial slice was used to represent the true muscle cross-section. The CSA of the masseter was taken at the midpoint between its origin and insertion. The muscle volume measurement was based on the sum of 3D-CT image voxels selected to represent the right masseter muscle. The muscle outlines from sequential axial slices were digitally traced from origin to insertion (Fig. 1). Each slice represents a volume of muscle equal to its CSA multiplied by the slice interval or thickness.

2.5. Assessment of mandibular dental and bone widths

For the assessment of mandibular bone widths, several slices were generated to enable correct orientation. As illustrated in

Table 1
Measurements used in this study

W6MF, W6MF: Mandibular width at the first molar, measured between buccal cortices at the level of the molar furcation
Canc6MF, Canc6MF: Buccal cancellous width at the first molar, measured at the level of the molar furcation
W6MA, W6MA: Mandibular width at the first molar, measured between buccal cortices at the level of the molar apex
Canc6MA, Canc6MA: Buccal cancellous width at the first molar, measured at the level of the molar apex
W6IB, W6IB: Mandibular width at the first molar, measured between buccal cortices at the inferior border of the mandible
Intermolar width: Distance between bilateral first molar mesiobuccal cusps
W3MF, W3MF: Mandibular width measured the canine, measured between buccal cortices at the level of the molar furcation
Canc3MF, Canc3MF: Buccal cancellous width at the canine, measured at the level of the molar furcation
W3MA, W3MA: Mandibular width at the canine, measured between buccal cortices at the level of the molar apex
Canc3MA, Canc3MA: Buccal cancellous width at the canine, measured at the level of the molar apex
W3IB, W3IB: Mandibular width at the canine, measured between buccal cortices at the inferior border of the mandible
Intercanine width: Distance between bilateral canine incisal tips
angle, Canine angle: Viewed from the front, the angle formed between the canine and the line across the inferior border of the mandible
MnP, MnP: Angle formed between the Frankfort horizontal and the Gonion-Menton plane
Gonial angle: Angle formed between the Articulare-Supragonion and Gonion-Menton planes
TAFH, TAFH: Distance from Nasion to Menton, measured perpendicular to the Frankfort horizontal
LAFH, LAFH: Distance from ANS to Menton, measured perpendicular to the Frankfort horizontal
LAFH/TAFH: Ratio of the lower anterior face height to the total anterior face height
TPFH, TPFH: Distance from Sella to Gonion, measured perpendicular to the Frankfort horizontal
Vol, Vol MM: Masseter muscle volume, calculated from the sum of 3D-CT image voxels
CSA, CSA MM: Cross-sectional area of the masseter, measured perpendicular to the mean fiber direction at the midpoint between origin and insertion

