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ORIGINAL ARTICLE

Anatomical Variations of the Greater Palatine Foramen in Different Facial Skeletal Relationships and its Implications on LeFort 1 Osteotomy (Trimble's Modification)

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Abstract

Purpose To determine the positional variations of the greater palatine foramen in different facial skeletal relationships and discuss its surgical implications on the Trimble's modification of Lefort I osteotomy.

Materials and Methods This retrospective study examined 50 computed tomography scans of patients a total of 100 sides. The sample was divided into four groups: Class 1, Class 2, Class 3 malocclusion and Unilateral cleft lip and palate). The outcome variables included the distance between anterior, middle and posterior points of the GPF to the distal of second molar and variables to assess relative position of the GPF to the posterior maxilla. Outcome measures were to demonstrate intra- and intergroup variability.

Results Fifty patients (100 sides) were divided into four groups. This included 23 males and 27 females with a mean age of 24.1 years. Significant intergroup variability was observed between all the parameters that demonstrate the relative position of the GPF to (i) the maxillary second molar and (ii) the posterior maxilla. The analysis revealed that the GPF was positioned significantly anterior in Class 2 patients when compared with Class 3 patients.

Conclusion The GPF exhibits significant positional variability in different facial skeletal relationships which should be borne in mind while designing and performing the Trimble's modification of the Lefort 1 osteotomy.

Keywords Greater palatine artery anatomy · Greater palatine foramen position · Lefort I osteotomy complications · Vascular complications in LeFort 1 osteotomy · Trimble's modification

Introduction

Lefort I osteotomy is a common yet versatile surgical procedure which is use to treat deformities of the maxilla across all three surgical planes. Despite its documented advantages, intra-operative haemorrhage is one dreaded complication that can arise during separation of maxillary tuberosity from the pterygoid plates. Potential damage to pterygoid venous plexus or the maxillary artery and its terminal branches can pose difficulties during the conventional Lefort I osteotomy [1]. The Trimble technique of Lefort I osteotomy significantly reduces vascular complications by positioning the osteotomy cut distally to the second molar across the tuberosity or through the third molar socket. One limitation of the Trimble's modification is injury to the greater palatine during the surgery [2]. Although the vascularity of the osteotomized maxilla is based on the terminal branches of the ascending pharyngeal and facial arteries, milder forms of ischemia and osteonecrosis due to injury of greater and lesser palatine arteries have been reported by Bell et al. [3]. The vascular supply of the anterior maxilla is dependent on the palatal pedicle which is primarily supplied by greater and lesser palatine branches of descending palatine artery. Sacrifice or injury to these two arteries may compromise vascularity to the anterior maxilla and dneto-alveolus [4].

The greater palatine foramen (GPF) is present on the postero-lateral aspect of the hard palate relative to the region of second and third molar. In children, the location of the foramen moves posteriorly as the posterior teeth erupt.

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Several authors have studied the location of the descending palatine artery and location of greater palatine canal as well as foramen [5–7] but there still remains wide variability in the relationship of GPF to the maxillary second and third molars. Additionally, there might be differences between the right and left sides of the same patient. This lacunae in literature needs to be addressed to provide a better anatomical basis for performing the Trimble's modification of Lefort I osteotomy while preventing damage to the greater palatine artery. The purpose of this study therefore was to determine the positional variations of the GPF in relation to the maxillary molars and posterior maxilla in different facial skeletal relationships and discuss its implications on the Trimble's modification of Lefort I osteotomy.

Materials and Methods

Study Design

A retrospective observational study was designed to investigate 50 computed tomography (CT) scans of individuals aged between 18 and 30 years. These data were sourced from the departmental database. The study was conducted between May 2022 and June 2023. The study design was approved by the Institutional Review Board in Meenakshi Ammal Dental College and Hospital vide MADC/IEC-I/12/2022. The criteria for inclusion encompassed individuals aged between 18 and 30 years, who were divided into four groups: skeletal Class 1, 2 and 3 malocclusion, as well as those with non-syndromic unilateral cleft lip/palate. This age range was chosen to establish consistency in skeletal structure and minimize the impact of age-related differences. The study excluded patients with (i) craniofacial syndromes, (ii) previously treated with orthognathic surgery, and (iii) a history of facial trauma or maxillofacial pathology.

