CLUSTERING OF MAXILLARY DENTAL ARCHES IN RELATION TO STOCK IMPRESSION TRAY DESIGN

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ABSTRACT

The study grouped Malay dental arches into clusters of shapes and sizes by applying the agglomerative hierarchical clustering (AHC) method, with the purpose of providing measurements for designing stock impression trays. Maxillary casts of 82 fully dentate subjects were used as control casts to group the arches. Eighteen variables, related to the length, breadth and palatal depth in each cast were measured. The lengths and widths were measured using Mitutoyo digimatic callipers and palate depths were measured using Mitutoyo digimatic indicator. Values of the 18 variables were subjected to normality tests and the AHC method was applied to establish clusters of dental arches. Forty one test casts were used to verify the defined clusters. Using mean and standard deviation values of the variables in each control cluster along with space for impression materials, three impression trays were designed. The sizes of test arches in each cluster were then compared with the dimensions of the stock tray calculated for each cluster. The amount of space for impression material in each tray was determined. Dental arches in the study were grouped into 3 feasible clusters: Cluster 1 (39.0%), Cluster II (46.3%) and Cluster III (14.6%). The length of the calculated trays provided adequate or optimal space (between 2mm and 9 mm) for impression material in Clusters I and II: 68.7% in Cluster I and 81.2% in Cluster II. However, the tray was too short (less than 2 mm of space) for 55.6% of the casts in Cluster III. The anterior width of all trays at the (canine region) provided optimal space for all (100%) of the casts in all clusters. The posterior width (at the first molar region) provided optimal space for all (100%) of the casts in Cluster II and III, and 93.8% of the casts in Cluster I. Two palate depths are required for each stock tray (shallow and deep), as every cluster had casts with deep and shallow palate depths. The calculated palate depth (deep) accommodated adequate or optimal space for all (100%) of the casts in Cluster I and Cluster II. However, there was inadequate space for the impression material (< 2 mm) *in 22.2% of the casts in Cluster III. Lowering the height of the palate depth of all trays by 4 mm (shallow) provided optimum space for 37.5% casts in Cluster I, 62.5% in Cluster II and 66.6% in Cluster III. However, there were 62.5% casts in Cluster I, 37.5% in Cluster II and 33.3% casts in Cluster III with too much space for the impression material (> 9 mm). In conclusion, the Malay dental arches may be grouped into 3 clusters. The estimated lengths and widths of the trays provided adequate space for impression materials. However two palate depths need to be incorporated in each tray to accommodate the deep and shallow palates present in each cluster of the Malay ethnic group.*

ABSTRAK

Kajian ini mengumpulkan arkus pergigian kumpulan etnik Melayu di dalam kelompok-kelompok mengikut bentuk dan saiz dengan menggunakan kaedah pengelompokan aglomeratif hierarki, dengan tujuan mendapatkan ukuran untuk mereka bentuk ceper impresi stok.Tuangan maksila 82 subjek yang bergigi digunakan sebagai tuangan kawalan untuk mengumpulkan tuangan-tuangan tersebut. Lapan belas pemboleh ubah yang berkaitan dengan panjang, lebar dan kedalaman lelangit setiap tuangan diukur. Panjang dan lebar tuangan diukur menggunakan angkup digimatik Mitutoyo dan kedalaman lelangit diukur dengan penunjuk digimatik Mitutoyo. Ujian kenormalan dilakukan ke atas kesemua nilai 18 pemboleh ubah, dan kaedah pengelompokan aglomeratif hierarki digunakan untuk menentukan pengelompokan arkus pergigian. Empat puluh satu tuangan ujian digunakan untuk menentu sahkan kelompok yang telah dikenal pasti. Dengan menggunakan nilai-nilai min dan simpangan baku pemboleh ubah setiap kelompok tuangan kawalan bersama-sama dengan nilai ruang untuk bahan impresi, tiga ceper impresi direka bentuk. Saiz arkus ujian di dalam setiap kelompok dibandingkan dengan dimensi kiraan ceper stok bagi setiap kelompok. Amaun ruang untuk bahan impresi di dalam setiap ceper ditentukan. Arkus pergigian di dalam kajian ini dikumpulkan di dalam 3 kelompok yang munasabah: Kelompok I (39.0%), Kelompok II (46.3%) dan Kelompok III (14.6%). Panjang ceper yang dikira memberikan ruang yang optimum atau memadai (antara 2mm dan 9 mm) untuk bahan impresi bagi Kelompok I dan II: 68.7% dalam Kelompok I dan 81.2% dalam Kelompok II. Walau bagaimanapun, ceper ialah terlalu pendek (kurang dari 2 mm ruang) untuk 55.6% daripada tuangan di dalam Kelompok III. Lebar anterior semua ceper (pada kawasan kanin) memberikan ruang yang memadai untuk semua (100%) tuangan dalam semua kelompok. Lebar posterior (pada kawasan molar pertama) memberikan ruang yang memadai untuk semua (100%) tuangan di dalam Kelompok II dan III, dan 93.8%

tuangan di dalam Kelompok I. Dua kedalaman lelangit diperlukan untuk setiap ceper stok (dalam dan cetek), oleh sebab setiap kelompok mempunyai tuangan yang mempunyai lelangit yang dalam dan cetek. Kedalaman lelangit yang dikira (lelangit dalam) memberikan ruang yang optimum atau memadai untuk semua (100%) tuangan di dalam Kelompok-kelompok I dan II. Walau bagaimanapun, terdapat tidak cukup ruang untuk bahan impresi (< 2 mm) dalam 22.2% tuangan di dalam Kelompok III. Perendahan ketinggian lelangit semua ceper dengan 4 mm (cetek) memberikan ruang yang cukup untuk 37.5% tuangan di dalam Kelompok I, 62.5% dalam Kelompok II dan 66.6% dalam Kelompok III. Walau bagaimanapun, terdapat ruang yang berlebihan untuk bahan impresi (> 9 mm) di dalam 62.5% tuangan dalam Kelompok I, 37.5% dalam Kelompok II dan 33.3% dalam Kelompok III. Sebagai kesimpulan, arkus pergigian Melayu boleh dikumpulkan di dalam 3 kelompok.. Kepanjangan dan kelebaran ceper yang dianggarkan memperuntukkan ruang yang cukup untuk bahan impresi. Walau bagaimanapun, dua kedalaman lelangit perlu dibuat bagi setiap ceper untuk menyesuaikan dengan lelangit yang dalam dan cetek yang terdapat di dalam setiap kelompok etnik Melayu.

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CHAPTER 1: INTRODUCTION

In restorative dentistry, dental impressions are made for diagnostic purposes and to construct dental restorations and appliances indirectly outside the mouth. Dental impressions are carried and confined to the mouth to make a negative likeness of the oral tissues of interest by an impression tray. Plaster or dental stone is then cast into the impression to make a life-sized likeness of the relevant dental hard and soft tissues. Accurate impressions are necessary for the construction of any dental restoration or prosthesis. Two impressions are normally required: a primary or preliminary impression made using stock trays and a final or working impression made using custom trays (Winstanley *et al.*, 2005).

Stock trays should have sufficient extension to support an impression of all structures to be recorded and have adequate space for impression material to make an accurate impression and minimise distortion. Manufacturers of stock trays claim that their stock trays are available in a range of sizes and shapes to cover a broad range of “the most common morphological dental arch shapes”. However, empirical references with regard to the range of arch sizes and shapes used to make these trays were not provided by these manufacturers to support their claims. Clinical experience has shown that in many instances the stock trays need to be modified before use for making impressions as the stock trays did not provide for variations in the anterior and posterior widths and the palatal depths of the dental arches (Wiland, 1971; Bomberg *et al.*, 1985). Stock trays made in Europe may also not be able to accommodate African arches, which are significantly bigger and wider (Mack, 1981). Image processing techniques have also shown that the available stock trays are only suitable for a particular population (Yergin *et al.*, 2001).

To ensure appropriate support and even distribution of impression materials (essential requirements for making accurate impressions), custom trays are used for individual patients. However, clinicians should specify the design detail and impression material to be used with the tray when ordering the tray to merit the extra time and cost of making the custom tray. Custom trays should also be made with the appropriate stops to ensure proper seating of the tray in the mouth (Smith *et al.*, 1999).

In a study to examine the quality of written instructions and choice of impression trays and materials for both fixed and removable prosthodontics in Ireland and the United Kingdom, it was found that only 24% of dentists (based on written instructions to commercial laboratories) used special trays for all prosthodontic items (Lynch and Allen, 2005). Only 14% of dentists providing cobalt-chromium based removable partial dentures used special trays and alginate for making working impressions. This result (14% of acrylic resin custom trays used in removable partial denture cases) was also reported in the United States of America (Shillingburg *et al.*, 1980) and in the Kingdom of Bahrain (Radhi *et al.*, 2007).

Studies conducted to evaluate the accuracy of casts made from stock tray and custom tray with non-aqueous elastomeric impression materials show that all casts distort, but a custom tray with 2.0 to 2.5 mm tray spacing had the least amount of variation. However, the differences between custom tray and stock trays (with tray spacing between 2 mm and 9 mm) may not be clinically significant (Valderhaug and Floystrand, 1984; Rueda *et al.*, 1995; Millstein *et al.*, 1998; Patil *et al.*, 2008).

In light of these observations, the primary objective of this study was to determine if the dental arches of the Malay ethnic group can be grouped in clusters so that stock impression trays suitable for each cluster are made. Other specific objectives were:

i. To provide arch measurements for the design of stock impression trays.

ii. To determine if the range of stock trays proposed would be suitable to a sample of the population studied.

These issues are important because the use of appropriately designed stock impression trays based on empirical measurements has the potential to allow more accurate and cost-effective use of stock trays, minimising or forgoing the need for custom trays. This can reduce treatment costs for dental restorative treatment for partially dentate patients.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

An impression is a negative imprint of hard (teeth) and soft tissues in the mouth from which a positive reproduction (cast) can be made (Nairn and Shapiro, 2005). Dental practitioners seem to pay more attention to selecting ideal impression materials rather than impression trays, which are sometimes regarded simply as a carrier for impression materials (Burton *et al.*, 1989; Beal, 2007).

The British Society for the Study of Prosthetic Dentistry (Barsby *et al.*, 2005) stated that impression trays should have sufficient extension to support an impression of all structures to be recorded. The choice of an impression material for a particular situation depends on the treatment being provided, operator preference and available materials in the dental surgery.

2.2 Impressions in restorative dentistry

There are two types of impressions in restorative dentistry i.e. primary and secondary impressions.

Almost all prosthodontic patients require preliminary impressions for diagnostic purposes. The British Society for the Study of Prosthetic Dentistry (Barsby *et al.*, 2005), stated that a good primary or diagnostic impression should be made with a rigid stock trays to fit the form of the mouth without excessive tissue distortion. The secondary impression is basically to improve on the primary impression, especially when the tissue details and functional denture sulcus and denture bearing areas were not adequately reproduced in the primary impression. Another motivation for making a working impression using a custom tray is to ensure an impression with dimensional stability, and this is achieved by making an impression with a uniform layer of impression materials which will prevent any distortion in the impression.

Knowledge of the key properties of available impression materials and their handling behaviour is necessary if these materials are to be used effectively. A variety of impression materials and techniques are currently available, depending on the final restoration to be made. However, their use is only successful if attention is paid to the detail of their properties, handling characteristics and individual limitations (Donovan and Chee, 2004; Stewardson, 2005).

2.2.1 Alginate (irreversible hydrocolloid)

Alginate impression materials are widely used as they are non-toxic or non-irritating, cost effective, easy to mix, have adequate flow properties and compatible with gypsum products (Nandini *et al.*, 2008). They have poor tear strength in thin sections, and produce dimensional stable and accurate impressions if they have a uniform thickness of 2-4 mm, and are poured immediately (within 10 minutes of the impression mix). Alginates have to be supported by appropriate sized impression trays as excess unsupported alginate can lead to a distorted impression, especially when the weight of the impression acts directly on the unsupported material, especially in the posterior areas of the upper and lower impressions. It is advisable to use adhesives, even with perforated trays as the use of alginate adhesives overcomes displacing forces during withdrawal of the impression from the mouth (Craig, 1988). Traditional alginate impressions should be poured immediately, although there are reports of newer alginates which can be poured 100 hours after impression making. However, all the extended pour alginates were shown to have statistically significant dimensional changes at 24 and 100 hours (0.6%-6.1%) in all storage conditions tested (Todd *et al.*, 2013).

2.2.2 Non aqueous elastomeric impression materials

As alginate impressions have to be poured immediately, non-aqueous elastomeric impression materials like polyether and poly vinyl siloxanes are alternatives to alginates when impressions have to cast later. Additionally, multiple casts can be obtained from a single elastomeric impression at various times of pours, although addition silicones as well as the condensation silicones recover better from induced deformation when compared to polyether (Kumar *et al.*, 2011).

2.3 Dental impression trays

The main purpose of the impression tray is to act as a rigid carrier for the impression materials, facilitating their insertion into the mouth and holding the impression materials in place while it sets. The thickness of the space between the tray and the preparation is one of the important factors related with the dimensional stability of the impression materials.

Although the custom tray is highly recommended to produce accurate working impressions, stock trays still remain the most popular used by dentists. The reason being stock trays are readily available and easy to use whereas custom made trays are time consuming to construct and hence more expensive. In a survey of 3,737 dentists in the United States, around 75% of the respondents preferred the use of stock trays routinely. However, the types of stock trays used, whether the cases were partially dentate or edentulous, steps in the treatment phases where the trays were used and whether there were any problems encountered with the use of the impression trays were not mentioned (Shillingburg *et al.*, 1980).