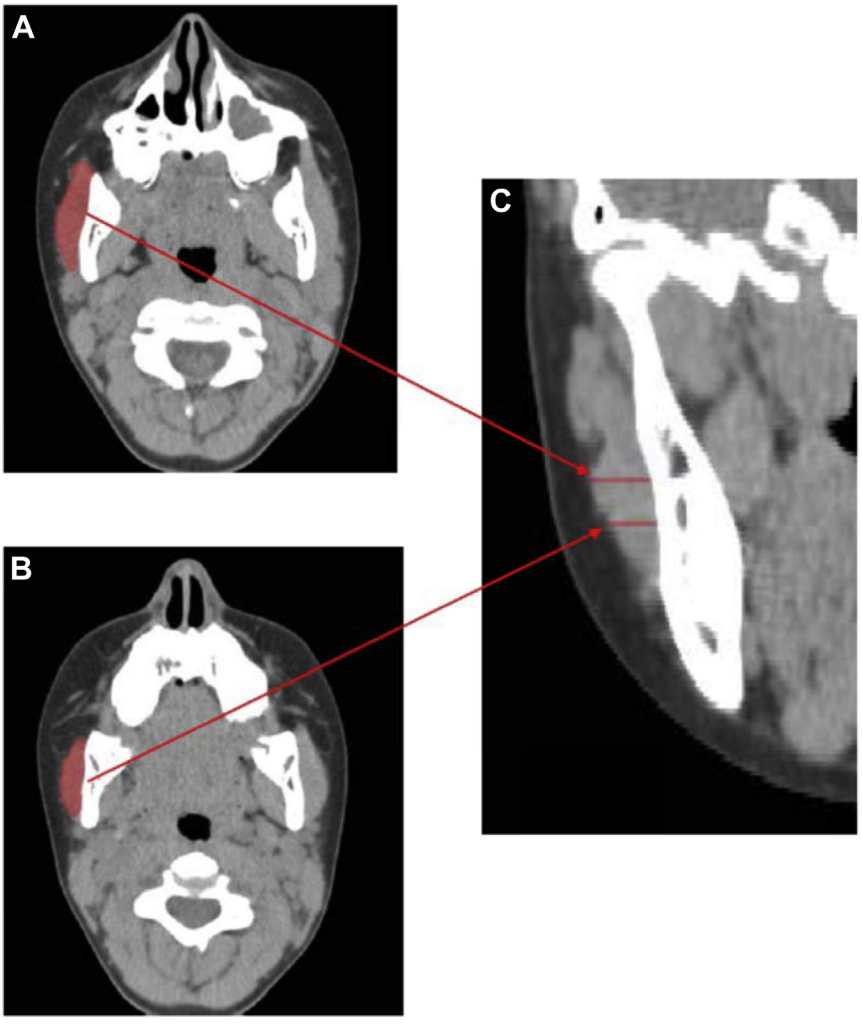

Fig. 1. Estimation of masseter muscle volume. (A) and (B) Superior views of two cross-sectional slices of right masseter muscle, (C) frontal view.

Figure 2, an axial slice was created parallel to the occlusal plane of the mandibular dentition. An *oblique coronal molar* slice was created for all measurements relating to molar bone dimensions (Fig. 3). It traversed the mesiobuccal cusp and mesial root apex, bilaterally. Similarly, an *oblique coronal canine* slice was created for all measurements relating to canine bone dimensions. The slice traversed the tip of the canine cusp and root apex bilaterally (Figs. 4 and 5). All measurements were recorded digitally using the Amira program in both the axial and coronal planes to enhance accuracy. For each patient, points were digitally located on the cusp tips of canines and the mesiobuccal cusp tip of the first molar. Intercanine width and intermolar width were then directly measured digitally. In addition, from the frontal view, the angle formed between the canine and the inferior border of the mandible was measured (Fig. 6).

2.6. Analysis of measurement error and statistical analyses

To determine the error of landmark location and measurement, six randomly chosen 3D-CT measurements were repeated 30 days later. The standard measure of error as described by Dahlberg and the coefficient of reliability were both calculated [14]. Analysis of the error of measurement showed a high coefficient of reliability. Descriptive statistics were calculated for all measurements. Differences in the mean measurements for the three vertical facial subgroups were analyzed with analysis of variance. The least significant

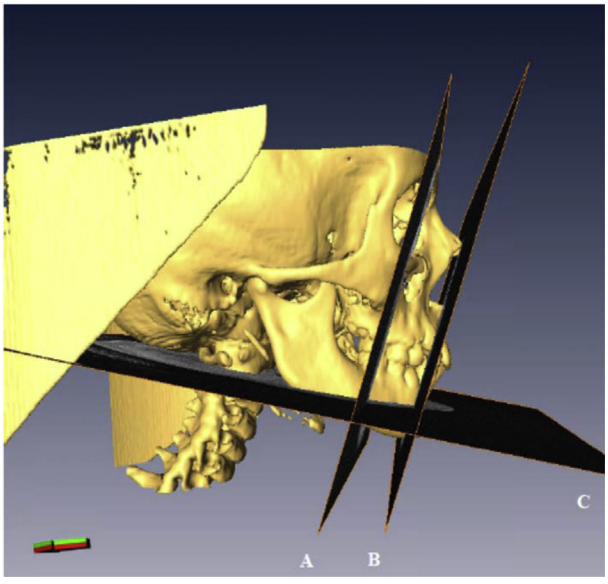

Fig. 2. Occlusal plane and oblique molar and canine plane slices. (A) Oblique molar slice, (B) oblique canine slice, (C) occlusal plane slice at the level of the molar apex.

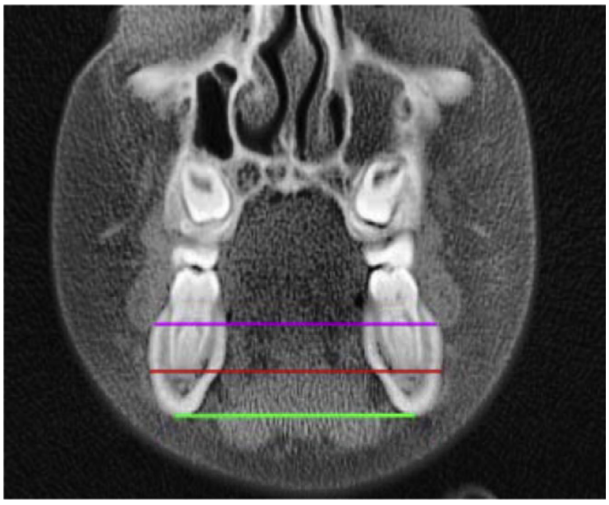

Fig. 3. Transverse mandibular bony dimensions in the molar region W6MF molar furcation level W6MA molar apex level W6IB inferior border level.

difference test was applied to measurements at which *P* values were found to be significant. Pearson's coefficients of correlation were also calculated for these variables. Differences in the measured variables in male and female individuals were analyzed with T-tests. Statistically significant results were set at the level of $P \leq 0.05$.