Hypothesis

The nulls hypothesis was that the position of GPF was not different with differences in facial skeletal relationship, while the alternate hypothesis was that the position of GPF was different with differences in facial skeletal relationship.

Methodology

The CT data were segregated into two: unilateral cleft lip and palate (UCLP) ($n=10$) and non-cleft ($n=40$). The right and left sides of the patients were individually evaluated; therefore, the sample comprised 100 sides. The non-cleft cohort was further divided into three groups: Class 1, Class 2, and Class 3 based on the ANB (A point, Nasion, B point) angle. This provided four groups for study [8] (ANB angles of 0 to + 3 were categorized as Class 1, + 4 or more as Class 2, and 0 or less as Class 3).

3D Model Reconstruction

Segmentation and three-dimensional (3D) reconstruction of the CT data was done using *Mimics V.19.0 (Materialise, Leuven, Belgium)* and the anthropometric analysis were made using *3-matic Medical V.11.0 (Materialise, Leuven, Belgium).* A mid-sagittal plane was constructed first from which a coronal plane was generated. This plane was generated perpendicular to the mid-sagittal plane and was taken as a *standard reference plane* (SRP) (Fig. 1). A second plane was developed parallel to the SRF distal to the second molar. These were the two planes used to generate measurements in the axial view of the maxilla.

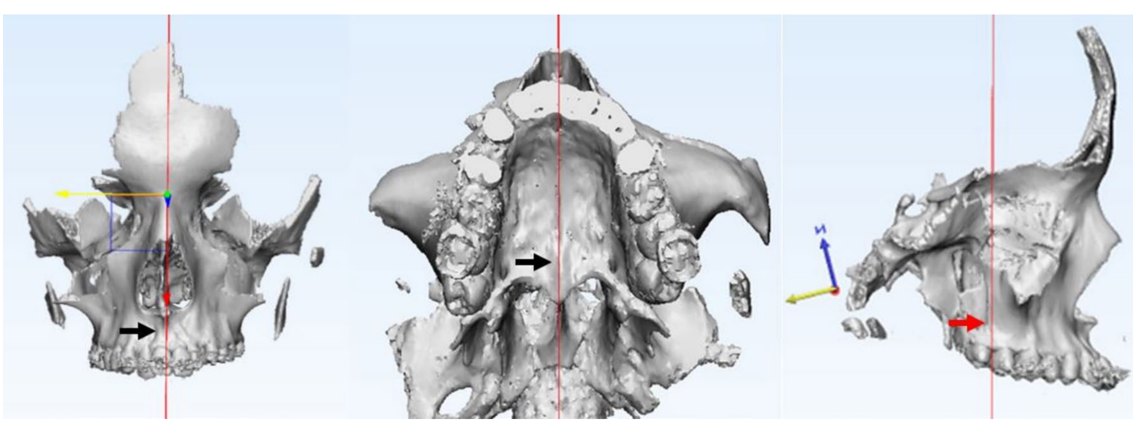

Fig. 1 Midsagittal plane and Standard reference coronal plane, Black arrow indicates the Midsagittal plane, Red arrow indicates the coronal plane

Study Variables

The predictor variable in this study was the categorizing of the samples into four separate skeletal relationships; Classes 1, 2, 3, and UCLP. Meanwhile, the outcome variables encompass a comprehensive array of anthropometric measurements, as elaborated below (Fig. 2).

i. Distance between the anterior most point of the greater palatine foramen to the distal margin of the second molar in mm (AF-DSM).
ii. Distance between the middle of the greater palatine foramen to the distal of second molar in mm (MF-DSM).
iii. Distance between the posterior most point of the greater palatine foramen to the distal of second molar in mm (PF-DSM).
iv. Distance between the distal most point of second molar to the pterygomaxillary junction in mm (DSM-PMJ).
v. Distance between the anterior of the greater palatine foramen to the pterygomaxillary junction in mm (AF-PMJ).
vi. Distance between the middle of the greater palatine foramen to the pterygomaxillary junction in mm (MF-PMJ).
vii. Distance between the posterior the greater palatine foramen to the pterygomaxillary junction in mm (PF-PMJ).

