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ORIGINAL ARTICLE

Relationship between pterygomaxillary fissure morphology and maxillary/mandibular position

A cone beam computed tomography assessment

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Abstract

Purpose The aim of this study was to investigate the possible correlation between maxillary and mandibular positioning via cephalometric analysis with pterygomaxillary fissure (PMF) morphology using cone beam computed tomography (CBCT).

Methods In this study, CBCT images from 825 individuals (448 female, 377 male; age range was 18-91 years with this cohort) were analyzed; PMF length and width were measured. Three-dimensional cephalometric analysis was also performed using cephalometric analysis software. The landmarks and measurements in relation to maxillary and mandibular positions were identified and performed for the cephalometric analysis. Analysis of variance (ANOVA) was used for comparison of the parameters, while the Bonferroni test was used for multiple comparisons. Pearson's test was also used to assess the correlations between the parameters.

Results The results showed that males had significantly larger PMF length ($p<0.001$) and width ($p<0.001$) compared to females. The mean PMF length was 17.7 mm (standard deviation [SD] 3.2 mm) for right and 17.7 mm (SD 3.3 mm) for left but were not significantly different ($p>0.05$). In terms of the cephalometric measurements, a significant correlation was found between upper central incisor (U1toAperp2D) and posterior facial height (PostFaceHtSGo2D) and PMF length, while correlations were found between PMF width and several cephalometric parameters such as lower lip (LwLiptoEPln2D and LwLiptoHLine2D) and occlusal plane (OPtoFHAng2D) ($p<0.05$).

Conclusion A significant relationship was observed between PMF morphology and the position of the maxilla or mandible. PMF lengths and widths were larger in males than females. Posteroanterior maxillary and mandibular lengths and posterior facial height are associated with PMF length and width.

Keywords Pterygomaxillary fissure · Morphology · Cephalometric analysis · Orthognathic surgery · Facial surgery

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Beziehung zwischen der Morphologie der Fissura pterygomaxillaris und der Position von Ober-/Unterkiefer

Eine Untersuchung mittels digitaler Volumentomographie

Zusammenfassung

Zielsetzung Ziel dieser Studie war die Untersuchung einer möglichen Korrelation zwischen Ober- und Unterkieferposition und der Morphologie der Fissura pterygomaxiallis (PMF). Die Ober- und Unterkieferposition wurde mittels kephalometrischer Analyse ermittelt, während die Morphologie der PMF mit Hilfe der digitalen Volumentomographie (DVT) untersucht wurde.

Methoden DVT-Bilder von 825 Probanden (448 weiblich, 377 männlich; Altersbereich 18–91 Jahre) wurden analysiert, PMF-Länge und -Breite wurden gemessen. Dreidimensionale kephalometrische Analysen wurde zudem mit einer kephalometrischen Analysesoftware durchgeführt. Dazu wurden die Landmarken und Messungen in Bezug auf die Kiefer- und Unterkieferpositionen identifiziert. Die Varianzanalyse (ANOVA) wurde für den Vergleich der Parameter verwendet, der Bonferroni-Test für Mehrfachvergleiche. Der Pearson-Test wurde außerdem zur Beurteilung der Korrelationen zwischen den Parametern verwendet.

Ergebnisse Die Ergebnisse zeigten, dass die männlichen Probanden im Vergleich zu den weiblichen Probanden eine signifikant größere PMF-Länge ($p<0{,}001$) und Breite ($p<0{,}001$) aufwiesen. Die mittlere PMF-Länge betrug 17,7 mm (Standardabweichung [SD] 3,2 mm) für die rechte und 17,7 mm (SD 3,3 mm) für die linke Seite, wobei die Unterschiede nicht signifikant waren ($p<0{,}05$). Bei den kephalometrischen Messungen zeigte sich eine signifikante Korrelation zwischen dem oberen zentralen Schneidezahn (U1toAperp2D) und der hinteren Gesichtshöhe (PostFaceHtSGo2D) und der PMF-Länge, während sich Korrelationen zwischen der PMF-Breite und verschiedenen kephalometrischen Parametern wie Unterlippe (LwLiptoEPln2D und LwLiptoHLine2D) und Okklusionsebene (OPtoFHAng2D) fanden ($p<0{,}05$).

Schlussfolgerung Beobachtet wurde ein signifikanter Zusammenhang zwischen der PMF-Morphologie und der Position des Ober- bzw. Unterkiefers. Die PMF-Längen und -Breiten waren bei den Männern größer als bei den Frauen. Es bestand eine Assoziation zwischen posteroanteriorer Ober- und Unterkieferlänge sowie posteriorer Gesichtshöhe und PMF-Länge und -Breite.