2.7. Radiation from CT

The radiation dose level was calculated for four randomly selected patients. The average radiation dose level was 0.37 mSv (±0.04 mSv).

3. Results

3.1. Muscle and general cephalometric measurements

Masseter muscle dimensions and various cephalometric measurements for the sample and its subgroups are presented in Table 2. As shown in Table 2, the means for CSA and volume of the masseter muscle, mandibular plane angle, gonial angle, total posterior face height and lower posterior face height were found to be significantly different among the vertical subgroups. However, there was wide individual variation within all groups. Means for all measurements were similar for male and female individuals within this sample of largely growing subjects.

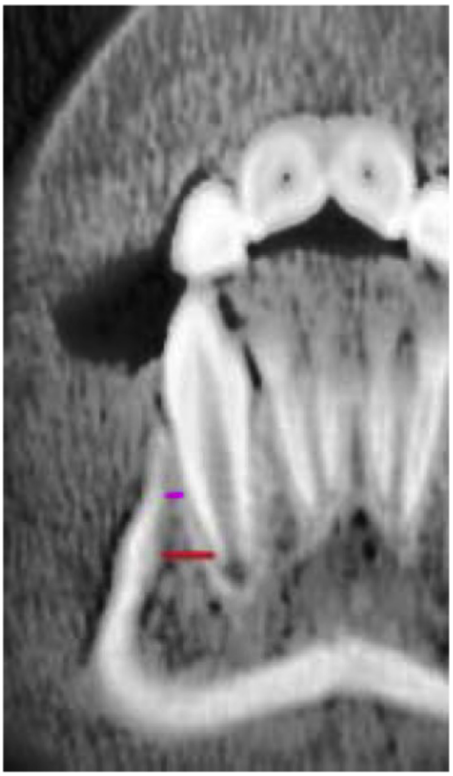

Fig. 5. Width of cancellous bone in the canine region Canc3MF molar furcation level Canc 3MA molar apex level.

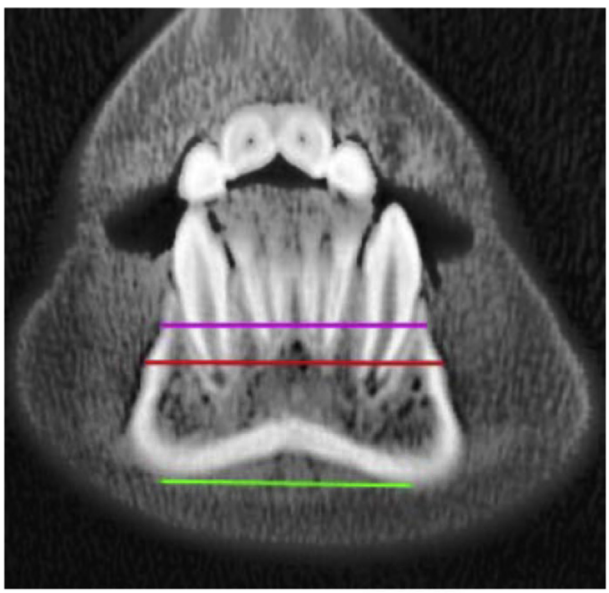

Fig. 4. Transverse mandibular bony dimensions in the canine region W3MF molar furcation level W3MA molar apex level W3IB inferior border level.

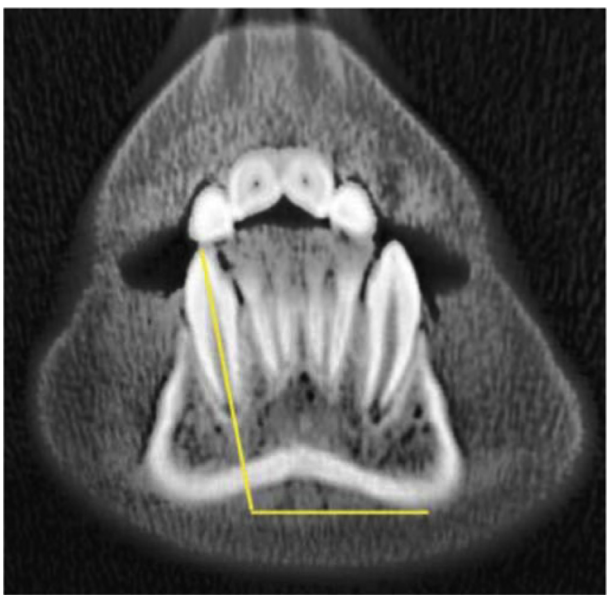

Fig. 6. Canine angle measurement.

