Original Communication

MORPHOLOGY OF THE HARD PALATE: A STUDY OF DRY SKULLS AND REVIEW OF THE LITERATURE

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RESUMEN

El objetivo de este estudio fue determinar la morfología del paladar duro para proporcionar directrices a los profesionales. Para dichos propósitos se midió el paladar duro de 63 cráneos de sexo y edad desconocidos, provenientes de una población del subcontinente Indio. Las medias y las desviaciones estándar de los siguientes parámetros fueron: anchura máxima del foramen palatino mayor, 2,3 ± 0,5 mm; anchura máxima del foramen palatino menor, de 0,9 ± 0,4 mm; anchura máxima del foramen incisivo, 4,08 ± 0,99 mm; distancia inter-alveolar de canino a canino, 23,5 ± 2,2 mm; distancia entre los forámenes palatinos mayores izquierdo y derecho, 27,6 ± 2,77 mm; anchura del paladar, 37,97 ± 3,32 mm; longitud palatal, 52,2 ± 3,2 mm; altura del paladar, 11,54 ± 2,4 mm; distancia entre el orificio palatino mayor a la base del hamulus pterigoideo, 8,7 ± 2,2 mm; distancia del foramen palatino mayor a la sutura maxilar mediana, 13,8 ± 1,5 mm; ángulo entre la línea media y la línea entre el foramen oral y el foramen palatino mayor, 16,45 ± 1,600. En esta investigación, los tipos más frecuentes de índice palatino e índice de altura paladar fueron el leptoestafilino y el ortoestafilino. Los Índices de asimetría oscilaron entre el 4,3 al 18,3%. El presente estudio proporciona datos morfométricos y cualitativos del paladar duro derivado de cráneos indios. El conocimiento de la posición y el diámetro de los forámenes palatinos es esencial para la aplicación de la anestesia localizada antes de realizar los procedimientos quirúrgicos. Además, los datos pueden ser útiles en la determinación de ascendencia del paladar duro.

Palabras Clave: *paladar duro, foramen incisivo, foramen palatino mayor, foramen palatino menor.*

ABSTRACT

The purpose of this study was to determine hard palate morphology to provide guidelines for practitioners. This study measured the hard palate of 63 skulls of unsexed and unknown age from Indian subcontinent. The means and standard deviations of the following parameters were: greater palatine foramen maximum width, 2.3 ± 0.5 mm; lesser palatine foramen maximum width, 0.9 ± 0.4 mm; incisive foramen maximum width, 4.08 ± 0.99 mm; canine to canine intersocket distance, 23.5 ± 2.2 mm; distance between right and left greater palatine foramen, 27.6 ± 2.77 mm; palatal breadth, 37.97 ± 3.32 mm; palatal length, 52.2 ± 3.2 mm; palatal height, 11.54 ± 2.4 mm; greater palatine foramen to the base of medial pterygoid hamulus distance, 8.7 ± 2.2 mm; distance from greater palatine foramen to median maxillary suture, 13.8 ± 1.5 mm; angle between the midline and a line between the orale and the greater palatine foramen, 16.45 ± 1.60^0. The leptostaphyline and orthostaphyline were the most prevalent types of palatine index and palate height index in this study. Asymmetry indices ranged between 4.3 - 18.3%. The present study provides morphometric and qualitative data of the hard palate derived from Indian skulls. Knowledge of the position and diameter of the palatine foramina is essential in performing localized anaesthesia before surgical procedures. In addition, the data may be useful in ancestry determination using the hard palate.

Keywords*: hard palate, incisive foramen, greater palatine foramen, lesser palatine foramen.*

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INTRODUCTION

Anatomical and morphometric knowledge of the hard palate is advantageous in many fields of science. The greater palatine foramen and lesser palatine foramen transmit the greater and lesser palatine nerves and vessels respectively, while the nasopalatine nerve and vessels exit through the incisive foramen. All three nerves are branches of the maxillary nerve, while vessels are branches of the maxillary artery. The greater palatine nerve and vessels supply the hard palate mucosa where it anastomoses with the naso-palatine nerve and vessels which supply the anterior palatal mucosa area between two canines. The lesser palatine nerve and vessels contribute to the soft palate (Moore et al, 2013).
Dentists and oromaxillofacial surgeons need a good knowledge of the location and morphology of the palatine foramen when conducting localized anaesthesia of the maxillary teeth before procedures to avoid injury to the nerves and blood vessels of the hard palate: for example: upper tooth extraction, maxillary dental implants, hemi-maxillectomy, orthognathic surgery, Le Fort fracture management, and cleft palate surgery (Das et al, 2006). In addition, differences in hard palate morphometry between races may be useful in human identification.
The first research on the palatine foramen in humans was conducted by Matsuda (1927), who reported on the distance between the maxillary central incisor alveolar border to the posterior border of the palatine foramen, and the alveolar palatal ridge opposite the middle third molar to the anterior border of the palatine foramen. Most anatomy textbooks refer to the location of the greater palatine foramen as being opposite the second molar (Blanton and Jeske, 2003); however Moore (2013) states that it is located medial to the third molar. Inconsistencies in anatomy textbooks concerning the precise location of the greater palatine foramen, as well as details of palate structures, was the underlying basis for this study examining the hard palate using both qualitative observations and quantitative measurements. The purpose of this study is to provide a morphometric analysis of the anatomical features of the hard palate, in addition reviewing the relevant literature.