Schlüsselwörter Fissura pterygomaxillaris · Morphologie · Kephalometrische Analyse · Kieferorthopädische Chirurgie · Gesichtschirurgie

Introduction

It is recognized that facial growth is not only dependent on the components of the face, but is also closely related to the skull base and the neurocranium [4, 17]. Although the development of the maxillomandibular complex is affected by neighboring structures, changes in these structures and their functions may in turn impact other structures such as soft tissues (e.g., lips) and facial expression [9].

The functional matrix hypothesis tries to explain the adaptation of skeletal tissues and organs during modification of craniofacial growth. According to this hypothesis, the two main units are skeletal structure and functional elements. Therefore, in the development of craniofacial skeletal structures, some adaptive responses can be influenced by functional components. [19–21]. Functional components refer to soft tissues surrounding skeletal units, organs, and operational volumes that perform a given function [4, 7, 17, 19].

Skeletal muscle contraction plays a typical functional matrix loading role [20]. Therefore, the frequency of muscle contraction is significantly related to bone growth and further adaptation responses [19, 21]. Musculoskeletal connection areas such as the pterygoid hamulus, and pterygomaxillary separation and fissure are closely related to specific muscle activity [12, 25]. The morphology of skeletal tissues has an important function in affecting muscle activity and thereby airway collapse [27].

The interaction between the skeletal unit and functional matrices may also have an effect on the spaces between skeletal units such as the pterygoplatine fossa [13]. The pterygoplatine fossa is a space between the maxilla, palatine, and sphenoid bones [3, 32]. The pterygomaxillary fissure (PMF), on the other hand, forms the lateral boundary of the pterygopalatine fossa.

In clinical terms, the PMF is in an important landmark for orthognathic surgical procedures such as Le Fort I osteotomy, and extraoral and intraoral maxillary nerve blockage [3, 13, 18, 26, 31]. Furthermore, during surgically assisted rapid maxillary expansion, the PMF and the remaining posterior connection of the maxilla with the pterygoid process region can improve blood circulation and also provide symmetrical openings of the maxillary shelves [33].

An observational experiment conducted on Rhesus monkeys showed that orthodontic forces can result in changes in both the skeletal anatomy of PMF and facial structures. With the distal forces on the maxilla and maxillary molars, they observed that the PMF was entirely closed [34]. Triftshauser and Walters [34] found that moving the maxilla posteriorly could have a limit for avoiding harmful effects on vital structures. Therefore, there should be specific boundaries according to maxillary positional differences. The PMF can be altered based on the position of facial structures [34].

The relationship between the cranium and various orthodontic anomalies has been previously studied [9, 12, 27]. Two-dimensional radiographic studies showed an expansion in the region of the pterygoid fossa in Class II open-bite patients [15, 28]. On the other hand, cone beam computed tomography (CBCT) has been recently used as an important tool for determining the fissure, not only for performing surgical procedures, but also for virtual surgical preoperative planning [6, 13, 18, 23, 24, 31].

The PMF seems to have an effect on both growth and developmental stages of the face and during application of orthodontic forces. Knowledge of the PMF morphology also seems to be essential during surgical procedures. Therefore, the aim of this study was to investigate the PMF morphology and possible correlation between facial structures, particularly maxilla–mandibular positioning using CBCT.

Materials and methods

Ethical approval was obtained from the Near East University Scientific Research Ethics Committee (IRB approval number 18/2011-16). The examiner only examined radiographs and was blinded to all other patient data in the radiographic examination procedure.

The study was based in the Near East Dental Hospital, Nicosia, Cyprus and used retrospective CBCT image data from 1000 subjects. These patients had presented to the hospital's Oral and Maxillofacial Radiology Unit for various reasons between 2011 and 2017. No gender preference was exercised in the sample choice.

In the present study, before applying inclusion criteria for the data collection, the following exclusion criteria were applied: age less than 18 years; a history of trauma to the head or neck; past sinus or skull base surgery; the presence of systemic conditions; the presence of a genetic disorder, syndrome, or congenital anomaly (craniosynostosis, hemifacial microsomia) affecting the head and neck region; and pathologies or fractures in the relevant region. Furthermore, only high-resolution tomography scans were included.

After exclusion based on the above criteria, the CBCT data of 825 patients (448 women, 377 men) were included in the final study group. The patients ranged in age from 18–91 years.