The first three measurements were considered as primary outcome variables and the last four were considered as secondary outcome variables. Negative values in the measurements denote that the foramen is anterior to the distal aspect of the second molar. Positive values denote that the foramen is posterior to the distal aspect of second molar.

Statistical Analysis

Statistical analysis was performed using *Stata statistical software, Release 17.0 (StataCorp LLC, College Station, TX)*. Descriptive statistics for each measurement was represented using mean, standard deviation, standard error of mean, 95% confidence interval. Testing for normality was performed using Shapiro Wilk test As the normality assumption was rejected, nonparametric tests were performed for intergroup comparison. Comparison between right- and left-side measurements for each type of skeletal malocclusion was performed using Mann–Whitney U test. Intergroup comparison between type of skeletal malocclusions was performed using Kruskal Wallis test followed by Drass-Steel-Critchlow-Fligner pairwise comparisons. For all comparisons, $p < 0.05$ was considered statistically significant (*).

Results

Computed tomographic data of 50 patients (100 sides) were included in the study. The sample comprised 27 male and 23 female, aged between 18 and 30, with an mean age of 24.1 years (Table 1).

The Outcome of the study was divided into 3 categories:

Table 1 Descriptive statistics of study variables

Samples	Patients/sides	Gender	
		Female	Male
Total	50/100	27	23
Class 1	11/22	6	5
Class 2	14/28	7	7
Class 3	15/30	7	8
UCLP	10/20	3	7

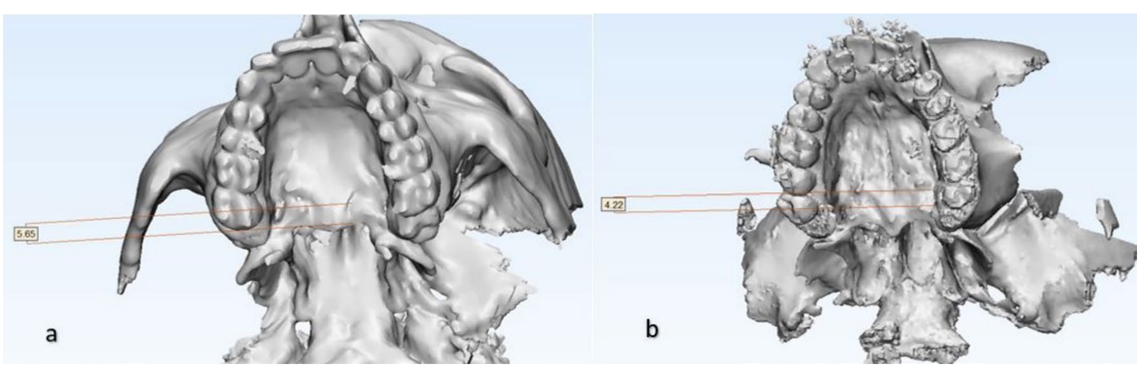

Fig. 2 Distance between the anterior most point of the greater palatine foramen to the distal of the second molar in Class II and Class III skeletal malocclusion. **a** Class II malocclusion; **b** Class III malocclusion

1. Intra-group comparison: Comparing the means of outcome variables between sides; right and left sides for each skeletal relationship (Cl 1, 2 and 3) and cleft and non-cleft sides for the UCLP group.
2. Intergroup comparison: Comparing the means of outcome variables between each skeletal base relationship including the UCLP group.