MATERIALS AND METHODS

The study was undertaken on 63 adult dry skulls of unsexed and unknown age, but considered to originate from the Indian sub-continent, from the collection in the Centre for Anatomy and Human Identification, University of Dundee, United Kingdom. Edentulous skulls were excluded from the study. Parameters were measured directly from each skull using a metal ruler, digital callipers and protractor. The palatal foramina were also assessed qualitatively.
For the qualitative study the following were determined bilaterally: (I) the number and shape of the greater palatine foramen; (II) position of the greater palatine foramen (GPF) in relation to the maxillary molars; (III) the number and shape of the lesser palatine foramen (LPF).

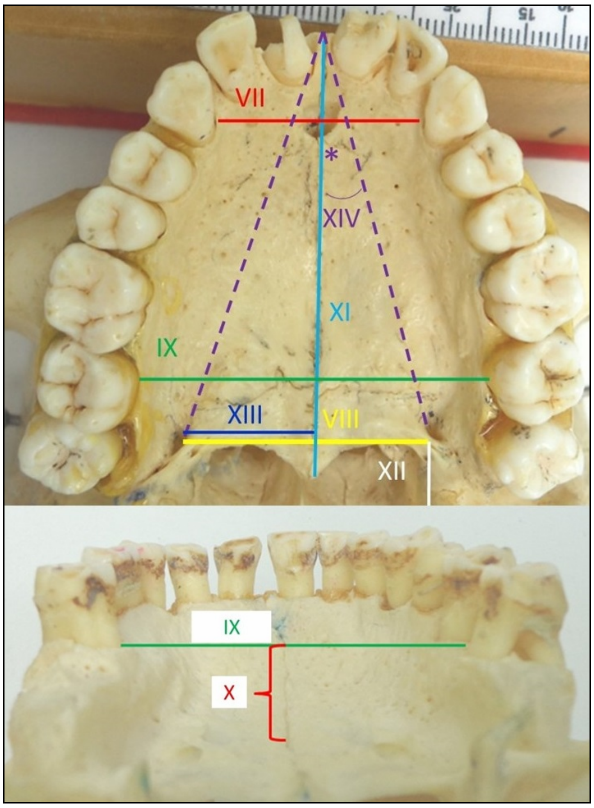

Figure 1. Parameters measured in present study (VII-XIV)

The quantitative measurements comprised: (IV) maximum width of the greater palatine foramen; (V) maximum width of the lesser palatine foramen; (VI) maximum width of the incisive foramen (IF); (VII) distance between the palatal wall of the two canine sockets; (VIII) distance between the medial margin of the greater palatine foramen on each side; (IX) palatal breadth - distance between the palatal wall of the upper second molars socket (endomolaria); (X) palatal height - distance between the deepest point of the palatal surface and the line of palatal breadth; (XI) palatal length-distance between the orale (the most anterior end of the median maxillary suture (MMS)) and the posterior nasal spine (Premkumar, 2011); (XII) distance between the posterior border of GPF and the base of hamulus of the medial pterygoid plate; (XIII) perpendicular distance between the medial wall of the GPF and the MMS; (XIV) angle formed by the MMS and a line between the orale and the medial wall of the GPF (Figure 1).

In addition, two indices were calculated using palatal breadth, height and length (Premkumar, 2011), these being:

1. Palatine index [[Palatal breadth/Palatal length] x100] (PI). The palatine index classification is: leptostaphyline (<79.9), mesostaphyline (80-84.9), brachystaphyline (85<)
2. Palatal height index [[Palatal height/Palatal breadth] x100] (PHI). The palatal height index classification is: chamestaphyiline (<27.9), orthostaphyiline (28-39.9), hypsistaphyline (40<)

Asymmetry indices were determined for measurements XII, XIII and XIV using the following formula: [[right side-left side]/right side] x 100 (Kizilkanat et al, 2011). All measurements were taken in millimetres. Statistical analysis was conducted using Microsoft Excel 2007, including the correlation between measured parameters. The reliability and repeatability of the measurements taken directly from the hard palate were assessed prior to the study.

RESULTS

The coefficient of variation for all parameters was less than 10%, consequently it can be concluded that the methodology employed in taking the measurements was reliable. In the inter observer study, there were no significant differences in the mean values of the measurements; consequently it is considered that the measurement of all parameters is repeatable.

Descriptive analysis

All except one skull examined had one GPF on each side: a single skull showed 2 GFPs on one side separate by a thin bony septum. In contrast the number of LPFs ranged from 1 to 6 on each side, whereas 68% skulls have multiple openings and 31% skulls have single opening. Only one skull showed an absence of lesser palatine foramen on the right side.