2.3.1 Stock impression trays

There has not been any improvement in the design of stock impression trays for partially dentate cases. The only significant advance in the past 45-50 years was the production of plastic ‘disposable’ impression tray (Beal, 2007).

2.3.1.1 Materials for stock impression trays

The stock trays for dentate patients may be perforated stock tray, used with alginate impression materials and non-perforated stock tray, used with the elastomeric impression materials. The stock tray might be metallic (Aluminium or stainless steel) and non-metallic (sterilisable plastic tray and disposable plastic tray). It has been shown that when disposable plastic stock trays were tested in conjunction with very high-viscosity impression materials there was distortion of the tray both across the arch and in cross section, while metal stock trays showed significantly less change in cross-arch dimension (Cho and Chee, 2004).

2.3.1.2 Problems with currently available stock impression trays

The currently available stock trays frequently require some form of tray modification before use (Bomberg *et al.*, 1985). Modifications to the tray can be done with wax, tracing stick impression compound or heavy-bodied silicone, depending on the operator's convenience. If a patient has a high palatal vault, pre-packing the centre of the maxillary tray with alginate or compound to reduce the bulk of alginate impression material can minimise distortion due to dimensional instability.

2.3.2 Custom impression trays

Custom trays are made in the dental laboratory for individual patients. The custom trays provide rigidity, as well as a uniform thickness of impression materials, and therefore provide greater accuracy of impression then what is achieved with stock trays (Thongthammachat *et al.*, 2002).

2.3.3 Difference between use of stock and custom impression trays

Stock trays are ready-made and come in specific sizes. They should be selected carefully for the best fit with a dental arch. Stock trays are usually meant to be used with specific impression materials and are re-useable after sterilization (Millstein *et al.*, 1998). On the other hand, custom trays are fabricated on the particular patient's cast thereby making it always are a better fit than stock trays and unique to the patient.

While a stock tray can be selected, adapted and used in a single visit for both an anticipated and unanticipated situation, making a custom tray requires planning a study model and laboratory time required in curing the acrylic resin tray and finishing the tray (Bomberg *et al.*, 1985). An impression will be most accurate when the impression material is evenly distributed and have uniform thickness, and therefore the use of a custom tray for impression making will minimize potential cast distortion (Millstein *et al.*, 1998). The volume of impression materials required to make an impression may be approximately twice than that needed to make an impression with a custom tray, and this unequal distribution of impression materials in the stock tray may lead to cast distortion, especially if impressions are not cast immediately.

2.3.4 Use of stock impression trays in general dental practice

Even though there are advantages of using custom trays in clinical practice, several survey reports have shown that most dental practitioners use stock trays compared to custom or special trays (Shillingburg *et al.*, 1980; Lynch and Allen, 2005; Radhi *et al.*, 2007). This is a contradiction to the theory that supports the use of custom trays. Although in theory optimum accuracy is obtained with the custom trays, the use of stock trays with elastomeric impression materials appears to have clinically insignificant results when custom trays are used, and therefore stock trays are popular in general dental practice (Donovan and Chee, 2004; Patil *et al.*, 2008).

2.4 Dental arch shape and size

Many factors such as heredity, growth of the alveolar bone, eruption and inclination of the teeth, external influences, function and ethnic background could affect the size and shape of the dental arches. The loss of teeth also leads to restoration of the alveolar process, which creates further changes to the shape of the dental arch (Mohammad *et al.*, 2011).

2.4.1 Arch shape

There have been many attempts to describe and classify the human dental arch form. It is commonly believed that the dental arch form is initially shaped according to the configuration of the supporting bone and following the eruption of the teeth, by the circumoral musculature and intra-oral functional forces, and the dental arch shape is preserved during growth by the equilibrium between tongue and circumoral muscle forces, and therefore not static (Braun *et al.*, 1998). The shape and form of the hard palate is subjected to various forces that change its shape, such as chewing forces, and forces of the tongue and perioral muscles (Moorrees *et al.*, 1969; Raberin *et al.*, 1993; Bishara *et al.*, 1997).

Dental arches have been described qualitatively as tapered, ovoid, square, parabolic and semi-ellipse (Felton *et al.*, 1987; Braun *et al.*, 1998; Paranhos *et al.*, 2011). Such categories are based mainly on clinical observation, purely subjective and may not be comparable due to different landmarks and different measurement techniques used.

2.4.2 Arch size

Researchers have measured the maxillary arch using several materials, techniques and landmarks, and a truly varied comparison may be difficult to obtain. The variables used to describe dental arches have included arch length, width, circumference, inter-canine and inter-molar distances and palate depths and angulations. Direct measurements yield the most accurate measurements, provided devices are used appropriately. Measurements of arch length, width and palate depths may be obtained directly intra-orally or from casts of the dental arches. Digital callipers are routinely used for making these direct measurements. Mohammad *et al.* (2011) used digital callipers for straight measurements on dental casts and calibrated tape to measure directly anterior and posterior arch circumferences. Omar and Isa (2006) measured the maxillary arch directly on the casts by using digimatic callipers, profile gauge and protractor. Hassanali and Odhiambo (2000) used vernier callipers for straight measurements, while the palatal depth was measured using flexible curvature gauge. A calibrated tape was used to measure the anterior and posterior arch circumferences. Indirect measurements may be made from photographs, radiographs or scanned images. However, images are two dimensional records of three dimensional objects, and therefore the parameters measured were in a projected form on a single plane rather than the real form. To reduce this error, measurements of linear distances of teeth and facial measurements and other intra-oral structures must be made with the objects in the same plane and in a standardized and calibrated manner (Bindra *et al.*, 2000).

Currently, technology provides three-dimensional digitizers that can directly be used on dental casts to supply the metric coordinates of selected landmarks. The coordinates can be used for any kind of mathematical modelling. Optical devices, electromechanical instruments and electromagnetic digitizers all can be used to collect three-dimensional data on the human arches and any differences between direct measurements and virtual measurements have been shown to be not clinically significant (Ferrario *et al.*, 2001; Persson *et al.*, 2009; Isa *et al.*, 2011; Nakatsuka *et al.*, 2011).

2.4.3 Influence of ethnic group and gender on arch size

Patients from different ethnic groups may exhibit differences in arch sizes (Lavelle, 1975; Braun *et al.*, 1998; Burris and Harris, 2000; Mohammad *et al.*, 2011). Mohammad *et al.* (2011) observed arch dimension of the Malaysian Malay ethnic group and found no significant differences between arch sizes of men and women. This was also found by Hayashi *et al.* (2006) in a young Japanese population. They measured the palatal width, arch width and arch length where no significant differences were observed in boys and girls between the ages of 7 and 12 years. The size and shape of the human dental arches may change with age. Harris and Smith (1982) conducted a longitudinal study of arch size and form on 60 adults when they were about 20 years, and 30 years later when they were about 50 years of age. They found that arch widths increased over time, especially in the distal segments, whereas arch length decreased. These altered the arch shape toward shorter and wider arches.

2.4.4 Palatal shape and form

There are various types of palate shape, depending on the criteria used to classify the shape. The hard palate shape has been classified as either "V" shape (narrow maxilla), rounded or normal "U" shape. The palatal vault may be defined as deep (high), medium (average/normal) and shallow (Younes *et al.*, 1995). Kazanje and INoori (2008) classified edentulous palate depth into three categories: deep (15.5 -20.0 mm), moderate (10.5 – 15.0 mm) and shallow (5.5 -10.0 mm). There seem to be no ethnic differences in relation to palate height and width (Younes *et al.*, 1995).

2.5 Clustering of human dental arches

In cluster analysis of dental arches, the purpose is to identify arches that are similar to each other but different from individuals in other groups (Cornish, 2007). Nakatsuka *et al.* (2011) and Isa *et al.* (2011) used the agglomerative hierarchical clustering method to group scanned images of maxillary casts according to arch forms. Nakatsuka *et al.* (2011) identified 4 of dental arches clusters in young Japanese students and Isa *et al.* (2011) identified 3 clusters in the sample of young Malaysian population (consisting of Malays, Chinese and Indian ethnic groups). Park *et al.* (2015) found 4 clusters of mandibular arch forms in young Korean adults based on lingual orthodontic bracket points.

2.6 Statement of the problem

It can be seen from the literature that although custom trays can minimise tissue distortion and make accurate impressions due to better fit with individual dental arches, they are not routinely used in general dental practice, because they incur extra time and expenses. Although stock impression trays are available in many shapes and sizes, clinical experience has shown that in many instances, they have to be modified before they can be used to make impressions in the mouth. It may be difficult to make impression trays that fit all arches, as arch sizes have been shown to differ among ethnic groups. Manufacturers of stock impression trays have made trays in various shapes and sizes, in different materials (metal and plastic) in different sections and some are meant to be for single use only (disposable). The many ranges of trays are made to suit a variety of dental arches, and so are made with low palates and many sizes. However, there have been no empirical data on how the impression trays are made.

2.6.1 Aim of the study

The aim of this study was to design stock impression trays that would be suitable for the Malay population in Malaysia.

2.6.2 Objectives of the study

The specific objectives of the study were:

i. To group Malay dental arches into clusters of shapes and sizes by applying the agglomerative hierarchical clustering (AHC) method.

ii. To provide arch measurements for the design of stock trays.

iii. To determine how suitable the trays would be to the sample of the population studied.

CHAPTER 3: MATERIALS AND METHODS

3.1 Subjects in the study

This study was conducted at the Faculty of Dentistry, University of Malaya, Kuala Lumpur, Malaysia. The subjects of the study were young Malay adults. The mean age of the sample was 22 years. They comprised of students, staff and patients who came for dental treatment at the out-patients clinic, Faculty of Dentistry, University of Malaya.

3.2 Selection of subjects in the study

123 healthy subjects (63 men and 60 women) who fulfilled the inclusion criteria of being fully dentate, with Class I Angle's Classification and regular arches with minimal attrition participated in the study. The sample was divided randomly into 82 control casts (used to cluster the sample) and 41 test casts (used to verify the existence of the clusters formed).

3.3 Ethics consideration

This study was approved by the Medical Ethics Committee of the Faculty of dentistry, University of Malaya (Appendix A). The details about the study were explained verbally to the subjects. All subjects signed a consent form to participate in the study.

3.4 Collection and preparation of stone casts

The protocol described by Isa *et al.* (2011) was followed when making impressions and preparing casts for this study. A maxillary impression was considered acceptable if the morphology of all teeth (third molars were excluded), the maxillary tuberosities, the hamular notches and the full depth of the sulcus were correctly recorded in the impression. After an impression was made, it was rinsed under running tap water and inspected to ensure that it was free from air bubbles. The alginate impression, the tray and tray handle were then sprayed with disinfectant solution i.e. 2% Perform®-ID (Schulke and Mayr, Germany). They were then wrapped in gauze moistened with the disinfectant and left for 10 minutes. The impression was then rinsed under running tap water and cast with type III dental stone (Heraeus Kulzer GmbH and Co., Germany). The stone casts were then based in Plaster of Paris of sufficient height to allow adequate material to be present below the arch form and around the sulci to permit trimming. Each cast was numbered and labelled, although detailed information regarding the age, sex and ethnicity of the subject from which the cast was obtained was not noted on the cast but were kept separately.

The casts were then placed upside down on a flat reference plate with the mesiopalatal cusps of the first molar teeth and the incisal edges of the central incisors in contact with the plate in the most stable position. A compass arm with a sharp pencil attached to it was placed on the reference plate parallel to the surface table and stabilized using cold cured acrylic resin. As the cast was turned, a line was scribed on the side of the cast by the pencil. The base of the cast was then trimmed following this line so that the occlusal plane was parallel to the horizontal plane.

3.5 Measurements of the casts

The length, breadth and palate depth of each maxillary cast was measured as follows:

A. Length.

The lengths were measured from the labial surface of the central incisor to a line joining the following:

i. Canine tips, LCIC.

ii. Buccal cusp tips of the first premolars, LCIP1;

iii. Buccal cusp tips of the second premolars, LCIP2;

iv. Mesiobuccal cusp tips of the first molars, LCIM1;

v. Mesiobuccal cusp tips of the second molars, LCIM2;

vi. Hamular notches on either side of the arch, LCIHN.

B. Breadth

The breadth (or width) measures the distance between the:

i. Canine tips, BCC

ii. Buccal cusp tips of the first premolars, BP1P1;

iii. Buccal cusp tips of the second premolars, BP2P2;

iv. Mesiobuccal cusp tips of the first molars, BM1M1;

v. Mesiobuccal cusp tips of the second molars, BM2M2;

vi. Hamular notches on either side of the, BHNHN.

C. Palate depth.

The palate depth measures the height of the vertical distance of a point in the midline of the palate from a plane that passes through the occlusal plane at a line where the depth measurements were made. A protractor was used to indicate a line joining the following points when depth measurements were made:

i. Depth in the midpoint of canine to canine, DCC;

ii. Depth in the midpoint of first premolar to first premolar, DP1P1;

iii. Depth in the midpoint of second premolar to second premolar, DP2P2;

iv. Depth in the midpoint of first molar to first molar, DM1M1;

v. Depth in the midpoint of second molar to second molar, DM2M2 and

vi. Depth in the midpoint of left hamular notch to right hamular notch, DHNHN.