Table 2
Sample characteristics

	n	Age, y					Mandibular plane angle, degrees					Gonial angle, degrees				
		Mean	SD	Min	Max	Signif	Mean	SD	Min	Max	Signif	Mean	SD	Min	Max	Signif
Total sample	58	13.27	1.59	11.63	15.08	N.S.	25.14	4.57	18.00	32.70	[a]	121.12	6.98	108.00	135.90	[a]
Male	32	13.00	1.63	11.63	15.08	N.S.	24.54	4.26	18.00	32.20	N.S.	121.12	8.20	108.00	135.90	N.S.
Female	26	13.60	1.53	11.83	14.92	N.S.	25.88	4.99	18.30	32.70	N.S.	123.82	5.45	113.10	129.60	N.S.
Brachyfacial	22	13.32	0.95	12.08	13.92	N.S.	20.25	1.55	18.00	21.68	[a]	116.25	5.44	108.00	125.80	[a]
Mesofacial	22	14.10	1.49	12.33	15.08	N.S.	26.22	1.58	23.40	28.80	[a]	120.62	5.98	113.40	133.90	[a]
Dolichofacial	14	12.88	1.73	11.63	13.67	N.S.	31.11	1.27	29.00	32.70	[a]	127.99	5.96	119.40	135.90	[a]

	CSA masseter, cm^2					Volume masseter, cm^3					TAFH, cm				
	Mean	SD	Min	Max	Signif	Mean	SD	Min	Max	Signif	Mean	SD	Min	Max	Signif
Total sample	3.43	0.48	2.24	4.71	[a]	16.77	2.28	10.02	21.08	[a]	10.95	0.67	9.82	12.15	N.S.
Male	3.41	0.51	2.24	4.71	N.S.	17.30	2.02	13.20	21.08	N.S.	11.17	0.58	10.13	11.98	N.S.
Female	3.45	0.46	2.67	3.98	N.S.	16.11	2.47	10.02	19.20	N.S.	10.67	0.68	9.82	12.15	N.S.
Brachyfacial	4.71	0.33	3.20	4.71	[a]	19.07	1.49	16.12	21.08	[a]	10.75	0.65	9.82	11.70	N.S.
Mesofacial	3.48	0.51	2.86	3.94	[a]	16.62	1.99	13.20	19.20	[a]	11.23	0.60	10.39	11.98	N.S.
Dolichofacial	3.10	0.44	2.24	3.96	[a]	13.94	2.61	10.02	17.96	[a]	10.80	0.73	9.98	12.15	N.S.

	LAFH, cm					LAFH/TAFH, %					TPFH, cm					LPFH, cm				
	Mean	SD	Min	Max	Signif	Mean	SD	Min	Max	Signif	Mean	SD	Min	Max	Signif	Mean	SD	Min	Max	Signif
Total sample	6.19	0.53	5.00	7.21	N.S.	0.56	0.03	0.51	0.61	N.S.	6.97	0.58	5.43	8.96	[a]	3.75	0.48	1.68	5.83	[a]
Male	6.40	0.33	5.53	6.82	N.S	0.57	0.02	0.53	0.61	N.S.	7.16	0.48	6.24	7.77	N.S.	3.86	0.41	3.21	4.55	N.S.
Female	5.93	0.63	5.00	7.21	N.S.	0.56	0.03	0.51	0.60	N.S.	6.73	0.63	5.43	8.96	N.S.	2.98	0.54	1.68	5.83	N.S.
Brachyfacial	6.04	0.53	5.00	6.59	N.S.	0.56	0.03	0.51	0.60	N.S.	7.93	0.43	6.50	8.96	[a]	4.95	0.50	3.29	5.83	[a]
Mesofacial	6.39	0.36	5.74	6.82	N.S.	0.57	0.02	0.55	0.61	N.S.	7.11	0.48	6.26	7.72	[a]	3.78	0.32	3.35	4.55	[a]
Dolichofacial	6.12	0.72	5.36	7.21	N.S.	0.57	0.03	0.52	0.60	N.S.	6.02	0.49	5.43	7.23	[a]	2.98	0.51	1.68	4.42	[a]

CSA, cross-sectional area; LAFH, Distance from ANS to Menton, measured perpendicular to the Frankfort horizontal; LPFH, lower posterior face height; Min, minimum value; Max, maximum value; N.S., not significant; SD, standard deviation; Signif, significance; TAFH, distance from Nasion to Menton, measured perpendicular to the Frankfort horizontal; TPFH, total posterior face height.
[a] $P \leq 0.05$ significant differences in means.

3.2. Measurements at the first molar

The transverse arch and bony dimensions of the mandible at the first molar (Fig. 3) are presented in Table 3. As shown in Table 3, there were no significant differences between the means for male and female individuals in intermolar width or the various mandibular widths, measured at the molar furcation, and apical and inferior border levels. Similarly, there were no significant differences in the mean widths at the first molar for any of these measurements among the three vertical subgroups. There was wide individual variation within all groups, with very large molar widths in some brachyfacials and relatively small molar widths in some dolichofacials.