The majority of greater palatine foramen were oval in shape (57.1%), while the lesser palatine foramen was dominated by the lancet (39.2%) and oval (39.2%) shapes. In only 4% of skulls was the GPF located opposite the second molar, 37.3% were between the second and third molars, and 58.7% opposite the third molar. All 63 skulls studied had a single opening for the incisive foramen.

Quantitative data

The mean widths of the lesser and greater palatine foramen were 0.9 ± 0.4 mm and 2.3 ± 0.5 mm, respectively, with the most common diameter of the LPF and GPF being 1 mm and 2 mm respectively. The mean values of the unpaired hard palate parameters were: (i) the greatest dimension of the incisive foramen, 4.1 ± 1 mm; (ii) the distance between the two canine sockets, 23.5 ± 2.2 mm; and the distance between the medial walls of the GPF, 27.6 ± 2.8 mm. The palatal breadth, length and height were 38 ± 3.3 mm, 52.3 ± 3.2 mm, and 11.5 ± 2.4 mm, respectively. Irrespective of side, the mean of the distance between (i) the GPF and MMS was 13.8 ± 1.47 mm, and (ii) the GPF and base of the hamulus of the medial pterygoid plate was 8.7 ± 2.2 mm. The angle between the line of the MMS and the line connecting the orale to the GPF was 16.45 ± 1.6^{o}.

The palatine index compares palatal breadth and length in each skull, while the palatal height index compares palatal height and breadth. Most skulls (53/63, 84%) had a leptostaphyline type of palatine index, with both the mesostaphyline and brachystaphyline types being observed in five skulls each (8%). The palatal height index was dominated by the orthostaphyline type (59%), while the chamestaphyline and hypsistaphyline types were found in 32% and 10% of skulls, respectively. The asymmetry index for measurements XII, XIII and XIV gave values of 6.5%, 4.3%, and 18.4% respectively. Significant correlations were only observed between measurements VIII and IX (r = 0.61), XIII and XIV (r = 0.64), and VIII and XIV (r = 0.63).

DISCUSSION

Thirty six previous publications which reported measurements of the hard palate related with the current study were identified (Table 1).

In the present study, most skulls exhibited a single GPF on each side; however one skull exhibited two GPFs separated by a thin bony septum. In terms of GPF shape the oval type dominated (57%), being similar to previous reports (Methathrathip et al, 2005; Klosek and Rungruang, 2009; Lopes et al, 2011; Nimigean et al, 2013). (Table 2).

Study	Sample	n	Sample characteristics
Matsuda (1927)	Mixed	380 dry skulls	380 maxilla;
Slavkin et al (1966)	Mixed	138 dry skulls	infants and children's cranium; ancestry (Eskimo, Negroid, Caucasian); age and sex recorded
Westmoreland and Blanton (1982)	East Indian	300 dry skulls	unsexed; adult; homogenous in ancestry and arch form
Langenegger et al (1983)	South African	100 dry skulls	Consisted of Cape, Natal Nguni and Southern Sotho tribe; 50 skulls for each male and female; mean age 42.7 years, SD 13.7, range 20-80 years;
Malamed and Triegger (1984)	Mixed	204 dry skulls	western USA, Scandinavia, Europe, North Africa
Wang et al (1988)	Chinese	l00 dry skulls	adult skulls; both sexes; fully erupted 3rd molar; no missing teeth and malpositioned teeth;
Hassanali and Mwaniki (1988)	Kenyan	125 dry skulls	90% Bantu (mainly Kikuyu) 10% Nilote, Nilo-Hamitic and unidentified; 60 males, 22 females, 43 unknown; 2 juveniles, 3 edentulous, the rest were adults with permanent dentition
Ajmani (1994)	North Indian	34 dry skulls	unsexed; adult; fully erupted 3rd molar
Ajmani (1994)	Nigerian	65 dry skulls	unsexed; adult; fully erupted 3rd molar
Aterkar et al (1995)	West Indian	165 dry skulls	adults; unsexed; 118 dentulous; 47 edentulous
Berge and Bergman (2001)	American (USA)	100 dry skulls	
Jaffar and Hamadah (2003)	Iraqi	50 dry skulls	adult; fully erupted molar teeth
Sujatha et al (2004)	South Indian	71 dry skulls	58 dentulous skulls: 56 bilateral and 2 unilateral, 13 edentulous: 11 bilateral and 2 unilateral; unsexed; adults;
Methathrathip et al (2005)	Thai	105 dry skulls	68 males; 37 females; age 18-83 years; 74.8% has molar teeth
Saralaya and Nayak (2007)	South Indian	132 dry skulls	unsexed; adult; fully erupted 3rd molar
Klosek and Rungruang (2009)	Thai	41 cadavers	24 males; 17 females;
Chrcanovic et al (2010)	Brazilian	80 dry skulls	
Urbano et al (2010)	Brazilian	43 dry skulls	
Texeira et al (2010)	Brazilian	141 dry skulls	macerated human skulls; 82 males; 59 females; age (mean/SD/range) 31.64/13.14/15-99
Osunwoke et al(2010)	Nigerian	150 dry skulls	adult; fully erupted 3rd molar
Lopes et al (2011)	South Brazilian	94 dry skulls	65 male, 29 female
Fu et al (2011)	American (USA)	11 cadavers	all male; mean age 75.7/58-91 years
Kumar et al (2011)	North Indian	100 dry skulls	skulls with fully erupted 3rd molar
Hwang et al (2011)	Korean	50 CT scans	22 males; 28 females; mean age 51 years (19-84)
Piagkou et al (2012)	Greek	71 dry skulls	unsexed; adult; fully erupted 3rd molar
D'Souza et al (2012)	South Indian	40 dry skulls	unsexed; all edentulous
Vinay et al (2012)	South Indian	150 dry skulls	adult; fully erupted 3rd molar
Ikuta et al (2013)	Brazilian	50 CBCT	27 males; 23 females; age (mean/SD) 35.8/10.99 years; fully erupted 3 molars
Nimigean et al (2013)	Romanian	100 dry skulls	75 skulls bilaterally edentulous; 25 skulls partially edentulous; age 25-40 years;
Renu (2013)	North Indian	100 dry skulls	both sexes; fully erupted 3rd molar
Jotania et al (2013)	West Indian	60 dry skulls	unsexed
Sharma and Garud (2013)	West Indian	100 dry skulls	unsexed; adult; 17 edentulous; 13 right side and 12 left side of the rest had unerupted 3rd molars
Dave et al (2013a)	West Indian	100 dry skulls	adult; sexed; 60 males; 39 females; 1 unknown
Dave et al (2013b)	West Indian	100 dry skulls	adult; sexed; 60 males; 39 females; 1 unknown
Tomaszewska et al (2014)	Polish	1350 (150 dry skulls and 1200 CT)	unsexed adults dry skulls; 655 males and 695 females; age mean/SD 44.9/17.1
Anjankar et al (2014)	Central Indian	86 dry skulls	adults; fully erupted 3rd molar
Present study	**Indian**	**63 dry skulls**	**unsexed adult skulls**