A schematic drawing of the measurement points is shown in Fig. 3.1. The Mitutoyo digimatic callipers (Mitutoyo, Japan) was used to measure length and width of the casts (Fig. 3.2), while the Mitutoyo digimatic indicator (Mitutoyo, Japan) was used to measure palate depths (Fig. 3.3).

Palate depths in the first molar region were used to classify the palate into deep (more than 22 mm), moderate (19 - 21 mm) and shallow (less than 18 mm), a modification of the edentulous palate depth classification used by Kazanje and INoori (2008).

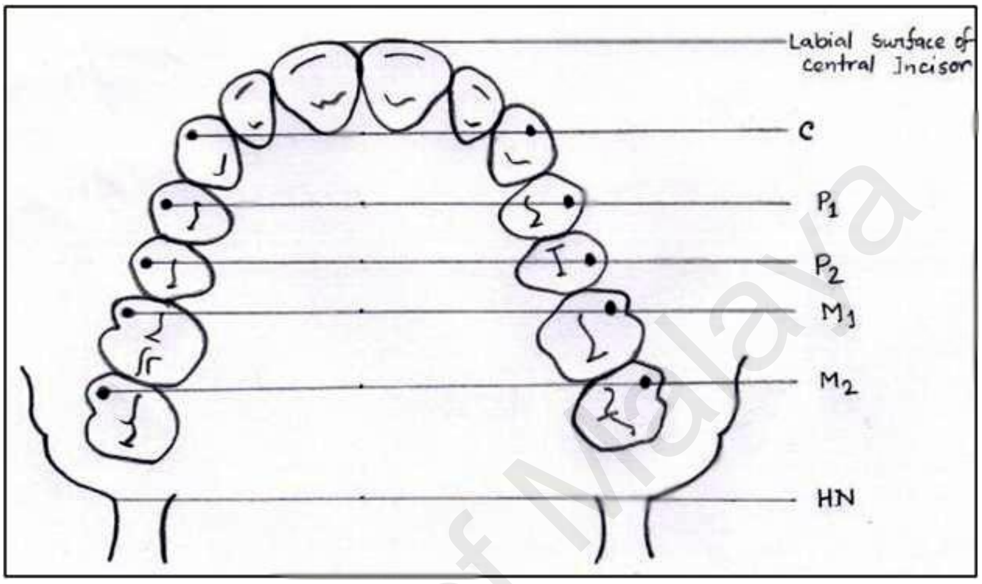


Figure 3.1: Measurement points.

Figure 3.2: Width measured using the Mitutoyo digimatic callipers.

Figure 3.3: Palate depth measured using the Mitutoyo digimatic indicator.

3.6 Calibration procedure

All measurements were made at 2 different times by 2 examiners, the second measurement made a month after the first measurement. To evaluate inter examiner reliability, 10 casts were measured, and the means of the measurements between the 2 examiners were found to be not significantly different. A mean value (from 4 measurements obtained) for each variable was used as the final measurement for each variable.

3.7 Statistical analysis

Statistical analyses of data were performed using GraphPad Prism 6 (GraphPad Software, Inc., La Jolla, California, USA).

3.8 Cluster analysis

The agglomerative hierarchical clustering with complete linkage method was used in this study (Isa *et al.*, 2011). The Minitab software was used to perform the cluster analysis (Minitab 16 Statistical Software, Sydney, Australia).

Hierarchical cluster analysis of the 82 control casts indicate the possibility of 5 clusters formed at different similarity levels (shown graphically in dendrograms in Figures 3.4 and 3.5). The horizontal axis indicates the position of each dental cast (identified by their numbers), and the height of the vertical axis (similarity level) is a measure of the disparity among the casts. At 100% level, all objects are 100% different to each other and at 0% level, all objects are closely related (i.e. objects belong to one single group).

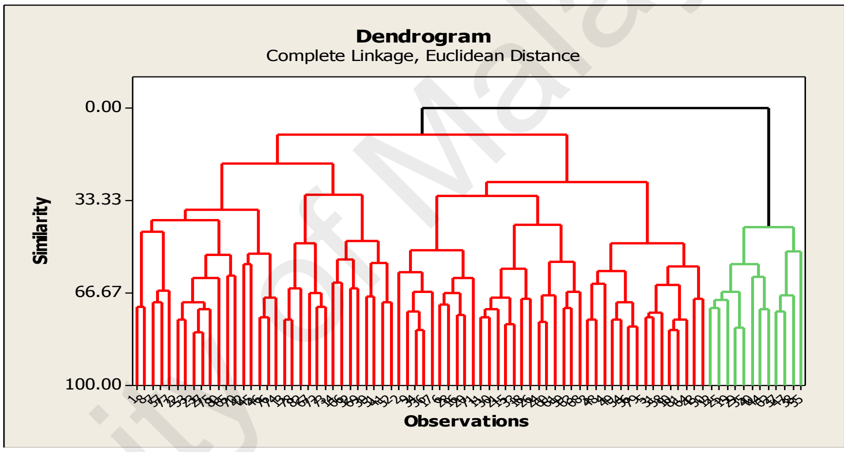
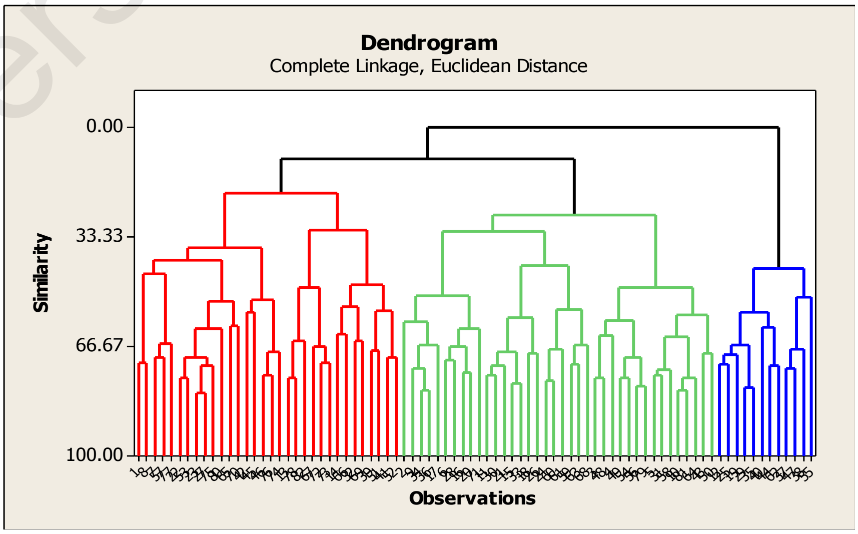
Number of clusters	**Dendrogram**
2	
3	

Figure 3.4: Dendrograms showing 2 (similarity level 9.8%) and 3 clusters (similarity level 20.2%).

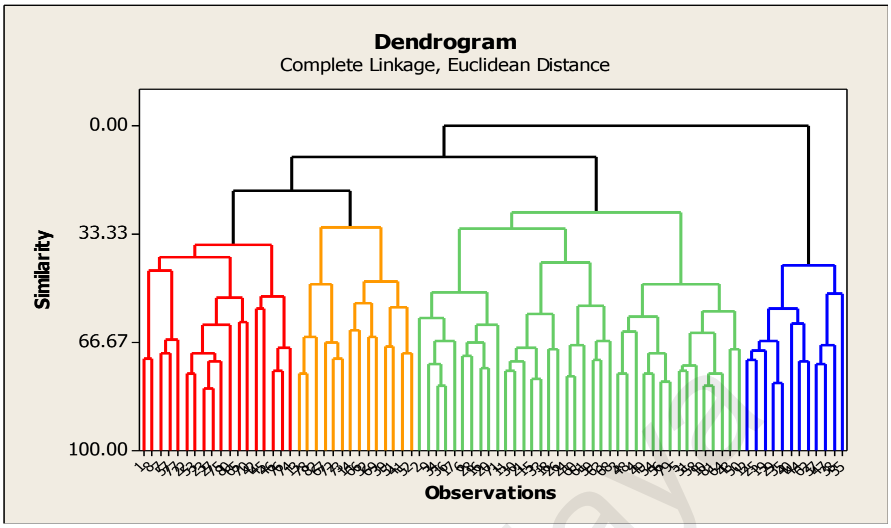
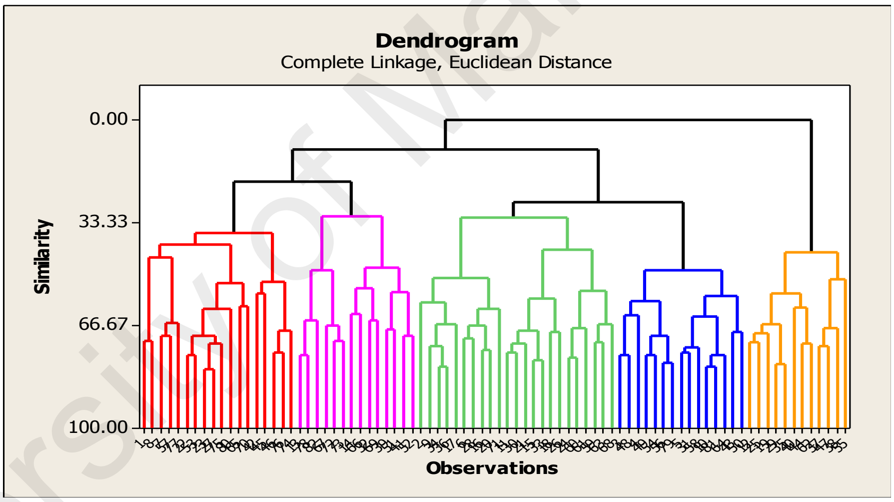
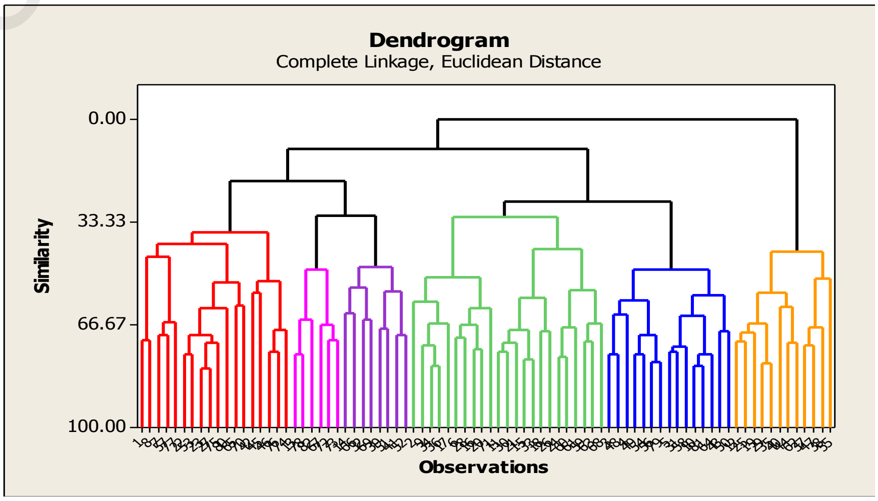
Number of clusters	Dendrogram
4	
5	
6	

Figure 3.5: Dendrograms showing 4 (similarity level 26.9%), 5 (similarity level 31.5%) and 6 (similarity level 31.6%) clusters.

3.8.1 Variance test for the clusters

Multivariate analysis of variance (MANOVA) tests were used to test for the difference in means among multiple variables at the same time, and thereby verifying that the clusters are significantly different from each other (Table 3.1).

Table 3.1: MANOVA of the clusters formed.

Cluster Number	Criterion	Test Statistics	F	P
2	Pillai's Trace	0.00643	0.518	0.474
	Wilks' Lambda	0.99357	0.518	0.474
	Hotelling's Trace	0.00647	0.518	0.474
	Roy's Largest Root	0.00647	0.518	0.474
3	Pillai's Trace	0.08094	**3.479***	0.036
	Wilks' Lambda	0.91906	**3.479***	0.036
	Hotelling's Trace	0.08807	**3.479***	0.036
	Roy's Largest Root	0.08807	**3.479***	0.036
4	Pillai's Trace	0.08794	2.507	0.065
	Wilks' Lambda	0.91206	2.507	0.065
	Hotelling's Trace	0.09642	2.507	0.065
	Roy's Largest Root	0.09642	2.507	0.065
5	Pillai's Trace	0.11049	2.391	0.058
	Wilks' Lambda	0.88951	2.391	0.058
	Hotelling's Trace	0.12421	2.391	0.058
	Roy's Largest Root	0.12421	2.391	0.058
6	Pillai's Trace	0.13649	**2.403***	0.045
	Wilks' Lambda	0.86351	**2.403***	0.045
	Hotelling's Trace	0.15806	**2.403***	0.045
	Roy's Largest Root	0.15806	**2.403***	0.045

*=significant at 5% level

The variables for all the measurements were significant (F= 3.479* at 5% level) for 3 clusters and (F= 2.403* at 5% level) for 6 clusters. Non-significant F values

(0.518, 2.507 and 2.391) were demonstrated for 2, 4 and 5 clusters. MANOVA analysis indicates that the dental arches studied may be grouped into 3 and 6 viable clusters.