Intra-group Comparison

The comparison of means between sides revealed no significant differences between the right and left sides for the different skeletal relationships (Table 2). Similarly, there were no significant differences between the means of the cleft and non-cleft side for the UCLP group (Table 3).

Table 2 Intra-group comparison of outcome variables between right and left sides of each skeletal relationship

Groups	Variables	N	Mean in mm		*P* value
			Right side	Left side	
Class 1	AF-DSM	11	−0.7727	0.3327	0.3
	MF-DSM	11	1.1309	1.8464	0.606
	PF-DSM	11	2.6773	3.5455	0.562
	DSM-PMJ	11	9.6609	10.0364	0.797
	AF-PMJ	11	10.3855	10.0945	0.748
	MF-PMJ	11	8.5164	8.1645	0.652
	PF-PMJ	11	6.8791	6.3945	0.652
Class 2	AF-DSM	14	−2.3629	−1.9657	0.734
	MF-DSM	14	−0.4129	−0.0779	0.839
	PF-DSM	14	1.3464	1.6707	0.804
	DSM-PMJ	14	7.3993	7.4514	0.946
	AF-PMJ	14	9.8921	9.9357	0.910
	MF-PMJ	14	8.3229	8.1893	1.000
	PF-PMJ	14	6.5600	6.5914	0.874
Class 3	AF-DSM	15	1.2520	1.2080	0.902
	MF-DSM	15	2.9867	2.9353	0.935
	PF-DSM	15	4.4420	4.6000	0.902
	DSM-PMJ	15	9.9740	10.0853	1.000
	AF-PMJ	15	8.7480	8.4740	0.512
	MF-PMJ	15	7.0073	6.5753	0.461
	PF-PMJ	15	5.5173	5.2293	0.713

AF-DSM The anterior point of the greater palatine foramen to the Distal of the second molar; *MF-DSM* The middle of the greater palatine foramen to the distal of second molar; *PF-DSM* Posterior point of the greater palatine foramen to the distal of second molar; *DSM-PMJ* Distal most point of second molar to the pterygomaxillary junction; *AF-PMJ* Anterior of the greater palatine foramen to the pterygomaxillary junction; *MF-PMJ* Middle of the greater palatine foramen to the pterygomaxillary junction; *PF-PMJ* Posterior the greater palatine foramen to the pterygomaxillary junction

Table 3 Intra-group comparison of outcome variables between cleft and non-cleft sides of UCLP group

Groups	Variables	N	Mean in mm		*P* value
			Cleft side	Non-cleft side	
UCLP	AF-DSM	10	−0.1230	−0.5130	1.000
	MF-DSM	10	1.4550	1.3810	0.739
	PF-DSM	10	3.4320	3.0530	0.853
	DSM-PMJ	10	8.7910	8.2800	0.631
	AF-PMJ	10	8.9320	8.7690	0.739
	MF-PMJ	10	7.1700	6.7820	0.631
	PF-PMJ	10	5.5770	5.2350	0.684

UCLP Unilateral cleft lip and palate; *AF-DSM* The anterior point of the greater palatine foramen to the distal of the second molar; *MF-DSM* The middle of the greater palatine foramen to the distal of second molar; *PF-DSM* Posterior point of the greater palatine foramen to the distal of second molar; *DSM-PMJ* Distal most point of second molar to the pterygomaxillary junction; *AF-PMJ* Anterior of the greater palatine foramen to the Pterygomaxillary junction; *MF-PMJ* Middle of the greater palatine foramen to the pterygomaxillary junction; *PF-PMJ* Posterior the greater palatine foramen to the pterygomaxillary junction

Intergroup Comparison

Analysis of our data revealed that all the parameters studied demonstrated significant differences in their means between the groups.

Primary outcome variables demonstrating the relationship of the GPA to the distal aspect of the second molar: The measurements from the anterior, middle and posterior margins of the GPA to the distal aspect of the maxillary second molar showed significant differences across the groups: AF-DSM ($p=0.007$), MF-DSM ($p=0.011$) and PF-DSM ($p=0.022$) (Table 4).