Table 1. List of studies on various parameters of hard palate

The most anterior position of the GPF, between the first and second molar, was seen in 1% of all skulls by Wang (1988) and 14% of female skulls by Klosek and Rungruang (2009).The majority of studies, including the present agree, that the position of the GPF is opposite the third molar (Table 2). This supports Slavkin et al (1966) who stated that the GPF in infants and children was located distal to the posterior deciduous molar and then moved posteriorly as the next posterior tooth erupted. This transition is caused by appositional and sutural growth at the interface between the maxilla and palatine bones, as well as by the increasing anteroposterior dimension of the palate associated with eruption of the dentition.

Study	GPF n	GPF location related to maxillary molars (%)							GPF shape (%)			
		1st-2nd	2nd		2nd-3rd	3rd		Retro molar	O	L	S	R
			ant half	post half		ant half	post half					
Slavkin et al (1966)	276	Age 0-2 years: 1-3 mm distal to m2 tooth bud (n=30); Age 3-6 years: 8-12 mm distal to m2 (n=27); Age 7-10 years: 4-6 mm distal to M1 (n=23); Age 11-14 years: 2-5 mm distal to M2 (n=30); Age 15-18 years: 1-3 mm to M3 (n=28)										
Westmoreland and Blanton (1982)	600		9.7		33.7	50.7		6				
Langenegger et al (1983)	200		1			67.5		36.5				
Malamed and Triegger (1984)	316		0	39.9		50.6	9.5					
Hassanali and Mwaniki (1988)	250		10.4		13.6	76						
Wang et al (1988)	200	1	17		48.5	33.5	0					
Ajmani (1994) †	68		0		32.35	64.69		2.94				
Ajmani (1994) ‡	130		13.07		38.46	48.46		0				
Aterkar et al (1995)	236*	2.1			26.2	69.1		2.6				
Jaffar and Hamadah (2003)	100		12		19	55		14				
Sujatha et al (2004)	142		0.88		13.15		85.95					
Methathrathip et al (2005)	210		5.6		23.1		64.4	6.9	82.4	7.1	5.7	4.8
Saralaya and Nayak (2007)	265		0.4		24.2	74.6		0.8				
Klosek and Rungruang (2009)	82	(F)14.3 (M)0	(F)35.7 (M)65		(F)35.7 (M)10	(F)14.3 (M)25			90			10
Chrcanovic et al (2010)	160				6.19	54.87		38.94				
Osunwoke (2010)	300		2		22.7	74.6		2				
Fu et al (2011)	21		19.1		66.6	14.3						
Kumar et al (2011)	200		5		9	85		1				
Lopes et al (2011)	188								56.9	26.1		17
D'Souza et al (2012)	80		2.5		23.75	73.75						
Vinay et al (2012)	300		3.67		19	76		1.33				
Piagkou et al (2012)	107		16.82			75.7		7.48				
Dave et al (2013b)	200		1		3	87.5		8				
Jotania et al (2013)	120		4.17		17.5	78.33						
Ikuta et al (2013)	100		0	3		53	39	5				
Nimigean et al (2013)	200		9		15	73		3	84			16
Renu (2013)	200		9		25.5	47.5		18				
Sharma and Garud (2013)	139		0.72	7.91		35.25	38.13	17.99				
Anjankar et al (2014)	172		6.98		16.27	73.26		3.49				
Tomaszewska et al (2014)	2700		16.3		6.8	74.7		2.2				
Present study	**126***		**4**		**37.3**	**58.7**			**57.1**	**30.2**		**12.7**