3.8.2 Establishment of final cluster number

To determine the final cluster number, the following criteria were considered:

a. Distribution of test samples into the 3 and 6 clusters

b. Similarity and distance level of the 3 and 6 clusters

(a) ***Distribution of test sample into 3 and 6 cluster***

In order to choose the appropriate cluster number as the final one to be used in the study, the 41 test casts were used. In cluster analysis, objects with smaller distances between one another are more similar, whereas objects with larger distances are more dissimilar. The nearest neighbour method was used to determine which of the 3 or 6 clusters will be used as the final number of clusters. The smallest difference between the sums of the values in the test casts and the means of the measurements in any one of the clusters determines into which cluster the cast will fall into. This was measured by the software as the Euclidian distance i.e. square root of sum of squares of differences between two points:

$$\text{Distance} = \sqrt{(X1-Y1)^2 + (X2-Y2)^2}$$

The following conditions were set to determine the final number of clusters (Isa *et al.*, 2011).

i. 90% of the test casts (i.e. 37 casts) must belong to all of the clusters formed.

ii. Any cluster with less than 10% membership (i.e. <4 casts) is not a valid cluster.

The result of the distribution of the test casts into the 3 and 6 cluster groups are shown in Tables 3.2 and 3.3.

Table 3.2: Distribution of test casts into the 3 cluster group.

Cluster No.	**Members (%)**
1	16 (39.0)
2	16 (39.0)
3	9 (22.0)
Total	**41 (100%)**

Table 3.3: Distribution of test casts into the 6 cluster group.

Cluster No.	**Members (%)**
1	9 (22.0)
2	3 (7.3)
3	11 (26.8)
4	11 (26.8)
5	7 (17.1)
6	0 (0)
Total	**41 (100%)**

Table 3.2 shows that all 41 casts can be distributed in the 3 cluster group following the criteria set. Table 3.3 shows that there were not sufficient number of test casts (<10%) in the 2nd and no casts in 6th cluster of the 6 cluster group. Therefore, 3 clusters were used as the final cluster number to be used in the study.

(b) ***Similarity and distance levels of the 3 and 6 clusters***

The similarity level for the 3 cluster was 20.2%. This implies the casts in each cluster have 20.2% dissimilarity to each other (and 80% similar to each other). The similarity level for the 6 clusters was 31.6%. This implies the casts in each cluster has 31.6% dissimilarity to each other, and 70% similarity to each other. However, in the 6 clusters group with the bigger difference, there were not enough members following the criteria set to indicate a valid cluster (Table 3.3). Hence the 3 cluster group was used as the final cluster number.

3.9 Assessing fit of trays using test casts

3.9.1 Pilot study

A pilot study was conducted to determine if stock trays made using the mean values of each cluster of the control casts can accommodate the test casts. Three light cure acrylic resin trays were fabricated and tested with 10 casts from the test group. Only length and width dimensions were used when fabricating these 3 trays.

3.9.1.1 Fabrication of acrylic resin stock trays from the calculated cluster mean values

The mean values of the variables from the 3 clusters of the control casts were used to fabricate 3 stock trays. Only one length measurement was used for each tray, i.e. the LCIHN values. For each mean value, one standard deviation value and 3 mm (space for impression material) was added. All 6 breadth measurements were used. For each breadth measurement, one standard deviation value and 3 mm (space for impression materials) was added to both sides of the tray (Fig. 3.6). For palate depth, only one depth of 10 mm was used. This was to ensure that all palate depths (deep and shallow) will be accommodated by the trays.

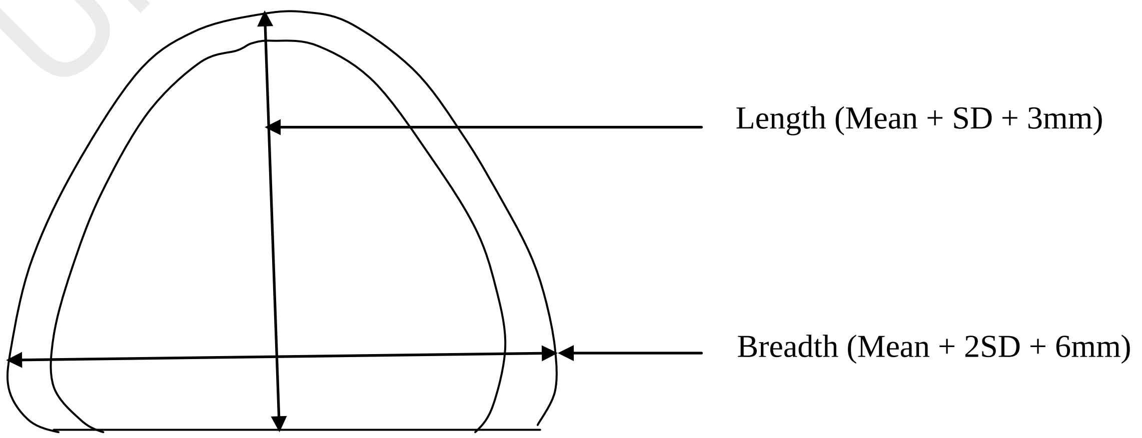


Figure 3.6: Measurements used for making acrylic resin trays for each cluster.

3.9.1.2 Construction of acrylic resin trays

The shapes of the trays were printed out and measurements verified directly with an mm ruler (Fig.3.7).

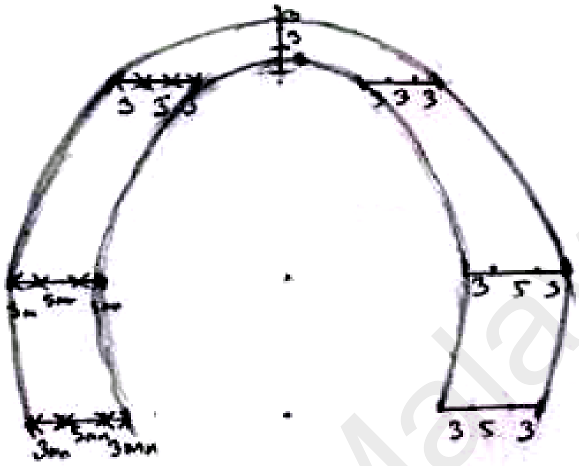


Figure 3.7: Print out of the length and breadth of each tray.

The shapes were then outlined on 3 sheets of shellac base plate material. These shellac base plates were used to indicate the shape of the moulds for the trays. The moulds were made from modelling wax. The box part of the trays was made to be approximately 16 mm wide (accounting for 10 mm of teeth width and 3mm on both sides of the teeth for the impression material). Only one height of 10 mm was used as the palate depth (Fig. 3.8).

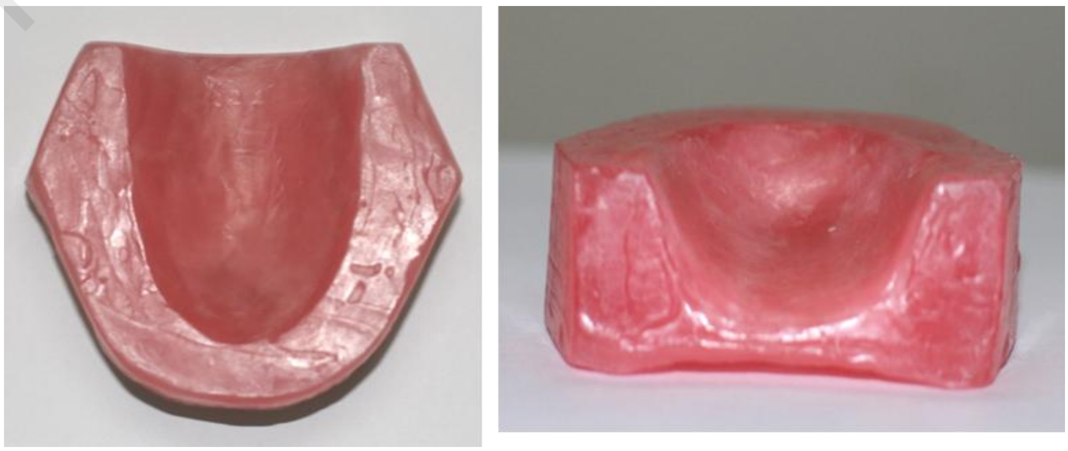


Figure 3.8: Wax moulds for making acrylic resin trays.

Alginate impression material was used to make an impression of the moulds and Plaster of Paris was used as backing support for the alginate impressions. Dental stone was then poured into the impression to obtain a model for making the trays. Before that, a round 8 bur was used to drill 3 holes of 3 mm deep on the surface of each model as a stop to maintain an even depth of impression materials. Light cure acrylic resin tray material (Huge Dental Light Curing Tray, Shanghai, China) was used to make the acrylic resin trays. The trays were perforated as a means of retention for the impression materials to be used (Fig. 3.9).

Figure 3.9: Acrylic resin trays fabricated using mean values of 3 clusters from the control group.

3.9.1.3 Testing the fabricated trays

In the pilot study, plasticine was used as the impression materials for convenience and simplicity. A jig was used so that the plasticine was loaded in a standardized and vertical manner, such that the cast is brought into the impression materials with the labial surface of the central incisors being 3 mm away from the edge of the tray (Fig. 3.10 and Fig. 3.11).

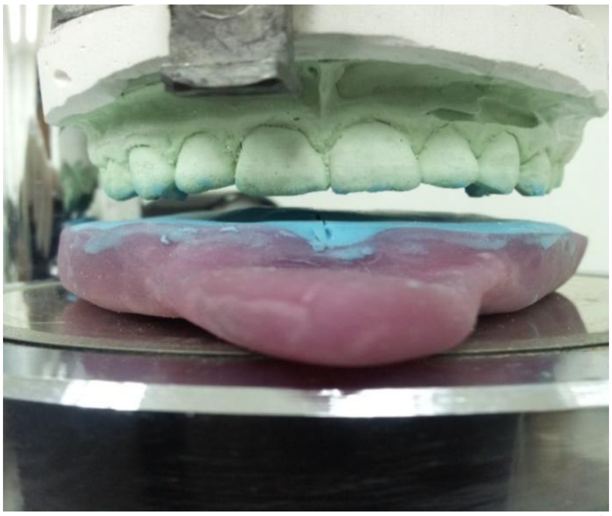


Figure 3.10: A cast being brought down into the loaded tray with the labial surface of the central incisors 3 mm away from the edge of the tray.

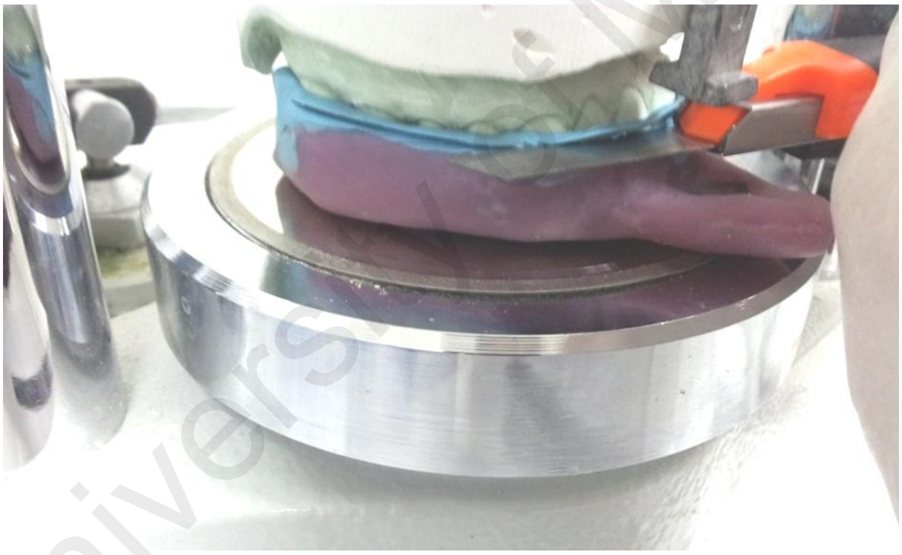


Figure 3.11: Cast seated in the impression tray vertically using a jig.

Once seated, the cast was carefully removed from the tray. Excess plasticine was removed with a sharp blade to ensure minimal distortion of the plasticine. The space for the impression materials was measured from the edge of the tray to the tips of the maxillary teeth on the cast (Fig. 3.12).

Figure 3.12: Space for impression materials.

3.9.2 Calculations for space for impression materials in the trays

The technique used in the pilot study above had the following limitations:

i. It was time consuming to construct the trays.

ii. The trays had to be loaded in a standardized way: always vertical and the labial surface of the central incisors should always be 3 mm away from the edge of the tray.

iii. The plasticine may distort as the cast was removed from the tray.

Due to the limitations of the above technique to measure the space for impression materials, a technique used by Ogden *et al.* (1994) was adopted. Using the 41 test casts, the measurements of each cast at each variable were compared to the measurements of the same variable for the tray that the test cluster belongs to.

For length and breadth, the measurements used were as shown in Fig. 3.6. For palate depth, 2 tray heights were used for each tray:

i. Deep palate: One standard deviation and 3 mm space for impression materials were subtracted from the mean palate depth values.

ii. Shallow palate: As each cluster had casts with deep, moderate and shallow palates, a second palate height was made by further reducing 4 mm from the values in (i) to accommodate the shallower palates.

The discrepancy between each dental cast and the tray measurements indicate the space for impression materials. If a tray fitted the cast appropriately, there should be an optimum space of 2-4 mm between the cast and the tray.

CHAPTER 4: RESULTS

4.1 Descriptive statistics of the control sample

Based on the D'Agostino-Pearson Omnibus normality test results, only LCIC, BCC and BHNHN measurements were not-normally distributed (p = 0.05). The median was then used as a summary statistic for these 3 measurements (Table 4.1).

