VARIATIONS IN DENTAL ARCH MORPHOLOGY ARE OUTCOMES OF THE COMPLEX ADAPTIVE SYSTEM ASSOCIATED WITH THE DEVELOPMENTAL VARIATION OF HYPODONTIA

DILAN PATEL[1], SADAF SASSANI[1], MAURO FARELLA[2], SARBIN RANJITKAR[1], ROBIN YONG[1], STEVE SWINDELLS[2] & ALAN BROOK[1, 3]
[1]Adelaide Dental School, the University of Adelaide, Australia.
[2]Faculty of Dentistry, University of Otago, New Zealand.
[3]Institute of Dentistry, Queen Mary University of London, United Kingdom.

ABSTRACT

Development of the human facial structures including the jaws and dentition occurs in a process that has the characteristics of a complex adaptive system (CAS) influenced by epigenetic, genetic and environmental factors. Earlier studies have suggested dental arch development to be reduced in size in subjects with hypodontia when compared with controls. Hypodontia is a variation of development and presents with a reduced number of teeth together with several other phenotypic changes. This study uses enhanced 3D imaging techniques to increase the accuracy of the measurements of dental arches. The sample consists of orthodontic patients, 60 with hypodontia (thirty males and thirty females), and 60 controls matched for age, gender and ethnicity. One operator using an Amann Girrbach Ceramill Map400 3D scanner recorded the 3D images from dental models. The 3D images were then viewed on MeshLab and the accuracy of the measurements were determined through repeat measurement of the same images; this was undertaken with intra- and inter-operator reproducibility. Ten repeat measurements were taken on 10 different models. Validation of the new system was undertaken by repeating the measurements using the standard 2D caliper technique. Arch dimension measurements were determined from distance between the left-hand side first molar to the right-hand side first molar. Similar measurements were also made for the inter-canine width. The results for average intra-operator measurements were 0.33 mm for the maxillary arch and 0.40 mm for the mandibular arch. The difference in average inter-operator reproducibility was also measured for inter-molar arch dimensions at 0.31 and 0.23 mm for maxillary and mandibular arches, respectively. This novel method provides an increased range of measurement of similar accuracy to standard techniques. This study will proceed to establish the variations on the 3D images between the hypodontia subjects and the control group.
Keywords: 3D imaging, dental arch, hypodontia, measurements, morphology, reliability, repeatability.

1 INTRODUCTION

Hypodontia is largely considered to be a variation of dental development with up to 6 congenitally missing teeth excluding third molars. It forms part of the complex adaptive system (CAS) of oro-facial development whereby epithelial tissues and neural crest mesenchyme are involved in delicate signalling pathways with multiple molecular events that overlap each other [1–4]. For a system to be considered as complex and adaptive, it should exhibit the principles of self-organisation and self-adaptation. The features of self-organisation and emergence occur during dental development at the initiation and morphogenetic stages. Separate genetic pathways and genetic/epigenetic/environmental interactions occur simultaneously throughout the dental developmental process; this is evidence of multitasking. The intricate and multi-level processes that occur during odontogenesis demonstrate the characteristics of a CAS [1, 5–8].

Hypodontia is widely reported to be the most common craniofacial malformation in humans with varying reports of between 2% and 10% of the global population in the permanent dentition excluding third molars [8–11].

The dental arch consists of the dentition and the surrounding structures; alveolar bone forms a large component of the tissues surrounding the dentition. Development of the alveolus is influenced by the presence of teeth. This forms a part of the CAS; however, there is a marked environmental influence during development and function [5, 7, 8].

2 AIM

Dental plaster study models of the maxillary and mandibular dentition have for several decades been used by dental practitioners as a vital aid in treatment planning and form part of the patients' clinical and medico-legal records. Plaster models are especially relevant for orthodontic patients, and many patients with hypodontia require orthodontic treatment as part of the multidisciplinary treatment planning. Plaster models are disadvantageous in that they are relatively delicate and require careful storage and labelling. When many models are collected over a long period, they can take up a considerable amount of space which also incurs a cost. Additionally, when measuring and using models over a long period they are subjected to a degree of wear and tear, which can alter the measurements [12–16].