Table 2. Comparison between studies regarding the greater palatine foramen (GPF): location related to maxillary molar and shape. Note: *only dentulous skulls; †North Indian; ‡Nigerian; O = oval; L = lancet; S = slit; R = round.

Study	GPF dimension*		GPF-MMS*			GPF-GPF*
	ant-post	transverse	Right	Left	Total	
Westmoreland and Blanton			14.8/0.07	15/0.07		
Langenegger et al (1983)		2.5/0.5/1-5	14.9/1.8/7.1-24.2	15.1/2.6/7.1-34.2		
Wang et al (1988)			15.95/0.15	16.01/0.14	16/0.14	
Ajmani (1994) †			14.7/0.96	14.7/0.96	14.7/0.96	
Ajmani (1994) ‡			15.4/0.21	15.4/0.21	15.4/0.21	
Aterkar et al (1995) (e)			16.2/0.9	16.1/1.1	16.1/1.1	
Aterkar et al (1995) (d)			15.2/1.3	15.3/3	15.3/2.4	
Jaffar and Hamadah	4.63/0.98/2.9-8.1	2.77/0.63/1.5-4.3			15.71/.36/ 12.2-18.6	
Methathrathip et al (2005)					16.2/1.3/ 12.8-19.7	
Saralaya and Nayak (2007)			14.7/0.155	14.7/0.146	14.7/0.261	
Klosek and Rungruang					14.7/3.3	
Chrcanovic et al (2010)			14.68/1.56	14.44/1.43		
Osunwoke et al (2010)			15.04/2.1	14.3/1.5		
Teixeira et al (2010)			15.7	16.2		
Urbano et al (2010)			16.63	16.39		32.74
Hwang et al (2011)	4.5/0.7/2.9-6.3	2.2/0.4/1.3-3.5			16.2/1.3/ 13.7-19.5	
Kumar et al (2011)			14.3/1.42	14.4/1.27	14.3/1.34	
Lopes et al (2011)			15.62/1.33	15.4/1.41		
D'Souza et al (2012)			14.6/1.47	14.4/1.404		
Piagkou et al (2012)					15.3/0.13	
Vinay et al (2012)			14.8/0.155	14.8/0.147		
Ikuta et al (2013)					15.2/1.45	
Dave et al (2013b)			M16.7/0.12 F16.2/0.12	M16.6/0.11 F16.4/0.11		
Jotania et al (2013)			14.8	14.83	15.2	
Nimigean et al (2013)	4.9/0.9/3-7	3/0.5/2-4			14.5/0.7/ 13.1-16.1	
Renu (2013)			15.3	15		
Sharma and Garud (2013)			14.71/1.38/12-17.9	14.41/1.39/11.2-17.68	14.49/1.79	
Anjankar et al (2014)			15.4	15.1	15.3	
Tomaszewska et al (2014)			16.1/1.5	15.6/1.5	15.9/1.5	29.1/ 2.6
Present study (d)		**2.3/0.5/1-4.5**	**14.02/1.4/9.2-16.9**	**13.57/1.5/ 10.5-17.9**	**13.8/1.5/9.2-17.9**	**27.6/ 2.77/22-34.8**

Table 3. Comparison between studies regarding: greater palatine foramen (GPF) dimension; distances from GPF to median maxillary suture (MMS), and distance between two GPF. Note: *mean/SD/range in mm; †North Indian; ‡Nigerian; e=edentulous; d=dentulous

With respect to GPF, LPF and IF dimensions only the width was measured because the transverse dimension of the foramen is marked by a distinct wall enabling measurements to be precisely taken. The anterior wall of the antero-posterior dimension slopes in the frontal plane and may therefore lead to inaccuracies in length measurement. In the present study the average width of the GPF was 2.3 mm, which corresponds with studies on various ancestries,