Secondary outcome variables demonstrating the relationship of the GPA to the pterygomaxillary junction (PMJ): The measures between the PMJ and the maxillary second molar as well as the GPA also demonstrated significant mean differences across the groups: DSM-PMJ ($p=0.011$), AF-PMJ ($p=0.020$), MF-PMJ ($p=0.006$) and PF-PMJ ($p=0.025$).

The Drass-Steel-Critchlow-Fligner pairwise comparisons revealed significant differences between Class 2 and Class 3 patients for AF-DSM ($p=0.004$), MF-DSM ($p=0.007$), PF-DSM ($p=0.015$), DSM-PMJ ($p=0.030$) and MF-PMJ ($p=0.043$), while for AF-PMJ significant differences were found between Class 1 and Class 3 patients ($p=0.038$).

For all comparisons a power of above 95% and $p<0.05$ was considered statistically significant.

Table 4 Intergroup comparison between the outcome variables of different skeletal malocclusions

Variables	Groups	N	Mean in mm Mean (St.Dev)	*P* value
AF-DSM	Cl 1	22	−0.220(2.82)	0.007*
	Cl 2	28	−2.164(3.65)	
	Cl 3	30	1.230(2.73)	
	CLP	20	−0.318(3.46)	
MF-DSM	Cl 1	22	1.489(2.72)	0.011*
	Cl 2	28	−0.245(3.53)	
	Cl 3	30	2.961(2.78)	
	CLP	20	1.418(3.15	
PF-DSM	Cl 1	22	3.111(2.86)	0.022*
	Cl 2	28	1.509(3.73)	
	Cl 3	30	4.521(2.90)	
	CLP	20	3.243(2.78)	
DSM-PMJ	Cl 1	22	9.849(3.32)	0.011*
	Cl 2	28	7.425(3.05)	
	Cl 3	30	10.030(3.23)	
	CLP	20	8.536(2.18)	
AF-PMJ	Cl 1	22	10.240(1.99)	0.020*
	Cl 2	28	9.914(1.95)	
	Cl 3	30	8.611(1.98)	
	CLP	20	8.851(2.45	
MF-PMJ	Cl 1	22	8.340(1.96)	0.006*
	Cl 2	28	8.256(1.81)	
	Cl 3	30	6.791(1.85)	
	CLP	20	6.976(2.19)	
PF-PMJ	Cl 1	22	6.637(1.96)	0.025*
	Cl 2	28	6.576(1.61)	
	Cl 3	30	5.373(1.77)	
	CLP	20	5.406(1.92)	

AF-DSM The anterior point of the greater palatine foramen to the distal of the second molar; *MF-DSM* The middle of the greater palatine foramen to the distal of second molar; *PF-DSM* Posterior point of the greater palatine foramen to the distal of second molar; *DSM-PMJ* Distal most point of second molar to the pterygomaxillary junction; *AF-PMJ* Anterior of the greater palatine foramen to the pterygomaxillary junction; *MF-PMJ* Middle of the greater palatine foramen to the pterygomaxillary junction; *PF-PMJ* Posterior the greater palatine foramen to the pterygomaxillary junction