Data acquisition and processing

CBCT scans were obtained using a NewTom 3G (Quantitative Radiology S.R.L., Verona, Italy) device. Patients were stabilized in a supine position using specially designed head bands and chin straps positioned with the Frankfort horizontal plane perpendicular to the floor and monitored to ensure that they remained motionless during scanning (36 s). All images were recorded at 120 kVp, 3–5 mA in a 9-inch imaging area, with an axial slice thickness of 0.3 mm and using isotropic voxels. The x-ray parameters for kV and mA were automatically determined from the scout images. All reconstructions and measurements were made on a 21.3-inch flat-panel color active-matrix thin-film transistor medical display (Nio Color 3MP, Barco, Belgium) with a resolution of 2048×1536 at 76 Hz and 0.2115 mm dot pitch operated at 10 bits. The examiner was also permitted to use enhancements and orientation tools (e.g., magnification, brightness, and contrast) to improve visualization of the landmarks.

To evaluate PMF morphology, CBCT axial images were initially exported in DICOM file format with a 512×512 matrix and imported into Maxilim® version 2.3.0 (Medicim, Sint-Niklaas, Belgium). Reconstruction was performed in multiple stages to obtain images that were diagnostically suitable for landmark identification and three-dimensional (3D) reconstruction. First, bone surfaces were segmented by applying a threshold on the acquired image volume of radiographic densities. An attempt was made to reduce noise without reducing actual osseous anatomy. To begin the analysis, the 3D segmented hard-tissue surface representations of the maxillary anatomy were virtually rendered. PMFs were then sculpted out of the 3D represented image and the PMF length and width were calculated using this software (Fig. 1).

To determine the length of the right and left PMF, the measurement between the highest point and the lowest point was performed with the linear measurement feature of Maxilim software in the 3D reconstruction of the sagittal plane from the most superior point of the fissure opening to the most inferior point (Fig. 1).

To determine the width of the right and left fissura pterygomaxillaris, via the individual analysis obtained using Maxilim software, the distance between the most anterior point of the fissure and the most posterior point of the fissure was measured in the sagittal section (Fig. 1).

Moreover, CBCT data were also transferred to InVivo-Dental (Version 5, Anatomage, San Jose, CA, USA) software for cephalometric analyses. Linear and angular measurements were made with the custom 3D cephalometric analysis program of the Anatomage InVivo software.

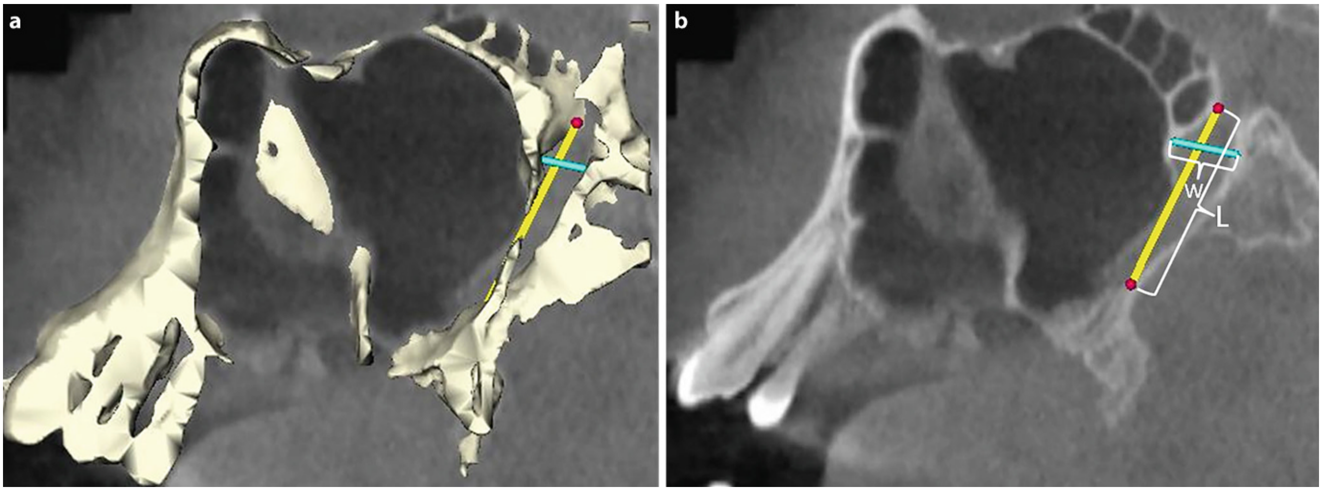

Fig. 1 **a** Three-dimensional (3D) representation and sagittal slice of the pterygomaxillary fissure (PMF) region using Maxilim software. Superimposed version of the 3D model matrix on the sagittal x-ray slice. **b** Measurement of PMF length and width from the 3D reconstruction. Sagittal x-ray slice only. *L* length of the PMF, *W* width of the PMF