which ranged between 1 and 4.3 mm in previous studies (Table 3). In the present study the mean LPF diameter was 0.9 mm, similar to Berge and Bergman (2001). The mean width of the IF in the present study was 4.08 mm which was comparable with previous study by Hassanali and Mwaniki in 1988 (3.5 mm).
LPF morphology was dominated by the lancet (39%) and oval (39%) shapes compared to round (22%). Although multiple LPFs were observed on most of sides of most skulls, their shape was uniform on each side rather than being different. As far as could be ascertained there are no previous reports detailing the shape of the LPF. Multiple openings of LPF were present in the majority (68%) of skulls examined in this study, agreeing with the findings of Berge and Bergman (2001), Jaffar and Hamadah (2003), Jotania et al. (2013), but in contrast with Hassanali and Mwaniki (1988), D'Souza et al (2012), Piagkou et al (2012) and Anjankar et al. (2014) who reported a single LPF opening to be dominant. The mean number of LPFs (2.1) observed in the present study is higher than reported previously. The importance of knowing that individuals may have more than a single LPF is that the lesser palatine nerves may be unintentionally blocked if the needle tip is located posterior to the greater palatine foramen, resulting in anaesthesia of the soft palate and inducing the gag reflex (Hassanali and Mwaniki, 1988).
In edentulous patients, the location of the GPF can be established using the distance between the MMS and GPF as a reference in maxillary tooth anaesthesia (Ikuta et al, 2013). Previous studies reported a mean GPF-MMS distance of between 14.3 and 16.7 mm, which is comparable to the present study (13.8 ± 1.5 mm) (Table 3). The mean distance between the two GPF in the present study was 27.6 mm, less than that reported by Urbano et al (2010) and Tomaszewska et al (2014) (Table 3).

Study	Palate dimension (mean/SD/range) (mm)			Palatine Index (PI) (%)			PI (mean/ SD)	Palate Height Index (PHI) (%)			PHI (mean/ SD)
				L	M	B		C	O	H	
	PB palatal breadth	PL palatal length	PH palatal height	<79.9	80-84.9	>85		< 27.9	28-39.9	>40	
Hassanali and Mwaniki (1988)	40.2/3	49.2/ 3.6	12.2 /0.16	43.2	23.7	33.1	82.01/ 7.84/M	40	56.67	3.33	30.30/ 6.30/O
Jaffar and Hamadah (2003)	39.29/ 3.41/ 31.3-46.5	50.82/ 0.53/ 43.3-57					77.6/ 5.97/B				
Klosek and Rungruang (2009)	31.1/5.2	51.4/5.8									
Chrcanovic et al (2010)		52.4/ 4.63/ 47.88-57.81									
D'Souza et al (2012)				37.5	22.5	40		87.5	12.5	0	
Dave et al (2013a)	33.83/ 0.2	43.54/ 0.28	9.87/ 0.23	63	24	13	77.97/ 7.02/L	42	54	4	29.23/ 2.54/O
Jotania et al (2013)	37.75	49.74		70	15	15					
Tomaszewska et al (2014)	46.9/ 3.3	47/4.5	13.1/ 2.7				99.8/ 5.4/B				30.1/ 3.1/O
Present study	**37.97/ 3.32/ 30.1-47.9**	**52.2/ 3.2/ 42.7-59.6**	**11.54/ 2.4/ 6-17**	**84.1**	**7.9**	**7.9**	**73/ 7.72/L**	**32**	**59**	**10**	**30.5/ 6.43// O**

Table 4. Comparison between studies regarding palate dimension, palatine index, and palate height index. Note: L=leptostaphyline; M=mesostaphyline; B=brachystaphyline; C=chamestaphyline; O=orthostaphyline; H=hypsistaphyline

The pterygoid hamulus is palpable in the oral cavity and is therefore a suitable anatomical landmark from which to determine the location of the GPF. The mean distance from the posterior wall of the GPF to the base of the pterygoid hamulus (8.7 mm) is similar to that reported by Langenegger et al (1983), but less than of Nimigean et al (2013) (12 mm). Several studies have determined the mean distance between the GPF and the tip of the pterygoid hamulus, with observations ranging between 11.47 and 12.6 mm (Langenegger et al, 1983; Malamed and Triegger, 1984; Sharma and Garud, 2013; Tomaszewska et al, 2014).

Significant differences have been reported in both mean palatal breadth and length, ranging from 31.1 to 46.9 mm and 43.54 to 52.4 mm respectively (Table 4). Palatal breadth in the present study was in the middle of this range, while palatal length was towards the upper end of the range. When determined in previous studies, mean palatal height show a wide range of values (9.87 to 13.1 mm), with that in the present study being close to that reported by Hassanali and Mwaniki (1988). The exception is Dave et al (2013a), who reported lower values of palatal breadth, length and height. It should be noted that generalized alveolar bone resorption and missing second molar teeth may reduce palatal height and thus compromise palatal height causing it to be within the low palate category.

The average width of the anterior part of the hard palate, represented by the distance between two maxillary canine sockets in this study, was 23.5 ± 2.2 mm. Smaller widths were reported by Klosek and Rungruang (2009), with the average palatine width at the point of first premolars being 20.4 ± 11 mm.

Palatine index and palatal height index reported in other studies are presented in Table 4. The majority (84%) of skulls in the present study exhibited a narrow palate (leptostaphyline), with intermediate (mesostaphyline) and broad palates (brachystaphyline) accounting for only 8% each. Similar findings, also in Indian skulls, were observed by most previous studies except that of D'Souza et al (2012), where brachystaphyline was marginally more common than leptostaphyline. Palatal height index showed the skulls in the present study had an intermediate palatal height (orthostaphyline), being observed in 59% of skulls (Table 4). This is consistent with the observations of Hassanali and Mwaniki (1988) in Kenyan skulls (56.67%) and Dave et al (2013a) in Indian skulls (54%), but differs from D'Souza et al (2012) who found a low palate (chamestaphyline) to be the most common (87.5%).