Three-dimensional scanning has been developed as a recent method for measuring and assessing dental models. With the development of scanning technologies, it has become increasingly relevant to apply this technology to the dental arch and test the accuracy of measuring dental scans between operators [14].

The aim of this paper is to determine the accuracy of 3D scanning technologies in assessing arch dimensions as part of a multicentre, multidisciplinary collaborative study of hypodontia relating genotype and phenotype.

3 MATERIALS AND METHODOLOGY

This study has a unique sample group with defined parameters. The 120 subjects are orthodontic patients from the University of Otago. The hypodontia group was matched for age, gender and ethnicity with equivalent controls. Thirty male hypodontia subjects are in the age range of 10.2–21.0 years old and matched with 30 controls in the age range of 10.1–17.3 years old (Table 1). Thirty female hypodontia subjects are in the age range of 10.8–19.3 matched with controls in the age range of 10.6–19.2 (Table 1). This is summarised in Table 1. The ethnicity of the sample was self-identified by each of the subjects who were matched together. A statistically relevant number of hypodontia and control subjects were recorded [15].

Duplicate die stone models were poured and trimmed from existing models of the maxillary and mandibular dental arches of each subject in the study. Each model was placed in a fixed repeatable position in an Amann Girrbach Ceramill Map400 3D scanner, with the scanner set on its highest detection limit of 20 microns.

Table 1: Study sample of hypodontia patients matched with controls for gender and age.

	Age range of subjects (in years)	
Number in each gender	60 Males	60 Females
Hypodontia	10.2–21.0	10.8–19.3
Controls	10.1–17.3	10.6–19.2

3.1 Validation

Caliper measurements of the same point-to-point measurements were recorded on the dental models using a Craftright 150-mm stainless steel digital Vernier caliper to validate the 3D scans.

3.2 Measurements

To assess the molar width of the arches, measurements of the 3D scans were recorded on the maxillary arch from the disto-buccal cusp tip of tooth 16 to the corresponding cusp on tooth 26 (Fig. 1). Similarly, on the mandibular arch, the distance was measured between the disto-buccal cusp of tooth 36 and the disto-buccal cusp of tooth 46 (Fig. 2). Ten measurements of each arch were recorded from the control group of this preliminary study.

The MeshLab software program was used to record measurements; it is a relatively simple mesh processing system and is often used in processing meshes from 3D scans. The software was chosen for its ease of use in recording simple point-to-point measurements including the ability to rotate the model in any direction, while taking a measurement, this assists in ensuring the highest point of the cusp tip is recorded.
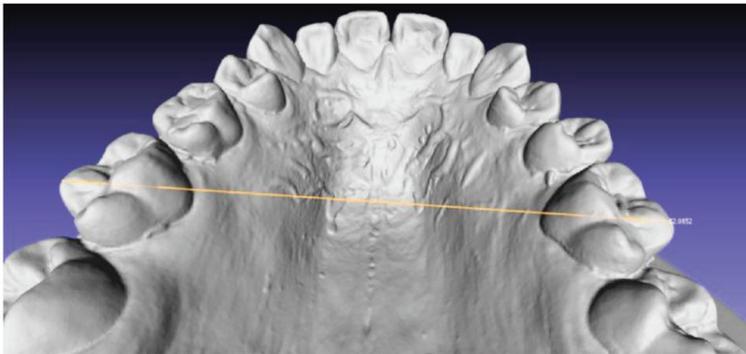
Figure 1: Maxillary inter-molar measurement, magnified view.
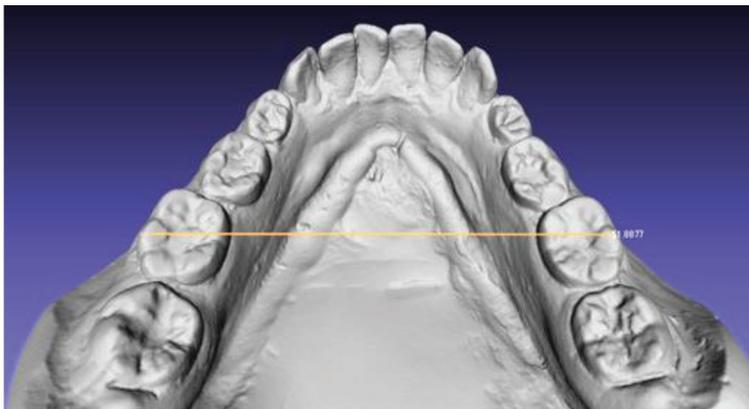
Figure 2: Mandibular inter-molar measurement, full arch view.