Table 4.1: Summary statistics (mm) of control casts (n=82).

Variable	Mean (SD)	Median (IQR)	Min	Max	95% CI
LCIC*		10.75 (1.92)	8.22	12.97	(10.23, 11.11)
LCIP1	16.03 (1.77)		12.23	20.27	(15.65, 16.42)
LCIP2	22.76 (2.19)		17.70	27.67	(22.28, 23.24)
LCIM1	28.75 (2.25)		23.40	32.89	(28.25, 29.24)
LCIM2	39.22 (2.98)		33.16	46.48	(38.57, 39.88)
LCIHN	55.55 (3.59)		48.14	62.78	(54.77, 56.34)
BCC*		35.17 (1.99)	30.49	38.16	(34.70, 35.62)
BP1P1	43.06 (1.91)		37.88	46.68	(42.64, 43.48)
BP2P2	47.94 (2.10)		43.26	52.70	(47.48, 48.40)
BM1M1	53.53 (2.59)		47.89	60.20	(52.96, 54.10)
BM2M2	59.57 (3.04)		54.30	67.09	(58.90, 60.24)
BHNHN*		50.88 (4.04)	46.34	60.58	(49.99, 52.12)
DCC	8.60 (1.27)		5.60	12.54	(8.32, 8.88)
DP1P1	15.05 (1.95)		11.25	20.16	(14.62, 15.48)
DP2P2	19.15 (2.01)		15.21	23.66	(18.71, 19.59)
DM1M1	20.63 (1.90)		16.30	24.96	(20.21, 21.04)
DM2M2	19.79 (2.31)		14.58	24.32	(19.29, 20.30)
DHNHN	15.95 (2.03)		11.13	20.91	(15.50, 16.39)

IQR: Inter-quartile range
* Measurements are not normally distributed.

4.2 Descriptive statistics of the test sample

Table 4.2: Summary statistics (mm) of test casts (n=41).

Variable	Mean (SD)	Median (IQR)	Min	Max	95% CI
LCIC	8.94 (1.05)		7.00	12.00	(8.61, 9.27)
LCIP1*		16.18 (2.29)	13.40	20.93	(15.41, 16.80)
LCIP2	22.65 (2.09)		19.20	27.64	(21.99, 23.31)
LCIM1	28.94 (2.58)		25.10	34.91	(28.12, 29.75)
LCIM2	39.36 (2.76)		34.74	46.50	(38.49, 40.23)
LCIHN	55.01 (3.89)		48.07	62.68	(53.79, 56.24)
BCC	34.26 (1.64)		29.80	38.13	(33.74, 34.78)
BP1P1	42.50 (2.47)		36.58	47.48	(41.72, 43.28)
BP2P2	48.27 (2.66)		41.53	53.17	(47.44, 49.11)
BM1M1	53.71 (3.41)		49.95	62.35	(52.63, 54.78)
BM2M2	59.35 (4.06)		50.65	68.21	(58.07, 60.64)
BHNHN*		50.54 (4.99)	44.31	63.09	(49.49, 51.76)
DCC	7.72 (1.06)		6.04	10.72	(7.39, 8.05)
DP1P1*		13.59 (3.08)	11.43	19.00	(13.07, 14.45)
DP2P2	18.44 (1.90)		14.27	22.74	(17.84, 19.04)
DM1M1	20.66 (1.84)		16.49	24.25	(20.08, 21.24)
DM2M2	19.94 (2.56)		14.56	24.41	(19.13, 20.75)
DHNHN	15.39 (2.30)		10.58	20.87	(14.66, 16.11)

IQR: Inter-quartile range
* Measurements are not normally distributed

4.3 Summary statistics of the three established clusters

The agglomerative hierarchical clustering of the 82 control samples established 3 clusters of dental arches (verified by the 41 test casts). LCIC and BCC measurements in Cluster I were not-normally distributed (p = 0.05). The median was used as a summary statistic for these 2 measurements (Table 4.2).

Table 4.3: Summary statistics (mm) of control casts in Cluster I (n=32).

Variable	Mean (SD)	Median (IQR)	Min	Max	95% CI
LCIC*		10.32 (2.26)	8.34	12.19	(9.39, 11.22)
LCIP1	16.27 (1.68)		12.97	20.27	(15.57, 16.88)
LCIP2	22.98 (1.88)		17.70	27.37	(22.30, 23.66)
LCIM1	29.01 (1.98)		24.97	32.49	(28.29, 29.72)
LCIM2	39.66 (3.03)		33.65	46.48	(38.57, 40.76)
LCIHN	57.01 (3.52)		50.73	62.78	(55.74, 58.28)
BCC*		35.60 (2.13)	30.49	38.16	(34.44, 36.34)
BP1P1	44.29 (1.61)		40.10	46.68	(43.71, 44.87)
BP2P2	49.35 (2.04)		45.11	52.70	(48.61, 50.09)
BM1M1	55.54 (1.98)		51.02	60.24	(54.83, 56.25)
BM2M2	61.88 (2.34)		56.93	67.09	(61.03, 62.72)
BHNHN	53.45 (2.67)		48.32	60.58	(52.49, 54.41)
DCC	8.37 (1.40)		5.60	12.54	(7.86, 8.88)
DP1P1	13.92 (1.70)		11.25	17.52	(13.30, 14.53)
DP2P2	18.39 (2.03)		15.21	22.76	(17.66, 19.12)
DM1M1	20.69 (2.14)		16.70	24.96	(19.91, 21.46)
DM2M2	20.44 (2.45)		15.94	24.32	(19.56, 21.32)
DHNHN	16.52 (2.04)		13.15	20.12	(15.79, 17.25)

IQR: Inter-quartile range
* Measurements are not normally distributed

Table 4.4: Summary statistics (mm) of control casts in Cluster II (n=38).

Variable	Mean (SD)	Median (IQR)	Min	Max	95% CI
LCIC	10.76 (1.26)		8.22	12.97	(10.35, 11.18)
LCIP1	16.53 (1.51)		12.47	19.37	(16.04, 17.02)
LCIP2	23.50 (1.87)		19.86	27.67	(22.28, 24.11)
LCIM1	29.48 (1.87)		24.34	32.89	(28.87, 30.10)
LCIM2	39.94 (2.48)		35.77	44.47	(39.13, 40.76)
LCIHN	55.06 (2.31)		51.82	61.07	(55.30, 56.82)
BCC	34.97 (1.25)		31.96	36.78	(34.56, 35.38)
BP1P1	42.43 (1.75)		37.88	45.33	(41.85, 43.01)
BP2P2	46.94 (1.57)		43.26	49.44	(46.42, 47.46)
BM1M1	52.30 (2.17)		47.89	56.51	(51.59, 53.01)
BM2M2*		59.97 (4.60)	54.43	62.99	(56.28, 59.35)
BHNHN	49.78 (1.88)		46.37	53.73	(49.16, 50.40)
DCC	8.58 (1.20)		6.44	11.64	(8.19, 8.98)
DP1P1	15.55 (1.81)		12.00	20.16	(14.96, 16.15)
DP2P2	19.74 (1.89)		17.06	23.66	(19.12, 20.36)
DM1M1	20.82 (1.70)		17.01	23.81	(20.26, 21.38)
DM2M2	19.73 (2.13)		15.44	23.66	(19.03, 20.43)
DHNHN	15.65 (1.96)		12.40	20.91	(15.00, 16.29)

IQR: Inter-quartile range
* Measurement BM2M2 not normally distributed

Table 4.5: Summary statistics (mm) of control casts in Cluster III (n=12).

Variable	Mean (SD)	Min	Max	95% CI
LCIC	10.72 (1.56)	8.33	12.59	(9.73, 11.71)
LCIP1	13.83 (1.06)	12.23	15.99	(13.16, 14.50)
LCIP2	19.84 (1.52)	17.75	22.35	(18.88, 20.81)
LCIM1	25.74 (1.60)	23.40	28.04	(24.72, 26.76)
LCIM2	35.77 (1.77)	33.16	38.92	(34.65, 36.90)
LCIHN	50.08 (1.52)	48.14	52.83	(49.11, 51.04)
BCC	34.09 (1.70)	31.55	37.04	(33.02, 35.17)
BP1P1	41.80 (1.33)	39.69	44.44	(40.96, 42.65)
BP2P2	47.37 (1.68)	44.76	50.42	(46.30, 48.43)
BM1M1	52.09 (1.85)	48.46	54.59	(50.91, 53.27)
BM2M2	57.80 (2.01)	54.30	61.01	(56.53, 59.08)
BHNHN	49.54 (1.91)	46.34	52.88	(48.33, 50.75)
DCC	9.27 (0.92)	7.82	10.62	(8.68, 9.85)
DP1P1	16.49 (1.45)	13.88	19.46	(15.57, 17.41)
DP2P2	19.32 (1.79)	15.51	21.49	(18.18, 20.46)
DM1M1	19.86 (1.77)	16.30	22.91	(18.74, 20.99)
DM2M2	18.29 (1.87)	14.58	20.40	(17.10, 19.48)
DHNHN	15.39 (2.06)	11.13	17.75	(14.08, 16.69)

All measurements are normally distributed

The measurements for length and breadth of the arches in each cluster were compared. Based on results of ANOVA for differences in means and Kruskal-Wallis test for differences in medians, only LCIC and BCC values are not significantly different (p<0.05) (Table 4.6).

Table 4.6: Results for differences in means for length and breadth measurements among all clusters.

Measurement	**Mean (SD)**			**Means significantly different (p<0.05)**
	Cluster I (n=32)	**Cluster II (n=38)**	**Cluster III (n=12)**	
LCIC*	10.32 (2.26)	10.76 (1.26)	10.72 (1.56)	No
LCIP1	16.27 (1.68)	16.53 (1.51)	13.83 (1.06	Yes
LCIP2	22.98 (1.88)	23.50 (1.87)	19.84 (1.52)	Yes
LCIM1	29.01 (1.98)	29.48 (1.87)	25.74 (1.60)	Yes
LCIM2	39.66 (3.03)	39.94 (2.48)	35.77 (1.77)	Yes
LCIHN	57.01 (3.52)	55.06 (2.31)	50.08 (1.52)	Yes
BCC*	35.60 (2.13)	34.97 (1.25)	34.09 (1.70)	No
BP1P1	44.29 (1.61)	42.43 (1.75)	41.80 (1.33)	Yes
BP2P2	49.35 (2.04)	46.94 (1.57)	47.37 (1.68)	Yes
BM1M1	55.54 (1.98)	52.30 (2.17)	52.09 (1.85)	Yes
BM2M2*	61.88 (2.34)	59.97 (4.60)	57.80 (2.01)	No
BHNHN	53.45 (2.67)	49.78 (1.88)	49.54 (1.91)	Yes

4.4 Palate depths in control and test casts

When palate depths were classified, both control and test casts contain palate heights which could be classified into deep, moderate and shallow (Table 4.7). Therefore in each cluster, there were casts which could be classified as having deep, moderate and shallow palates.

Table 4.7: Palate heights of the sample studied.

Palate height	Control sample (82) n (%)	Test Sample (41) n (%)
Deep	22 (26.8)	8 (19.5)
Moderate	46 (56.1)	26 (63.4)
Shallow	14 (17.1)	7 (17.1)

4.5 Calculated dimensions for stock trays

The present study indicated that 3 sizes of stock trays may be sufficient to accommodate a sample of the population studied. The trays are shown individually and superimposed on top of each other in Fig. 4.1.

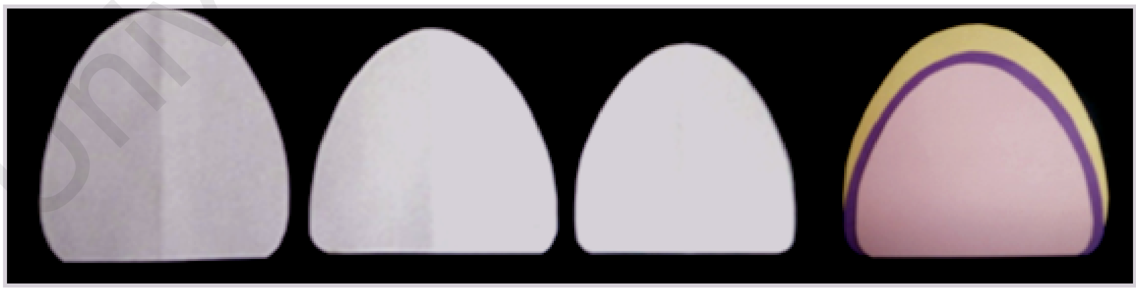


Figure 4.1: Schematic drawing to show the different trays.

The dimensions of the individual trays are shown in Table 4.8.

Table 4.8: Measurements of the proposed trays in mm.

Measurement	Tray I	Tray II	Tray III
LCIHN	63.52	61.37	54.60
BCC	44.75	43.46	43.48
BP1P1	53.51	51.93	50.46
BP2P2	59.43	56.09	56.72
BM1M1	65.49	62.63	61.79
BM2M2	72.55	69.46	67.82
BHNHN	64.79	59.54	59.35
DCC	3.96	4.38	5.35
DP1P1	9.22	10.75	12.04
DP2P2	13.37	14.85	14.53
DM1M1	15.55	16.12	15.10
DM2M2	14.99	14.59	13.41
DHNHN	11.48	10.68	10.33

*All palate depth measurements represent calculated depths (deep palate).

4.6 Classification of space for impression material

The adequacy of the impression materials is assessed by the thickness of the impression materials that is present between the tray and the tissue impressed. In this study, the following classification was used (Table 4.9).