Also advantageous in predicting the location of the GPF clinically is the angle formed between the MMS and a line connecting the orale and medial wall of the GPF. In the present study the mean value of this angle was 16 ± 1.6^{o}, while Saralaya and Nayak (2007) found it to be 21 ± 2^{o}. Other studies have reported the angle between the MMS and a line joining the IF and GPF, with the average value being 22.12o (Chrcanovic et al, 2010) and 26.3o (Tomaszewska et al, 2014) as expected, the mean angle in these studies was greater than that reported here. The oral was selected in the present study as the anterior anatomical landmark because it is easy to determine in living subjects. This angular value can therefore guide practitioners in performing accurate greater palatine nerve blockade.

The asymmetry index may be zero or have a positive or negative value, with a zero value signifying complete symmetry, whereas positive and negative values indicate that one side is larger than the other. In determining mean asymmetry indices, all negative values were ignored. A prominent asymmetry index (18.3%) was observed for the distance between the GPF and the base of the pterygoid hamulus. It is assumed that this disharmony of the posterior proportion of the hard palate may be due to uneven dental structures in that area, for example an impacted third molar or missing molar tooth on one side of the dental arch. Hence, not only does sutural growth and dental eruption influence palatal length, but malpositioned molars and tooth loss may shorten the posterior part of the hard palate, causing an imbalance of the left and right sides. Positive correlations between measurements VIII and IX, XIII and XIV, and VIII and XIV suggest that the broader the palate then the distance between the two greater palatine foramens and the calculated angle also increases.

In conclusion, the current study provides important data regarding the morphology of the hard palate which will be valuable not only in dentistry, whereas maxillary anaesthesia is required as dental routine treatment procedure to avoid complications, but also offers anthropological references for hard palate measurements for Indian subcontinent skulls. Unsuccessful greater palatine canal injection may result in strabismus, intravascular injections, ptosis, diplopia, nasopharyngeal injections, nerve injuries, and anaesthetic failure (Das et al, 2006). Different results have been reported in other races, suggesting differences in the morphology of the hard palate between races. Interestingly, there are also differences in some measured parameters between studies of Indian populations, suggesting that anatomical variation may also present within a population.

Conflict of Interest

None

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Ethical approval
Not required

Informed Consent
Not required

Contributions
The study was designed by ES and RS; ES collected the data which was analysed by ES and RS; the manuscript was written by ES and RS.

REFERENCES

Ajmani M. 1994. Anatomical variation in position of the greater palatine foramen in the adult human skull. J Anat 184: 635.

Anjankar VP, Gupta S, Nair S, Thaduri N, Trivedi G, Budhiraja V. 2014. Analysis of position of greater palatine foramen in central Indian adult skulls: a consideration for maxillary nerve block. Indian J Pharm 2: 51-54.

Aterkar S, Rawal P, Kumar P. 1995. Position of greater palatine foramen in adults. J Anat Soc India 44: 126-133.

Berge JK, Bergman RA. 2001. Variations in size and in symmetry of foramina of the human skull. Clin Anat 14: 406-13.

Blanton PL, Jeske AH. 2003. The key to profound local anesthesia. J Am Dent Assoc 134: 753-60.

Das S, Kim D, Cannon TY, Ebert CS, Senior BA. 2006. High-resolution computed tomography analysis of the greater palatine canal. Am J Rhinol 20: 603-08.

Dave MR, Gupta S, Vyas KK, Joshi HG. 2013a. A study of palatal indices and bony prominences and grooves in the hard palate of adult human skulls. NJIRM 4: 7-11.

Dave MR, Yagain VK, Anadkat S. 2013b. A study of the anatomical variations in the position of the greater palatine foramen in adult human skulls and its clinical significance. Int J Morphol 31: 578-83.

D'Souza AS, Mamatha H, Jyothi N. 2012. Morphometric analysis of hard palate in south Indian skulls. Biomed Res 23: 173-75.

Fu J-H, Hasso DG, Yeh C-Y, Leong DJ, Chan H-L, Wang H-L. 2011. The accuracy of identifying the greater palatine neurovascular bundle: a cadaver study. J Periodontol 82: 1000-06.

Hassanali J, Mwaniki D. 1984. Palatal analysis and osteology of the hard palate of the Kenyan African skulls. Anat Rec 209: 273-80.

Hwang SH, Seo JH, Joo YH, Kim BG, Cho JH, Kang JM. 2011. An anatomic study using three-dimensional reconstruction for pterygo-palatine fossa infiltration via the greater palatine canal. Clin Anat 24: 576-82.