3.3 Error determination and repeatability testing

Variability in the measurement process results in multiple repeat measurements of the same distance. In instances where the molar cusp tip was not clearly defined or there was significant wear of the cusp, the reference points for the linear measurement may cause greater variance. Technical error of measurement (TEM) should be considered to determine if a statistically significant difference between repeat measurements exists. To quantify the TEM, a two-way random effect statistical model with single measure and absolute agreement was applied to the data. An intraclass correlation coefficient (ICC) model was used to calculate the above measurements using SPSS software for statistical analysis. To test for intra-operator error, these measurements were repeated 8 weeks later by the same operator (Operator 1). Additionally, a second operator with equal experience in using the MeshLab software (Operator 2) performed the same measurements to test for inter-operator error [15, 16].

4 RESULTS

The results for intra and inter-operator error are given in Tables 2–5 below. All measurements listed are graded in millimetres (mm).

Table 2: Intra-operator error in the maxillary arch (in mm).

Measurement time 1	Measurement time 2	Differential
51.38	51.54	0.16
53.06	53.63	0.57
58.19	58.54	0.35
49.14	49.75	0.61
57.72	57.89	0.17
48.84	49.59	0.75
56.21	56.01	0.20
54.34	54.53	0.19
51.88	51.66	0.22
45.02	44.98	0.04
		Mean: 0.33

Table 3: Intra-operator error in the mandibular arch (in mm).

Measurement time 1	Measurement time 2	Differential
54.82	54.91	0.09
46.69	46.61	0.08
53.06	52.52	0.54
43.17	44.35	1.18
51.18	51.39	0.21
42.89	43.62	0.73
49.26	48.88	0.38
47.99	48.45	0.46
45.13	45.49	0.36
40.21	40.20	0.01
		Mean: 0.40

Table 4: Inter-operator error in the maxillary arch (in mm).

Operator 1	Operator 2	Differential
51.99	51.54	0.45
53.29	53.63	0.34
57.92	58.54	0.62
49.45	49.76	0.31
57.83	57.89	0.06
49.55	49.60	0.05
56.48	56.01	0.47
54.29	54.53	0.24
51.66	51.66	0.00
45.55	44.98	0.57
		Mean: 0.01

Table 5: Inter-operator error in the mandibular arch (in mm).

Operator 1	Operator 2	Differential
54.92	54.85	0.07
46.61	46.84	0.23
52.52	52.30	0.22
44.35	43.71	0.64
51.40	50.91	0.49
43.62	43.55	0.07
48.88	48.91	0.03
48.45	48.07	0.38
45.49	45.36	0.13
40.20	40.21	0.01
		Mean: 0.227

Using the statistical applications mentioned above, the ICC for the maxillary and mandibular arches are as follows:

ICC values	Intra-operator	Inter-operator
Maxilla	0.996	0.996
Mandible	0.993	0.998

5 DISCUSSION

The above results demonstrate the high correlations for both intra-operator and inter-operator dimensions of inter-molar distances. An ICC reading of greater than 0.75 is indicative of good reliability and an ICC of 1 is an identical match in measurements. Studies have also indicated that digital models are a more reliable and clinically acceptable method of assessing inter-molar and inter-canine distances [5, 13–16].

In the literature, it is suggested that variations can arise in measurements relating to the operator position and point chosen on the digitized casts. However, as in our study, the variation is often less than that of caliper hand measurements [13].

6 CONCLUSION

The above results have shown that three-dimensional scanning techniques are an appropriate method of assessing dental arch morphology than using digital calipers to measure dental arch casts, which provides more extensive measurements. The preliminary results of this study demonstrate that it is viable for future detailed analysis of the dental arch morphology in this sample.

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