3.3. Measurements at the canine

The transverse arch and bony dimensions of the mandible at the canine (Figs. 4 and 5) are presented in Table 4. As shown in Table 4, there were significant differences in the means for the vertical pattern subgroups for buccal cancellous width (the amount of cancellous bone lateral to the canine root), measured both at the level of the molar furcation and at the lower level of the molar apex. No differences were found in the mean widths at the canine in male and female individuals. Once again, there was wide individual variation in widths at the canine in all groups. For interest only, a comparison of cross-sectional images through the canines, from two obviously brachyfacial and dolichofacial

Table 3
Transverse arch and bony dimensions of the mandible at the first molar

	n	Intermolar width, mm					Mandib width, furcation, mm					Mandib width, apex, mm				
		Mean	SD	Min	Max	Signif	Mean	SD	Min	Max	Signif	Mean	SD	Min	Max	Signif
Total sample	58	44.47	3.08	35.48	49.60	N.S.	57.33	3.36	50.61	64.48	N.S.	68.27	4.60	55.44	76.28	N.S.
Male	32	45.42	2.74	40.88	49.60	N.S.	58.40	2.85	53.88	64.48	N.S.	70.03	3.76	63.97	76.28	N.S.
Female	26	42.30	3.16	35.48	47.28	N.S.	56.01	3.58	50.61	63.09	N.S.	68.12	4.75	55.44	73.77	N.S.
Brachyfacial	22	44.99	3.09	39.48	49.60	N.S.	57.34	3.39	51.55	64.48	N.S.	69.22	3.91	62.07	74.03	N.S.
Mesofacial	22	44.88	2.28	40.93	48.38	N.S.	57.65	2.91	53.88	63.09	N.S.	69.05	4.07	62.59	76.28	N.S.
Dolichofacial	14	42.01	4.03	35.48	48.53	N.S.	56.82	4.35	50.61	61.67	N.S.	65.56	5.85	55.44	74.40	N.S.

	Mandib width, inferior border, mm					Bucc cancel width, furcation, mm					Bucc cancel width, apex, mm				
	Mean	SD	Min	Max	Signif	Mean	SD	Min	Max	Signif	Mean	S.D	Min	Max	Signif
	57.74	4.37	50.08	65.73	N.S.	3.88	1.32	1.18	5.30	N.S.	4.62	1.19	3.02	7.11	N.S.
	58.70	4.47	52.35	65.73	N.S.	3.08	1.65	1.42	5.30	N.S.	5.11	1.22	3.66	7.11	N.S.
	56.56	4.11	50.08	65.44	N.S.	2.89	1.46	1.18	4.66	N.S.	4.13	1.01	3.02	6.79	N.S.
	59.30	4.42	52.35	65.73	N.S.	3.66	1.94	1.33	5.30	N.S.	5.28	1.22	3.94	7.11	N.S.
	56.86	4.44	50.08	64.54	N.S.	2.87	1.33	1.18	4.67	N.S.	5.33	0.84	3.02	6.76	N.S.
	56.68	4.06	51.69	63.97	N.S.	3.04	1.41	1.61	4.94	N.S.	4.57	1.23	3.21	6.44	N.S.

S.D, standard deviation; Min, minimum value; Max, maximum value; N.S., not significant ($P < 0.05$).

Table 4
Transverse arch and bony dimensions of the mandible at the canine

	n	Intercanine width, mm					Mandib width, furcation, mm					Mandib width, apex, mm				
		Mean	SD	Min	Max	Signif	Mean	SD	Min	Max	Signif	Mean	SD	Min	Max	Signif
Total Sample	58	26.39	2.30	19.23	30.75	N.S.	32.98	2.06	28.56	36.93	N.S.	38.42	6.26	29.65	63.69	N.S.
Male	32	27.15	1.69	24.36	30.75	N.S.	33.91	1.74	30.94	36.93	N.S.	39.33	3.11	33.51	45.04	N.S.
Fem6ale	26	24.46	2.65	19.23	29.50	N.S	31.85	1.90	28.56	35.83	N.S.	37.30	8.77	29.65	63.69	N.S.
Brachyfacial	22	26.72	1.97	22.94	30.75	N.S.	33.16	1.46	31.18	35.48	N.S.	40.48	8.84	31.75	63.69	N.S.
Mesofacial	22	26.51	1.19	24.36	28.16	N.S.	33.11	2.09	30.39	35.83	N.S.	38.45	3.35	33.51	43.08	N.S.
Dolichofacial	14	24.68	3.87	19.23	30.60	N.S.	32.51	2.95	28.56	36.93	N.S.	35.14	3.68	29.65	41.04	N.S.