Discussion

The Lefort I osteotomy has proven its effectiveness as the standard orthognathic surgical procedure used to treat dento-facial abnormalities throughout the world. However, like any other surgery the Lefort I osteotomy also has its share of complications. A significant complication among those documented is haemorrhage [9]. Performing an osteotomy through the maxillary tuberosity or through the third molar socket as described by Trimble [2, 10] is an important description to prevent this complications. The literature reveals that when compared to conventional dysjunction, it decreased the likelihood of unfavourable fractures of the pterygoid plates and increased the safety to structures of the sphenopalatine fossa thereby reducing the incidence of vascular complications associated with pterygomaxillary dysjunction. The Trimble's method require an osteotomy to be performed distal to the maxillary second molar, which predisposed the descending palatine artery to injury. This is a vulnerable source of bleeding during the Lefort I osteotomy and may be closer to the osteotomy site as it moves away from the pterygopalatine fossa [11]. Though the blood supply to the maxillary segment is not necessarily at risk if the descending palatine artery is ligated [12], there is certainly a degree of relative vascular compromise. This necessitates a need to evaluate the relative position of the GPF in relation to the maxillary second and third molars in different facial skeletal relationships, which enables us to determine the chances of injuring the artery or help us modify our osteotomy to prevent this from occurring. The hypothesis of this study was that there was a positional variation of the GPF in different skeletal relationships with specific objectives were to evaluate the anatomical position of the GPF in relation to the maxillary molars and posterior maxilla. Our study revealed differences in the position of the GPF for different skeletal relationships.

Maxillary ischemic necrosis is a rare but severe complication. The degree of vascular impairment is associated to the severity of postoperative sequelae attributable to ischemic necrosis following Lefort I osteotomy [1, 13, 14]. One such reason for devascularization of the soft tissue in Lefort I osteotomy is the excessive stretching of the palatal pedicle from the bone or the reduced perfusion of the mobilized segment due to insult of the palatal mucoperiosteum [15]. Hence, it may be perceived that that preservation of the palatal pedicle may not only add to the perfusion of the soft tissue pedicle but also prevent any sudden and unanticipated haemorrhages during surgery.

Literature documents minimal amount of avascular ischemia and osteonecrosis due to injury of the greater and lesser palatine arteries [3]. It is hence important to understand the anatomic location and the surgical implications of the greater palatine foramen and artery in varied skeletal deformities. In Trimble technique of Lefort I osteotomy, the cut is usually placed distal to second molar which may induce injury to the greater palatine artery. Although numerous studies have been performed to evaluate the anatomy and morphological variations of the GPF in relation to the molars [16–19], there is no existent literature revealing the anatomical variations of the GPF in different skeletal malocclusions. Understanding the positional variations of the GPF may provide a more reliable basis for predicting complications and enabling better planning of the the osteotomy in different skeletal relationships.

Most often the GPF lies in the area of second and third molar [16]. Matsuda et al. in their study concluded that the GPF lies opposite to the middle of third molar [20]. A recent study in Sri Lankan population by Fonseka et al. [21] revealed that most common relationship was that the GPF being in between the second and third maxillary molar followed by being opposite the upper third molar and the upper second molar. Our study not only validates the integrity of these findings but additionally reveals that there are distinctive positional variations of the greater palatine foramen in different facial skeletal relationships. The position of the GPF in relation to the distal aspect of the maxillary second molar is most anterior in Class 2 patients, followed by class 1 and UCLP patients. Its is most posteriorly positioned in Class 3 patients. This implies that performing a Trimble's procedure could expose the greater palatine artery to a higher chance of injury. The osteotome during the procedure is recommended to be more posteriorly directed in Class 3 patients as compared with the other groups.

Merits and Limitations

The incorporation of different skeletal relationships relevant to the surgical procedure discussed adds value to the results of the study. However, the reduced sample size may be a limitation, considering that a higher sample could have yielded a correlation model with better strength.

Future Perspectives

Prospects for future research include; (i) A similar study with a larger sample evaluating association between the variables and (ii) a clinical study evaluating modified osteotomy designs for the tuberosity osteotomy with an objective to assess integrity of the greater palatine artery.

Conclusion

The greater palatine foramen exhibits positional variations in different facial skeletal relationships. This paves way to better understanding to perform the Trimble's osteotomy in a safe and predictable manner while minimising complications associated with the greater palatine artery.

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Declarations

Conflict of interest The authors have no financial or non-financial interests to disclose.

Ethical approval Ethical approval was given by the Institutional Review Board in Meenakshi Ammal Dental College and Hospital, Chennai-95. Reference number: MADC/IEC-I/12/2022.

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