Table 4.9: Classification of impression materials thickness.

Space for impression materials	Category
<2 mm	Not enough space
2-4 mm	Optimum space
4-9 mm	A lot of space
>9 mm	Too much space

4.6.1 Box and whisker plots

Box and whisker diagrams were used to display the calculated space available for impression materials, which could either be irreversible hydrocolloids (alginates) and non-aqueous impression materials. The box plot shows the median as a horizontal line inside the box and the inter-quartile range as the length of the box. The minimum and maximum values are represented by the whiskers. A box plot that is symmetric with the median line at approximately the centre of the box and with symmetric whiskers suggests that the data may have come from a normal distribution. Tables of the space for impression material are also presented.

4.6.1.1 Space for impression material when length measurements of trays were assessed

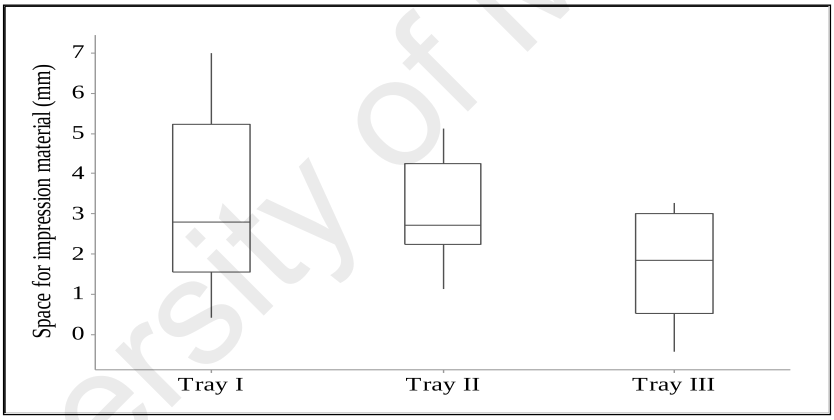


Figure 4.2: Space available when LCIHN measurements of trays were compared with LCIHN measurements of maxillary casts in each cluster.

Table 4.10: Space available for impression material for LCIHN measurements.

Space	Tray I	Tray II	Tray III
<2 mm	5 (31.25%)	3 (18.75%)	5 (55.55%)
2-4 mm	6 (37.50%)	8 (50%)	4 (44.44%)
4-9 mm	5 (31.25%)	5 (31.25%)	0
>9 mm	0	0	0

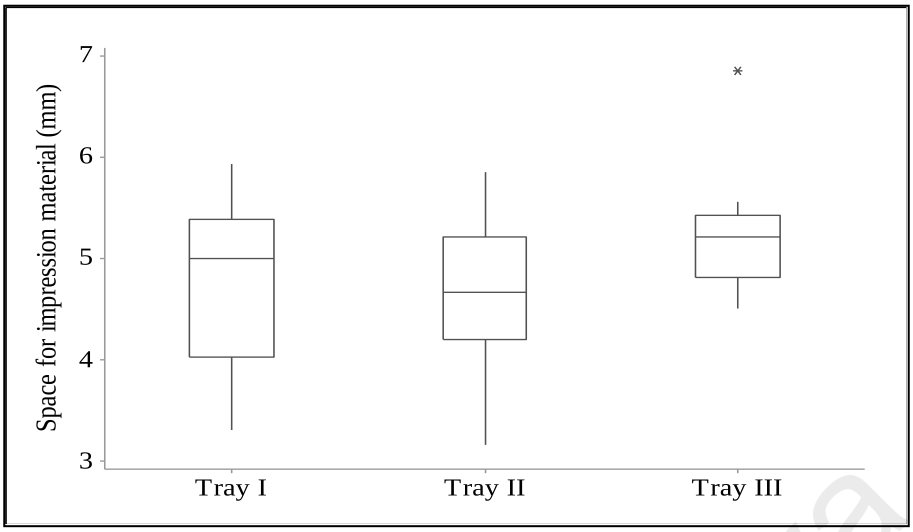


Figure 4.3: Space available when BCC measurements of trays were compared to BCC measurements of casts in each cluster.

Table 4.11: Space available for impression material for BCC measurements.

Space	Tray I	Tray II	Tray III
<2 mm	0	0	0
2-4 mm	4 (25%)	3 (18.8%)	0
4-9 mm	12 (75%)	13 (81.3%)	9 (100%)
>9 mm	0	0	0

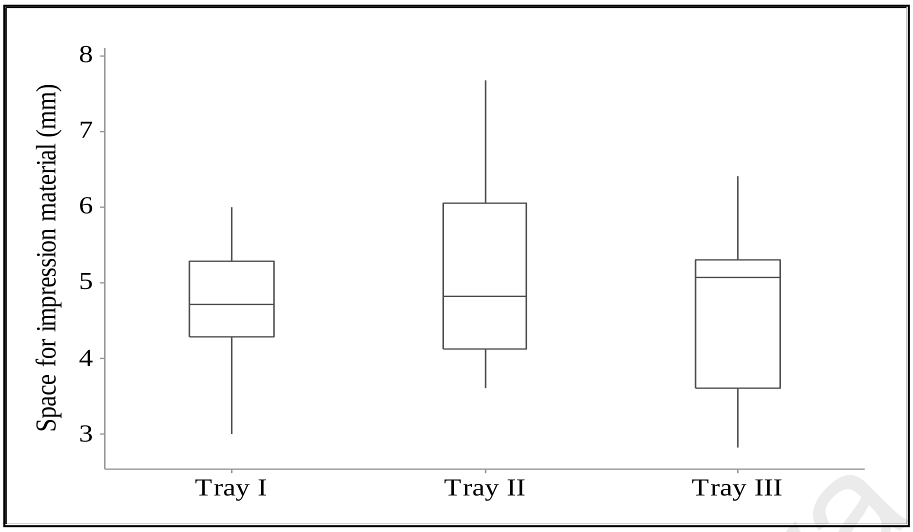


Figure 4.4: Space available when BP1P1 measurements of trays were compared to BP1P1 measurements of casts in each cluster.

Table 4.12: Space available for impression material for BP1P1measurements.

Space	Tray I	Tray II	Tray III
<2 mm	0	0	0
2-4 mm	3 (18.8%)	3 (18.8%)	2 (22.2%)
4-9 mm	13 (81.3%)	13 (81.3%)	7 (77.8%)
>9 mm	0	0	0

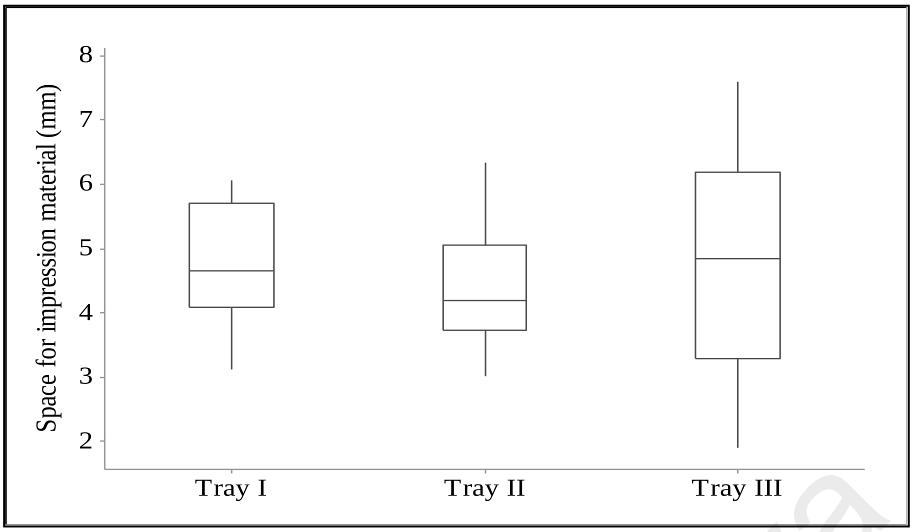


Figure 4.5: Space available for impression materials when BP2P2 measurements of trays were compared to BP2P2 measurements of casts in each cluster.

Table 4.13: Space available for impression material for BP2P2 measurements.

Space	Tray I	Tray II	Tray III
<2 mm	0	0	1 (11.1%)
2-4 mm	3 (18.8%)	7 (43.8%)	1 (11.1%)
4-9 mm	13 (81.3%)	9 (56.3%)	7 (77.8%)
>9 mm	0	0	0

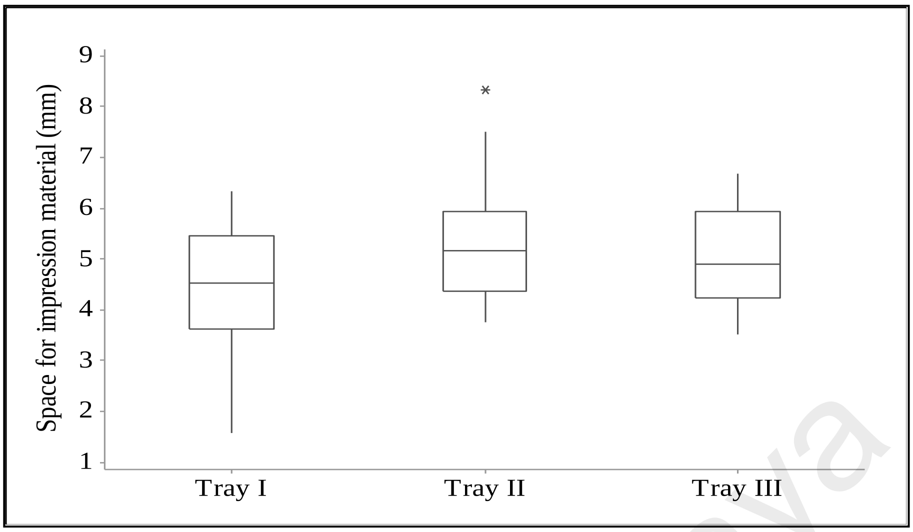


Figure 4.6: Space available for impression material when BM1M1 measurements of trays were compared to BM1M1 measurements of casts in each cluster.

Table 4.14: Space available for impression material for BM1M1 measurements.

Space	Tray I	Tray II	Tray III
<2 mm	1 (6.3%)	0	0
2-4 mm	3 (18.8%)	3 (18.8%)	1 (11.1%)
4-9 mm	12 (75%)	13 (81.3%)	8 (88.9%)
>9 mm	0	0	0

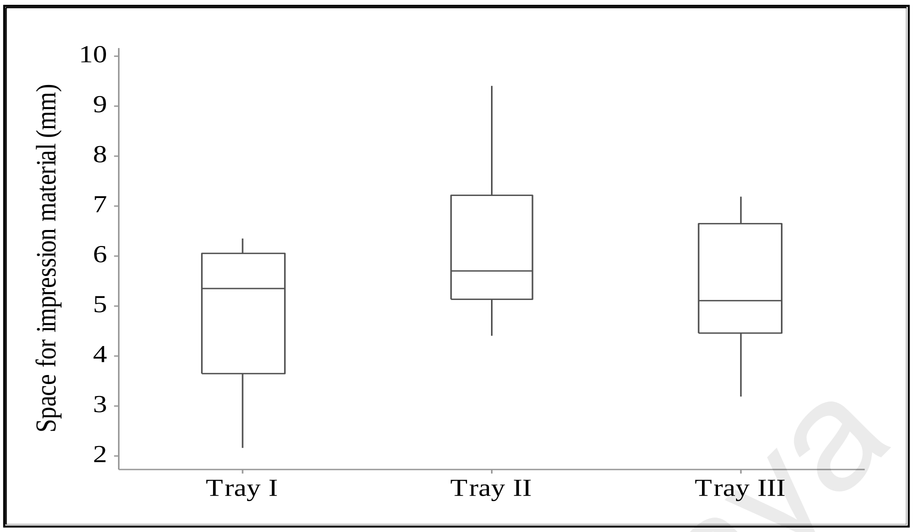


Figure 4.7: Space available for impression material when BM2M2 measurements of tray were compared to BM2M2 measurements of casts in each cluster.

Table 4.15: Space available for impression material for BM2M2 measurements.

Space	**Tray I**	**Tray II**	**Tray III**
<2 mm	0	0	0
2-4 mm	5 (31.3%)	0	1 (11.1%)
4-9 mm	11 (68.8%)	15 (93.8%)	8 (88.9%)
>9 mm	0	1 (6.3%)	0

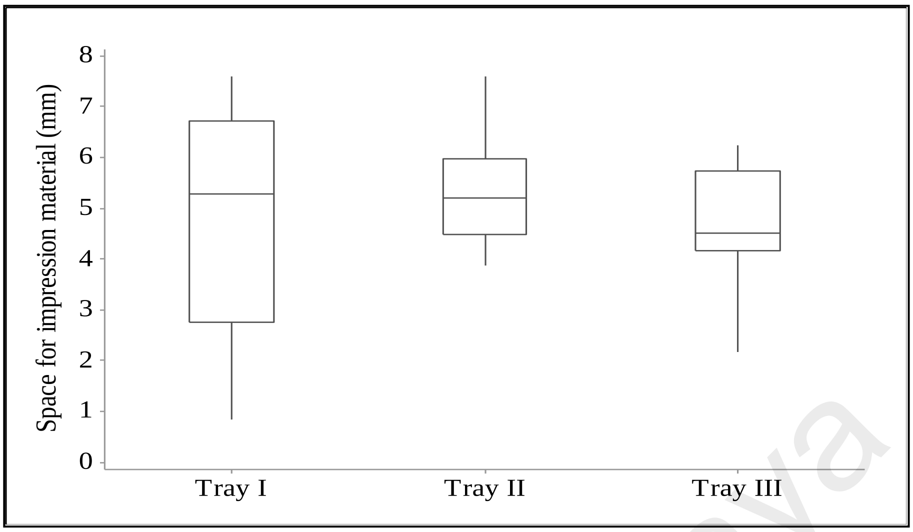


Figure 4.8: Space available for impression material when BHNHN measurements of trays were compared to BHNHN measurements of casts in each cluster.