Mand width, inf border, mm					Canine angle, degs					Bucc cancel width, furcation, mm					Bucc cancel width, apex, mm				
Mean	SD	Min	Max	Signif	Mean	SD	Min	Max	Signif	Mean	SD	Min	Max	Signif	Mean	SD	Min	Max	Signif
31.17	5.34	23.08	46.28	N.S.	96.69	4.47	85.10	104.80	N.S.	4.66	1.31	2.10	7.21	N.S.	6.03	1.24	2.96	10.22	N.S.
32.30	5.10	23.08	46.28	N.S.	96.79	4.70	85.10	104.70	N.S.	4.89	1.55	3.02	7.21	N.S.	6.15	1.22	4.66	10.22	N.S.
29.78	5.51	24.03	43.86	N.S.	96.58	4.37	89.70	104.80	N.S.	4.58	1.09	2.10	6.74	N.S.	5.65	1.30	2.96	7.22	N.S.
32.66	6.70	25.19	46.28	N.S.	98.41	3.24	94.80	104.70	N.S.	5.33	1.31	3.88	7.21	[a]	8.42	1.16	7.03	10.22	[a]
30.68	4.55	23.08	36.18	N.S.	95.63	4.76	85.10	101.00	N.S.	4.82	1.41	3.04	6.46	[a]	5.58	1.20	3.97	8.21	[a]
29.61	4.09	25.77	36.67	N.S.	95.02	5.26	90.90	104.80	N.S.	2.97	1.40	2.10	5.22	[a]	4.07	1.03	2.96	5.28	[a]

Bucc, buccal; Mandib, mandibular; Min, minimum value; Max, maximum value; N.S., not significant; SD, standard deviation; Signif, significance.
[a] $P \leq 0.05$ significant differences in means.

orthodontic patients (not in this study sample), is presented in Figure 7.

3.4. Pearson's correlation coefficients

Calculation of Pearson's coefficients largely reflected the figures shown in Tables 3 and 4. There was a positive correlation between the mandibular plane and gonial angles. There were significant positive correlations between the intermolar width and the various mandibular widths (W6MF, W6MA, W6IB) at the first molar. There were negative correlations between the mandibular plane angle and the total posterior face height, the volume and cross-section of the masseter, and the canine buccal cancellous width. This negative correlation between the mandibular plane angle and the canine buccal cancellous width supports the results presented in Table 4. This means that, as the mandibular plane angle decreases, the amount of cancellous bone between the lateral surface of the canine root and the cortical bone is likely to increase. There were also similar correlations for this canine buccal cancellous width with the lower anterior face height, the anterior face height ratio, and the mandibular inferior border width at the canine (all positive), and with the masseter CSA and volume (both negative). No correlation could be found between the canine angle (with the inferior mandibular border) and any of the measures of vertical pattern. This then meant that buccal or lingual tipping of the canine crown could be excluded as a confounding factor in any of the measurements related to the canines or the amount of bone surrounding them.

4. Discussion

4.1. 3D imaging and dosage

The continual development of 3D reconstructive imaging software has provided researchers with the ability to accurately assess previously immeasurable dimensions, short of actually dissecting cadaver material. The relatively low radiation doses, used for the subjects in this sample, had enabled high-quality diagnostic images to be taken with the lowest possible dose. The calculated mean radiation dose was 0.37 mSv (±0.04 mSv) and would generally be considered low for routine cranial CT examinations and well below the reported average natural background radiation of 3 mSv per year [15]. However, if one were considering its potential use in orthodontic diagnosis, it should be recognized that it is several times greater than the combined dose likely to be received from a digital lateral cephalogram and a panoramic radiograph or from a low-dose cone-beam CT [16,17]. Despite the higher radiation dose from the cranial CT examination, it is also still less than a published recommended 1-mSv annual dose for diagnostic imaging [18]. The potential detail gained with these cranial CT images is greater than could have been obtained from a cone-beam CT. Having said that, once again, these subjects had not been assessed for orthodontic reasons. Rather, the availability of these records gathered over an 8-year period was simply fortuitous and such cranial CT could not yet be recommended for routine use in orthodontic or orthognathic surgery diagnosis and planning. The availability of such a unique sample, though, provided an opportunity for assessment that might not have otherwise been possible.

4.2. Masseter properties and vertical pattern

It has been reported previously that a negative correlation exists between vertical facial height and the CSA of the masseter muscle [19–21]. Although CSA has been acknowledged to have a high correlation with muscle volume, interestingly, it has also been shown that muscle volume seems to be a better predictor of vertical craniofacial dimensions than CSA [22,23]. Similarly, the mandibular plane angle also demonstrated a greater negative correlation with masseter muscle volume than with CSA. On average, greater muscle volumes are found in brachyfacial individuals with larger transverse head dimensions, short faces, and reduced gonial angles [23]. In this sample, there was a significant difference between muscle measurements in the various vertical pattern subgroups. This is consistent with the results of previous studies that have shown brachyfacial individuals to have larger muscle CSAs and volumes than dolichofacials.