Ikuta CRS, Cardoso CL, Ferreira-Júnior O, Lauris JRP, Souza PHC, Rubira-Bullen IRF. 2013. Position of the greater palatine foramen: an anatomical study through cone beam computed tomography images. Surg Radiol Anat 35: 837-42.

Jaffar A, Hamadah H. 2003. An analysis of the position of the greater palatine foramen. J Basic Med Sci 3: 24-32.

Jotania B, Patel S, Patel S, Patel P, Patel S, Patel K. 2013. Morphometric analysis of hard palate. Int J Res Med 2: 72-75.

Kizilkanat E, Boyan N, Ozsahin E, Tekdemir I, Soames R, Oguz O. 2011. Importance of craniofacial asymmetry in surgery. Neurosurg Q 21: 147-49.

Klosek SK, Rungruang T. 2009. Anatomical study of the greater palatine artery and related structures of the palatal vault: considerations for palate as the subepithelial connective tissue graft donor site. Surg Radiol Anat 31: 245-50.

Kumar A, Sharma A, Singh P. 2011. Assessment of the relative location of greater palatine foramen in adult Indian skulls: consideration for maxillary nerve block. Eur J Anat 15: 150-54.

Langenegger J, Lownie J, Cleaton-Jones P. 1983. The relationship of the greater palatine foramen to the molar teeth and pterygoid hamulus in human skulls. J Dent 11: 249-56.

Lopes P, Santos A, Pereira G, Oliveira VD. 2011. Análisis Morfométrico del Foramen Palatino Mayor en Cráneos de Individuos Adultos del Sur de Brasil. Int J Morphol 29: 420-23.

Malamed SF, Trieger N. 1983. Intraoral maxillary nerve block: an anatomical and clinical study. Anesth Prog 30: 44.

Matsuda Y. 1927. Location of the dental foramina in human skulls from statistical observations. Int J Orthod Oral Surg 13: 299-305.

Methathrathip D, Apinhasmit W, Chompoopong S, Lertsirithong A, Ariyawatkul T, Sangvichien S. 2005. Anatomy of greater palatine foramen and canal and pterygopalatine fossa in Thais: considerations for maxillary nerve block. Surg Radiol Anat 27: 511-16.

Moore KL, Dalley AF, Agur AM. 2013. Clinically oriented anatomy: Lippincott Williams & Wilkins. p 934, 996-1000.

Nimigean V, Nimigean VR, Buțincu L, Sălăvăstru D, Podoleanu L. 2013. Anatomical and clinical considerations regarding the greater palatine foramen. Rom J Morphol Embryol 54: 779-83.

Osunwoke E, Amah-Tariah F, Bob-Manuel I, Nwankoala Q. 2011. A study of the palatine foramen in dry human skulls in South-South Nigeria Sci Afr 10: 98-101.

Piagkou M, Xanthos T, Anagnostopoulou S, Demesticha T, Kotsiomitis E, Piagkos G, Protogerou V, Lappas D, Skandalakis P, Johnson EO. 2012. Anatomical variation and morphology in the position of the palatine foramina in adult human skulls from Greece. J Craniomaxillofac Surg 40: e206-10.

Premkumar S. 2011. Textbook of Craniofacial Growth: JP Medical Ltd. p 181-82.

Renu C. 2013. The position of greater palatine foramen in the adult human skulls of North Indian origin. J Surg Acad 3: 54-57.

Sharma NA, Garud RS. 2013. Greater palatine foramen--key to successful hemimaxillary anaesthesia: a morphometric study and report of a rare aberration. Singapore Med J 54: 152-59.

Slavkin HC, Canter MR, Canter SR. 1966. An anatomic study of the pterygomaxillary region in the craniums of infants and children. Oral Surg Oral Med Oral Pathol 21: 225-35.

Sujatha N, Manjunath KY, Balasubramanyam V. 2004. Variations of the location of the greater palatine foramina in dry human skulls. IJDR 16: 99-102.

Teixeira C, Souza V, Marques C, Silva Junior W, Pereira K. 2010. Topography of the greater palatine foramen in macerated skulls. J. Morphol Sci 27: 88-92.

Tomaszewska IM, Tomaszewski KA, Kmiotek EK, Pena IZ, Urbanik A, Nowakowski M, Walocha JA. 2014. Anatomical landmarks for the localization of the greater palatine foramen– a study of 1200 head CTs, 150 dry skulls, systematic review of literature and meta-analysis. J Anat 225: 419-35.

Urbano E, Melo K, Costa S. 2010. Morphologic study of the greater palatine canal. J Morphol 27: 102-04.

Vinay K, Beena D, Vishal K. 2012. Morphometric analysis of the greater palatine foramen in south Indian adult skulls. Int J Basic Appl Med Sci 2: 5-8.

Wang T, Kuo K, Shih C, Ho L, Liu J. 1988. Assessment of the relative locations of the greater palatine foramen in adult Chinese skulls. Cells Tissues Organs 132: 182-86.

Westmoreland EE, Blanton PL. 1982. An analysis of the variations in position of the greater palatine foramen in the adult human skull. Anat Rec 204: 383-88.