Table 4.16: Space available for impression material for BHNHN measurements.

Space	Tray I	Tray II	Tray III
<2 mm	2 (12.5%)	0	0
2-4 mm	3 (18.8%)	2 (12.5%)	1 (11.1%)
4-9 mm	11 (68.8%)	14 (87.5%)	8 (88.9%)
>9 mm	0	0	0

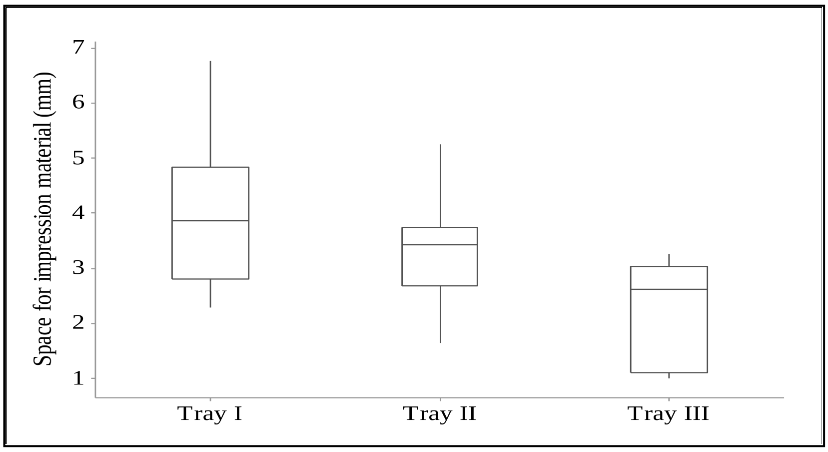


Figure 4.9: Space available for impression material when DCC measurements of trays (deep palate) were compared to DCC measurements of casts in each cluster.

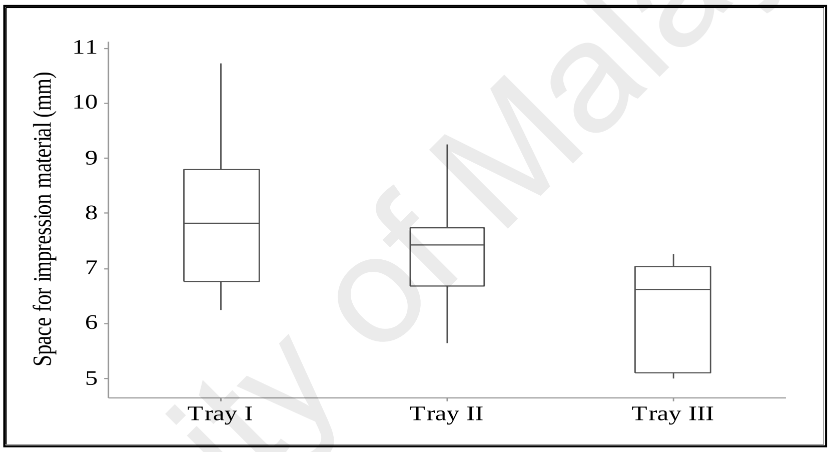


Figure 4.10: Space available for impression material when DCC measurements of trays (shallow palate) were compared to DCC measurements of casts in each cluster.

Table 4.17: Space available for impression material for DCC measurements.

Space (mm)	Tray I		Tray II		Tray III	
	Deep	Shallow	Deep	Shallow	Deep	Shallow
<2	0	0	1 (6.3%)	0	4 (44.4%)	0
2-4	11 (68.8%)	0	12 (75%)	0	5 (55.6%)	0
4-9	5 (31.3%)	12 (75%)	3 (18.8%)	15 (93.8%)	0	9 (100%)
>9	0	4 (25%)	0	1 (6.3%)	0	0

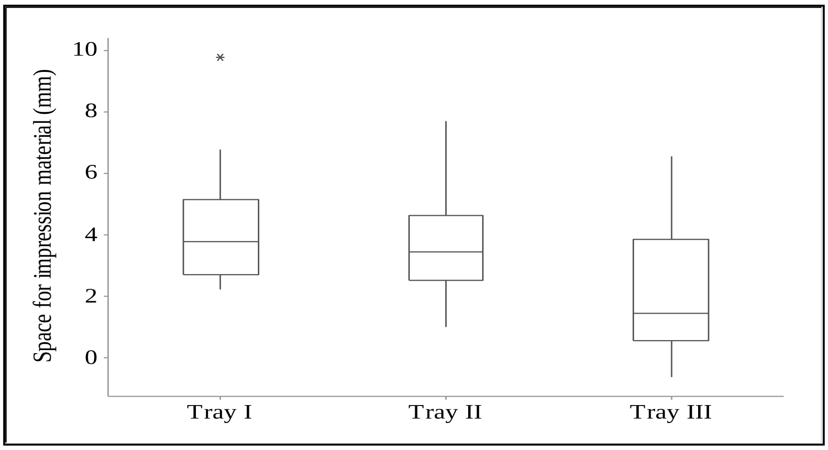


Figure 4.11: Space available for impression material when DP1P1 measurements of tray (deep palate) were compared to DP1P1 measurements of casts in each cluster.

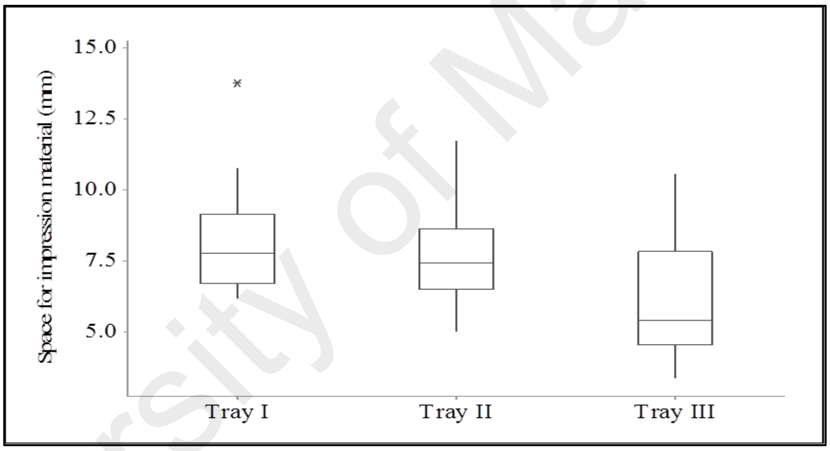


Figure 4.12: Space available for impression material when DP1P1 measurements of tray (shallow palate) were compared to DP1P1 measurements of casts in each cluster.

Table 4.18: Space available for impression material for DP1P1 measurements.

Space (mm)	Tray I		Tray II		Tray III	
	Deep	Shallow	Deep	Shallow	Deep	Shallow
<2	0	0	3 (18.8%)	0	5 (55.6%)	0
2-4	10 (62.5%)	0	7 (43.8%)	0	2 (22.2%)	2 (22.2%)
4-9	5 (31.3%)	12 (75%)	6 (37.5%)	14(87.5%)	2 (22.2%)	6 (66.7%)
>9	1 (6.25%)	4 (25%)	0	2 (12.5%)	0	1 (11.1%)

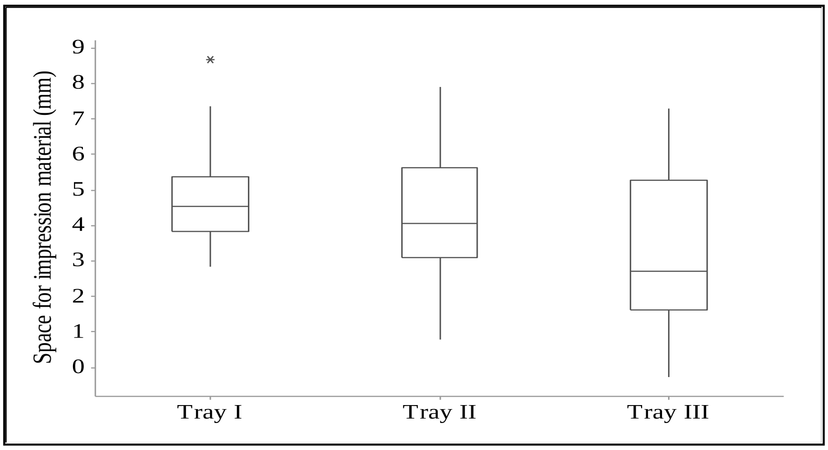


Figure 4.13: Space available for impression material when DP2P2 measurements of trays (deep palate) were compared to DP2P2 measurements of casts in each cluster.

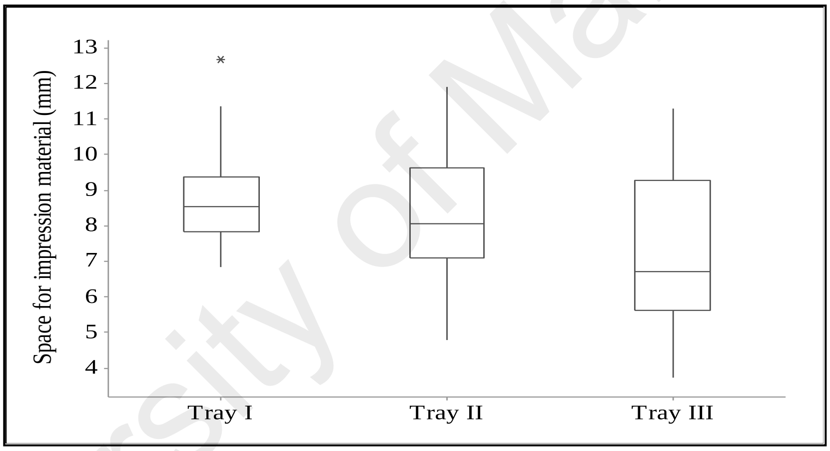


Figure 4.14: Space available for impression material when DP2P2 measurements of trays (shallow palate) were compared to DP2P2 measurements of casts in each cluster.

Table 4.19: Space available for impression material for DP2P2 measurements.

Space (mm)	Tray I		Tray II		Tray III	
	Deep	Shallow	Deep	Shallow	Deep	Shallow
<2	0	0	3 (18.8%)	0	2 (22.2%)	0
2-4	5 (31.3%)	0	4 (25.0%)	0	4 (44.4%)	1 (11.1%)
4-9	11 (68.8%)	11 (68.8%)	9 (56.3%)	10(62.5%)	3 (33.3%)	6 (66.7%)
>9	0	5 (31.3%)	0	6 (37.5%)	0	2 (22.2%)

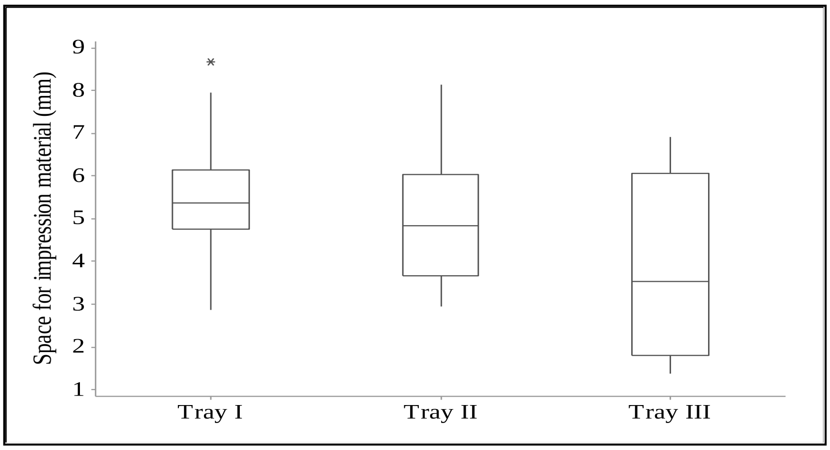


Figure 4.15: Space available for impression material when DM1M1 measurements of trays (deep palate) were compared to DM1M1 measurements of casts in each cluster.

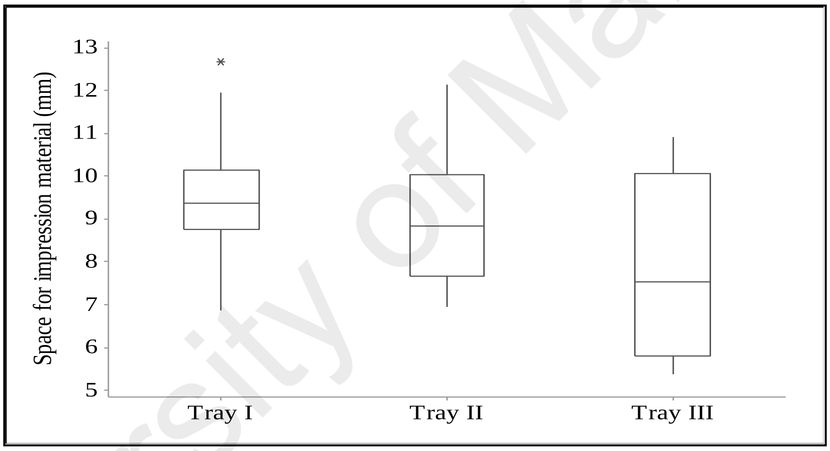


Figure 4.16: Space available for impression material when DM1M1 measurements of trays (shallow palate) were compared to DM1M1 measurements of casts in each cluster.