4.3. Arch dimensions, gender and vertical pattern

The fact that mean dental arch and basal bone widths were generally greater in male than in female individuals is consistent with the results of previous studies [24–27]. Having said that, the raw measurements and statistics might have been different if all subjects had been fully grown. This was obviously not possible with this clinical sample of previously gathered images. Only a few previous authors have recognized and discussed possible

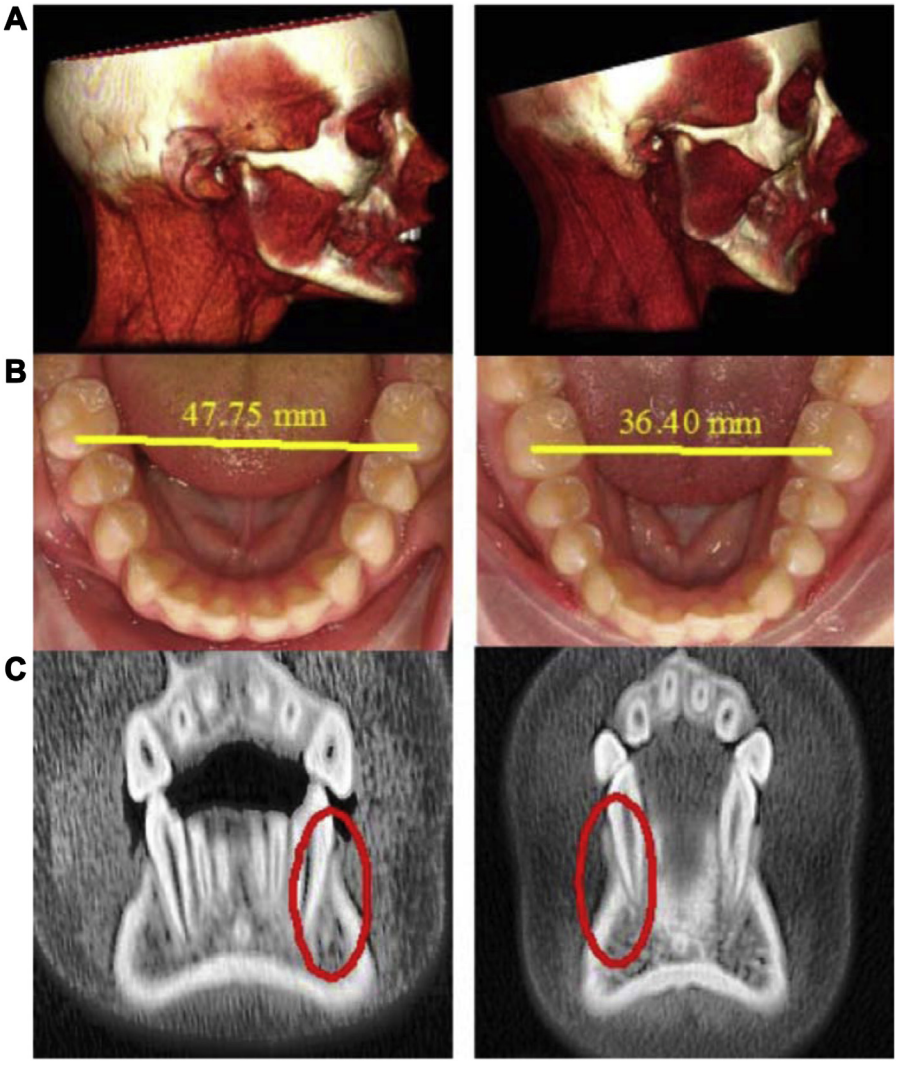

Fig. 7. Comparison of obvious brachyfacial and dolichofacial orthodontic patients (not part of the study sample - image previously published in Aust Dent J 2017;62:78-85). (A) Lateral view, 3DCT image, (B) intraoral mandibular occlusal view, (C) oblique coronal slice through mandibular canines. Note: (A) Differences in mandibular plane angulation and anterior border of masseter muscle; (B) differences in molar width, (C) difference in width of cancellous bone lateral to the canines.

differences in dental arch dimensions in subjects with different underlying vertical patterns [12,28,29], generally showing that mean intermolar widths tend to increase as the mandibular plane angle decreases or the subjects become more brachyfacial.

4.4. Expansionary tooth movements at the first molar

There has long been a debate regarding the success and sensibility of different methods of mandibular archform management [1–4]. No one method has yet been found to provide universal long-term stability after active orthodontic treatment. The fact that significant correlations were found among intermolar width and the corresponding mandibular widths at all levels would suggest that, in an untreated individual, there is likely to be a strong correlation between the positions of teeth within the dentoalveolus and the underlying basal bone in the molar region. Thus, individuals with larger intermolar widths are likely to have larger transverse bone dimensions, and vice versa. Although it is yet to be proven, anecdotally at least, a general consensus would seem to be that the dentoalveolus is likely to be somewhat affected by tooth movement, with the limit of this effect in individual patients still unknown. In contrast, the underlying basal bone is not affected at all by expansionary tooth movements [2]. With the increasing use of cone-beam imaging, it may be possible to further focus on these relationships.