Abb. 1 **a** Dreidimensionale (3-D) Darstellung und ein sagittaler Schnitt der PMF(Fissura pterygomaxillaris)-Region mit der Maxilim Software. Überlagerte Version der 3-D-Modellmatrix auf dem sagittalen Röntgenschnitt. **b** Bestimmung der PMF-Länge und -Breite anhand der 3-D-Rekonstruktion. Nur sagittaler Röntgenschnitt. *L* Länge der PMF, *W* Breite der PMF

The landmarks and measurements in relation to maxillary and mandibular position were identified and used for the cephalometric analysis (Table 1).

Statistical methods

The data obtained during this study were analyzed using SPSS version 21.0 (SPSS, Chicago, IL, USA) software package. All measurements were repeated within 1 month by the same investigator who was blinded to the initial results. If any discrepancy emerged, averages were used for analyses. Intraobserver results were statistically evaluated by the Wilcoxon matched-pairs signed-rank test.

Analysis of variance (ANOVA) was used for comparison of the parameters. The Bonferroni test was used for multiple comparisons and Pearson's test was used to assess correlations between parameters. The bivariate correlation analysis was used for sides (right/left) comparisons of parametric values, and the marginal homogeneity test was applied for right/left comparisons of nonparametric values. The t-test was used to detect gender differences. Arithmetic mean, standard deviation, and standard error values of the data were determined in Microsoft Excel. A p value < 0.05 was considered statistically significant.

Results

Repeated CBCT evaluation and measurements showed no significant intraobserver variation ($p > 0.05$). All measurements were found to be highly reproducible with no significant differences between pairs of measurements made by the observer ($p > 0.05$). The mean of all measurements was used as the final value.

The mean PMF length and width according to sides and gender are shown in Table 2. Mean values were used for right/left and male/female comparisons. The results showed that males had significantly larger PMF length ($p < 0.001$) and width ($p < 0.001$) compared to females. There were significant differences between the genders in terms of mean PMF variables ($p < 0.001$). However, no difference was found in the left/right comparison ($p > 0.05$).

The mean PMF lengths on both sides with respect to the cephalometric analysis are listed in Table 3. There was a significant positive correlation between right PMF length and U1toAperp2D values in the male patients ($p < 0.05$), while the left PMF length was significantly correlated with PostFaceHtSGo2D values for females ($p < 0.05$). No other cephalometric parameters were statistically different for PMF length ($p > 0.05$).

The comparison between PMF width and cephalometric parameters are listed in Table 4. There were significant correlations for males between the left PMF width and MaxSkeletal2D and MandSkeletal2D ($p < 0.05$), whereas the right PMF width was significantly correlated with LwLiptoEPln2D, LwLiptoHLine2D, and OPtoFHAng2D values ($p < 0.05$). In female patients, significant differences between right PMF width and SNB, SNBAng2D, SNPogAng2D, PostFaceHtSGo2D, and PAFaceHtRatio2D values ($p < 0.05$) were also found. No other cephalometric parameters were statistically different for PMF width ($p > 0.05$).

Table 1 Landmarks and cephalometric measurements
Tab. 1 Landmarken und kephalometrische Messungen