Table 4.20: Space available for impression material for DM1M1 measurements.

Space (mm)	Tray I		Tray II		Tray III	
	Deep	Shallow	Deep	Shallow	Deep	Shallow
<2	0	0	0	0	2 (22.2%)	0
2-4	1 (6.25%)	0	4 (25.0%)	0	4 (44.4%)	0
4-9	15 (93.8%)	6 (37.5%)	12 (75.0%)	10(62.5%)	3 (33.3%)	6 (66.7%)
>9	0	10 (62.5%)	0	6 (37.5%)	0	3 (33.3%)

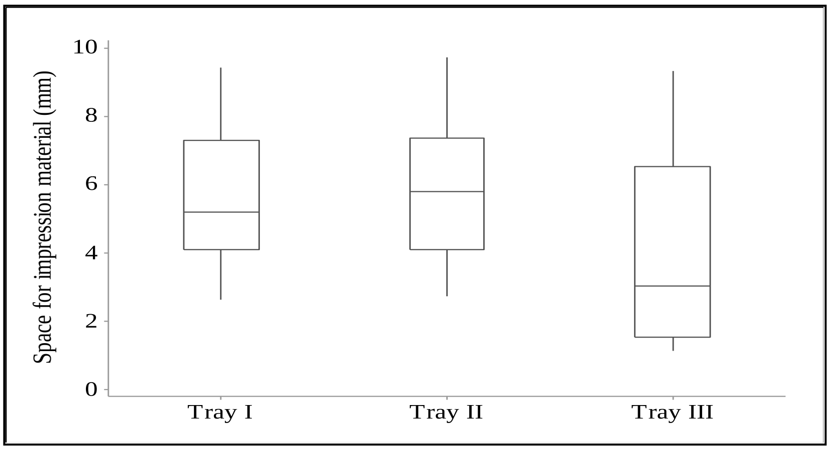


Figure 4.17: Space available for impression material when DM2M2 measurements of trays (deep palate) were compared to DM2M2 measurements of casts in each cluster.

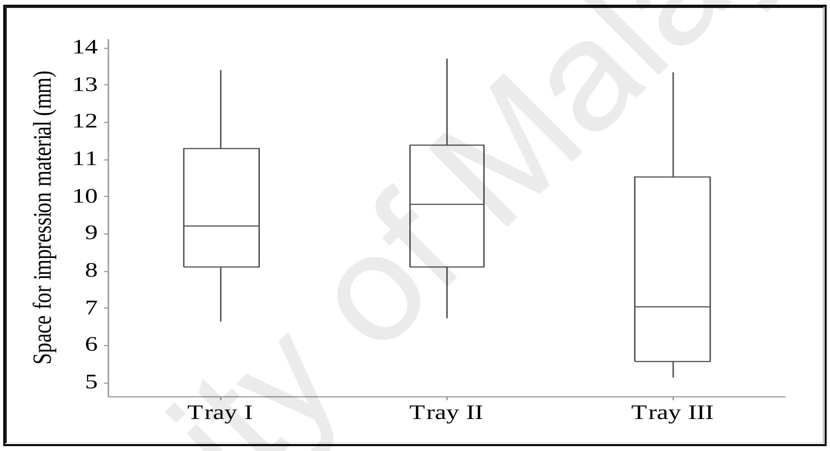


Figure 4.18: Space available for impression material when DM2M2 measurements of trays (shallow palate) were compared to DM2M2 measurements of casts in each cluster.

Table 4.21: Space available for impression material for DM2M2 measurements.

Space (mm)	**Tray I**		**Tray II**		**Tray III**	
	Deep	Shallow	Deep	Shallow	Deep	Shallow
<2	0	0	0	0	2 (22.2%)	0
2-4	3 (18.8%)	0	4 (25.0%)	0	4 (44.4%)	0
4-9	11 (68.8%)	7 (43.8%)	11 (68.8%)	4 (25.0%)	3 (33.3%)	6 (66.6%)
>9	2 (12.5%)	9 (56.3%)	1 (6.3%)	12 (75.0%)	0	3 (33.3%)

CHAPTER 5: DISCUSSION

The current study was measured dimensions of Malay maxillary dental arches in order to provide dimensions to design stock impression trays suitable to the Malay arches. Only the Malay dental arches were studied, as they form slightly more than 50% of the Malaysian population. Malaysia is a multiracial country, and the other major ethnic groups are Chinese (25% of the population) and Indians (7% of the population), besides other minority ethnic groups. Isa *et al.* (2011) had studied a sample of Malay, Chinese and Indian ethnic groups, and found that the sample studied could be grouped into 3 clusters, without any discrimination by ethnic group or gender. This justifies the use of only the Malay ethnic group in this study, as they are the more predominant ethnic group in the setting of the study.

Frequently in clinical practice, stock impression trays need to be modified before use (Bomberg *et al.* 1985; Beal, 2007). An earlier study Omar and Isa (2006) had determined that 41.3% of their subjects could not be accommodated in length by available stock trays. These subjects had arch lengths longer than 57 mm. The longest arch length in this study is 55.6 ± 3.59 mm, measured from the labial surface of the central incisors to the joining point of hamular notches (Table 4.1). This may imply that some of the subjects in this study would also not be accommodated by the available stock trays. The largest width of the arches in this study was at the second molar region, which has a value of 59.57 ± 3.04 mm (Table 4.1). This is different from the finding of Omar and Isa (2006), where there were subjects with arch width of more than 72 mm. With regard to palate depth, the subjects in this study had maximum palate depths up to 20 mm, as in the study of Omar and Isa (2006) and commercially available stock trays only have one palate depth (about 10 mm). This would always necessitate pre-packing of the trays to accommodate the deeper palates.

Thus, the aim of the present study was to design ideal stock impression trays for the Malay ethnic group. As the arches may have variations in length, width and palate depths, it was practical to group the arches so as to design trays for individual clusters or groups of arches using cluster analysis techniques. In this study, 82 casts were used as the control casts to cluster the arches, and 41 test casts used to verify the clusters (Table 4.1 and 4.2). Isa *et al.* (2011) used 124 casts as the control samples and 40 casts as the test casts. A dental arch consists of many variables, and each variable is dependent on the other. For this reason, the variables measured were assessed using multivariate techniques. This study measured arch length, width and palate depths (18 reference points) by direct techniques. Isa *et al.* (2011) used scanned images of dental casts (14 measurement points) and used quadratic curves to represent the arches. However, using the agglomerative hierarchical clustering technique, they also determined that the casts in their study could be grouped into 3 clusters.

The results of the clustering of the arches are shown in Tables 4.3 to 4.5. Even though grouped using multivariate techniques, Table 4.6 shows that the apart from the length of the arches and the anterior width at the canine region, the means of length and width variables are statistically significant ($p<0.05$). This can be seen graphically when trays are made for these clusters (Fig. 4.1). Even though statistically, the palate depths in all clusters are significantly different (Table 4.6), all clusters contain arches with deep, moderate and shallow palates (Table 4.7). Clustering of the arches with just length and width variables (omitting the palate depth variables) produced 12 groups, and this is not feasible for tray designing. Therefore, the palate depths were included. When clustering of the arches arrived at a feasible number of clusters that was used to design stock trays, suitable for the sample studied.

Table 4.8 shows the dimensions of the proposed trays for each cluster in this study. Omar and Isa (2006) measured 4 commercially available stock trays. However, they only provided the largest dimensions of the trays. The longest tray was about 62 mm and the widest was about 75 mm. All trays had the same palate depth, i.e. about 10 mm. After allowances made for 4 mm of space for impression material, the longest tray in this study was calculated to be 64 mm. Two other tray lengths are 62 mm and the shortest tray is 55 mm. The widest tray in this study was 73 mm at the second molar region. The other widths are 70 mm and 68 mm.

Table 4.9 shows the classification used to determine the amount of space for impression materials in the study. A value of 2-9 mm was chosen as acceptable as studies had shown that although 2.0 to 2.5 mm of tray spacing produced the most accurate impressions, a space up to 9 mm did not produce any clinically significant differences in the resultant casts (Rueda *et al.*, 1995; Millstein *et al.*, 1998; Patil *et al.*, 2008).

When the sizes of the impression trays were compared with the size of arches to determine the space for impression materials, it was found that:

(a) ***For arch length measurements:***

Figure 4.2 shows impression materials thickness of casts using 3 trays by box plots as percentile while Table 4.10 shows the numerical values. For length measurements the LCIHN variable demonstrated less than 2 mm in case of 31.2% casts with tray I, 18.7% casts with tray II and 55.5% casts with tray III while rest of the casts fall into optimum space and a lot of space category. This may not be clinically significant as the length measurements were made up to the hamular notches. Previously, Omar and Isa (2006) observed inadequate space for impression materials with stock trays in 41.3% of their population studied. This agrees with the finding of Wiland (1971) who observed that several mouths just barely fit the length of the largest tray tested and suggested that the length of stock trays be increased.

(b) ***For arch breadth measurements:***

For breadth measurements, Figures 4.3, 4.4, 4.5, 4.6, 4.7 and Figure 4.8 along with Tables 4.11, 4.12, 4.13, 4.14, 4.15 and Table 4.16 demonstrated the suitability of all 3 trays at canine, first premolar, second premolar, first molar, second molar and hamular notch regions. Generally, all suggested tray sizes accommodated the test casts with optimum and a lot of space (between 2-9 mm of space). These results indicate the acceptance and accuracy of proposed tray design for breadth measurements of the arches studied. In earlier studies, Omar and Isa (2006) found inadequate impression materials space for only 5.6% of the population studied with available stock trays and Wiland (1971) observed little or no variation in anterior and posterior widths of the stock trays when compared with diagnostic casts. Using edentulous casts Ogden *et al.* (1994) found that 86% of the casts were narrower than the trays in the canine region, and 80% of the casts were narrower in the molar region.

(c) ***For palate depth measurements:***

The impression materials thickness for deep palate is presented in Figures 4.9, 4.11, 4.13, 4.15 and Figure 4.17 while for shallow palate in Figures 4.10, 4.12, 4.14, 4.16 and Figure 4.18 along with Tables 4.17, 4.18, 4.19, 4.20 and Table 4.21. For all trays, 2 palate depths were needed so that both deep and shallow palates are accommodated for. This supports the finding of Omar and Isa (2006) where they found that none of the available stock trays they tested could accommodate the depth of maxillary arches properly without pre-packing impression materials. This is because most available trays have flat shallow palates. Ogden *et al.* (1994) found that 80% of edentulous stock trays were too shallow at the posterior palatal region, 81% trays were too shallow at the canine region and 48% of trays were too shallow at the molar region.

In this study, the results of the 95% confidence interval values of measurement variables in the control sample, test sample and 3 clusters (Tables 4.1 to 4.5) show that the samples collected were from the same population. However, the distribution of variables into 3 clusters was distinct (Table 4.6). This was consistent with the finding of Isa *et al.* (2011) who found 3 clusters of dental arches, and Nakatsuka *et al.* (2011) who found that the arches could be grouped into 4 clusters. Both these studies used multivariate measurements of the arch form obtained from scanned images of dental casts and used mathematical coordinate systems and functions to define forms of dental arches.

CHAPTER 6: CONCLUSIONS

1. Using the AHC method and using direct measurements of the length, width and palate depths of the maxillary dental arches simultaneously, 3 clusters of dental arches of the Malay sample was obtained.
2. The clusters may be described as follows:
   a. The clusters were not significantly different in anterior length and width (at the canine region), but were significantly different in all the other length and width variables.
   b. The longer arches may be related to the wider arches. Cluster I had the longest and widest arch and Cluster III had the shortest and narrowest arch.
   c. However, all clusters had arches with deep, moderate and shallow palate depths.
3. In general, 3 stock trays with 2 palate depths were made according to the mean measurements of the variables used to define the clusters provided adequate or more than enough space for the impression materials in all clusters by length, width and palate depth.
4. Two palate depths had to be used for each stock tray (shallow and deep) to accommodate the deep, moderate and shallow palates presents in all clusters.

6.1 Limitation of the study

1. Limitation in time and cost. The study was only carried out in the Faculty of Dentistry, University of Malaya and only involved the Malay ethnic group.
2. The sample is limited to subjects with regular dental arches.
3. The arch dimensions are only related to length, width and palate depths of the dental arches, and did not consider the buccal bone measurements that would also need to be made an impression tray.

4. Palatal shape was not considered in the study, and the depth measurement was only measured at the midline.

6.2 Suggestions for further study

1. It would be beneficial if 3D scanners can be used to scan and measure arches in 3D.
2. Mathematical functions, rather than 2D linear measurements may be better to relate size and shape of arches.
3. Other dimensions of the tray should be considered. For example, a tray has vertical flanges, and the buccal bone of a tooth is at an angle to buccal surface of the tooth.
4. The inclination of the labial and palatal aspect of the anterior and posterior arch in relation to the impression tray design need to be further studied. Cross arch palatal forms may have steep anterior inclines, curved or flat palates in the mid-palatal and posterior sections.

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LIST OF PUBLICATIONS AND PAPERS PRESENTED

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