4.5. Intermolar width

The results of previous work have shown that there is a tendency for expanded intermolar widths to return partially or completely to pretreatment values, with several authors concluding that real stability of orthodontic treatment can be achieved only when the preexisting intermolar width has not been changed [5,8]. However, other authors have found that expansion of the intermolar width can be maintained to a significant degree in some cases [30]. The variability seen in the results from different studies may possibly be due to variation among the samples themselves and different methods of expansion and retention. The fact that no direct correlation was found in this study between the vertical facial pattern and the lateral cancellous bone thickness at the first molar, might suggest then that the individual vertical pattern may not be a major factor in the stability of intermolar transverse expansion.

4.6. Intercanine width

It has commonly been perceived that the individual mandibular arch form, especially at the canines, somehow represents a musculo-occlusal equilibrium and should not be altered in treatment. Accordingly, posttreatment stability would then be associated with maintenance of the original intercanine width and arch form [5,7,8,30–34]. The significant finding of a negative correlation between the lateral cancellous bone width at the canine and both the mandibular plane angle and the masseter volume suggests that, on average, there is more cancellous bone between the lateral root surface of the canine and the cortical bone in brachyfacial individuals than in dolichofacials. This is obviously different from the situation in the molar region. It might be reasonable to suggest then that there is a greater potential to expand the mandibular canines laterally through cancellous bone, in patients with reduced vertical facial dimensions. Many authors have promoted the concept of "the sanctity of the mandibular intercanine width," although some have suggested that in Class II Division 2 subjects, especially, there might be a greater potential for retaining some increase in intercanine width, after deep overbites have been reduced in growing patients [8]. This may be at least partly explained by the fact that most Class II Division 2 malocclusions occur in individuals with reduced vertical facial dimensions [35]. It would also be consistent with the findings in the present sample. It would be reasonable, therefore, to think that there might be more scope for intercanine expansion in brachyfacials. In acknowledged classical retention studies [7,8,32,33], various pretreatment measurements have been suggested as predictive of long-term stability or otherwise, for cases in which the intercanine width has been increased. These have included incisal overbite [7], Angle's molar classification [8], crowding [7], and the ratio of intercanine to intermolar width. The findings of this present study would suggest that the individual underlying vertical facial pattern should perhaps also be considered in future studies of retention and stability.

4.7. Direct clinical considerations

In contemporary practice, with the streamlining of treatment protocols, selection of orthodontic archwires is often reduced to a single arch form and size, based on the preference of the clinician or some corporate-based treatment philosophy. In recognition of individual variations in arch form, clinicians may then choose to customize prefabricated rigid arch wires toward the end of active treatment, in an attempt to somehow enhance the chances of long-term stability. There also has been an increased tendency to place fixed bonded lingual wire retainers to try to disguise the expansion and to try to diminish any post-expansionary relapse potential. With the increased use of elastic wires, however, especially during the initial aligning stages of treatment, some expansion of the arches should be expected, regardless of the lightness of the force being delivered. If the aim is to maintain the teeth within their preexisting bony limits then, in the absence of significant vertical occlusal trapping of the lower anterior arch, arch wires corresponding to the preexisting individual arch form should probably be used. Based on the findings of this study, it seems logical to use arch wires that correspond to the original arch form in most patients. Some clinicians will point out, however, that at times, the lower buccal teeth seem to be tipped-in lingually, in the presence of a narrow upper arch, with or without crossbite. In those cases, it may be reasonable to upright the posterior teeth, but only if a significant and appropriate transverse increase has also been provided in the upper arch. It is possible that, in the future, the amount of cancellous bone lateral to the canine roots may be assessed for each individual with the use of cone-beam 3D-CT images, rather than universally expanding arches beyond the boundaries of the apical base by "creating" bone, – even when "extremely light forces" have been used [36]. Unfortunately, there appears to be no real evidence yet to apply such a reborn "bone creation" theory to all active orthodontic patients.

5. Conclusions

Taking into account the limitations of any study of human morphology and then attempting to extrapolate for clinical application, the following conclusions can be drawn from this work:

1. Subjects with dolichofacial patterns are likely have relatively smaller masseter CSAs and volumes. The opposite would apply to brachyfacials.
2. In untreated subjects, there is likely to be a close association between mandibular intermolar width and the widths at the apical and underlying basal bone levels. In contrast, the mandibular intercanine width is likely to be associated only with the apical width.
3. Brachyfacials are likely to have a greater width of buccal cancellous bone through which the canines can potentially be expanded laterally. The increasing use of CT imaging may make it possible to assess the amount of cancellous bone through which the canines might be expanded in individual orthodontic patients.

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