ANB	Angle indicating the position of the maxilla and the mandible relative to each other in the sagittal direction
ANBAng_2D	Projection of ANB angle on the midsagittal plane
AntCranBase (SN)_2D	Projection of the distance between Sella Nasion on the midsagittal plane
AntFaceHt(N-Me)_2D	Projection of the distance between N-Me on the midsagittal plane
FHSNAng_2D	Projection of the angle between PoOr and SN on the midsagittal plane
FMA(MP-FH) Ang_2D	Projection of the angle between GoMe and PoOr on the midsagittal plane
FMIA(L1-FH) Ang_2D	Projection of the angle between the incisal tooth crown-apex of the lower jaw and the OrPo on the midsagittal plane
GoGn to SN Ang_2D	Angle between skull base and mandibular plane
IMPA (L1-MP) Ang_2D	Projection of the angle between the right and left incisal teeth crowns of the lower jaw and Go-Me on the midsagittal plane
JawRe1Ang_2D	Projection of the angle between A-N ND Pog on the midsagittal plane
L1OP Ang_2D	Projection of the angle between the incisal tooth line of the lower jaw and the occlusal plane on the midsagittal plane
L1SN Ang_2D	Projection of the angle between the incisal tooth crown-apex of the lower jaw and S-N on the midsagittal plane
L1 to NB_2D	Projection of the distance between the labial of the right incisal tooth of the lower jaw and the N-B line on the mid-sagittal plane
L1 to NB Ang_2D	Projection of the angle between the incisal tooth crown-apex of the lower jaw and N-B
LFH	Angle between ANS and Me
LMdBL(Go_LPog)	Distance between left Go and Pog
LMdL	The distance between the determined point on the left condyle and Pog
LMdRH	The distance between the determined point on the left condyle and Go
LwFaceHt(ANSMe)_2D	Projection of the distance between SNA and Me on the midsagittal plane
MandBodyLeng-2D	Projection of the distance between Go and Me on the midsagittal plane
MandLeng(GoPog)_2D	Projection of the distance between the right Go and Pog on the midsagittal plane
MandLeng(CP-Gn)_2D	Projection of the distance between the point determined on the right condyle and Gn point on the midsagittal plane
MaxLeng(CP-A)_2D	Projection of the distance between the point determined on the right condyle and point A on the midsagittal plane
Max-Mand Differential	Length difference between CP-A and CP-Gn
MP-OP Ang_2D	Projection of the angle between right Md line (Right Go-Me) and occlusal plane on the midsagittal plane
MP-SN Ang_2D	Projection of the angle between right Md line (Right Go-Me) and S-N on the midsagittal plane
MxL (ANS-PNS)	Distance between left ANS and PNS
OP to FH Ang_2D	Projection of the angle between the occlusal plane and FH plane on the midsagittal plane
OP to SN Ang_2D	Projection of the angle between the occlusal plane and S-N line on the midsagittal plane
Overbite_2D	Projection of the distance between the right incisal tooth crown of the lower jaw and the right maxillary tooth crown of the upper jaw of the N-occlusal plane measurement on the midsagittal plane
Overjet_2D	Projection of the distance between the right incisal tooth crown of the lower jaw and the right maxillary tooth crown of the upper jaw of the occlusal plane measurement on the midsagittal plane
PAFaceHtRatio_2D	Ratio of posterior face height to anterior face height (S-Go/N-Me)
Palatal-Mandible Ang_2D	Projection of the angle between ANS-PNS and Me-Right Go on the midsagittal plane
Palatal-Occlusal Ang_2D	Projection of the angle between ANS-PNS and occlusal plane on the midsagittal plane
Pog to NB_2D	Projection of the distance between Pog and N-B line on the midsagittal plane
PostFaceHt(S-Go)_2D	Projection of the distance between S and right Go on the midsagittal plane
RMdBLGo_RPog	Distance between right Go and Pog
RMdL	Distance between the point determined on the right condyle and Pog
RMdRH	Distance between Go and the point determined on the right condyle
SNA	Angle indicating the position of the maxilla in the sagittal direction relative to the skull base
SNAAng_2D	Projection of the angle between S-N-A on the midsagittal plane
SNB	Angle indicating the position of the mandible in the sagittal direction relative to the skull base

Table 1 (Continued)
Tab. 1 (Fortsetzung)

SNBAng_2D	Projection of the angle between S-N-B on the midsagittal plane
SN-Basion Ang_2D	Projection of the angle between S-N-Ba on the midsagittal plane
TotFaceHt(N-Gn)_2D	Projection of the distance between N and Gn on the midsagittal plane
U1InclinationAng_2D	Projection of the angle between upper jaw right incisal tooth apex-crown line and A-Pog line on the midsagittal plane
U1OP Ang_2D	Projection of the angle between the upper jaw right incisal tooth apex-crown line and occlusal plane on the midsagittal plane
U1PalatalPlnAng_2D	Projection of the angle between the upper jaw right incisal tooth apex-crown line and the SNA-SNP line on the midsagittal plane
U1ProtrU1APog_2D	Projection of the distance between the upper jaw right incisal tooth apex-crown line and Pog-A line on the midsagittal plane
U1toFHAng_2D	Projection of the angle between upper jaw right incisal tooth apex-crown line and right Po-right Or on the midsagittal plane
U1toL1Ang_2D	Projection of the angle between the upper jaw right incisal tooth apex-crown line and lower jaw right incisal tooth apex-crown line on the midsagittal plane
U1toNA_2D	Projection of the distance between upper jaw right incisal tooth labial and A-N line on the midsagittal plane
U1toNAAng_2D	Projection of the angle between upper jaw right incisal tooth apex-crown and B-N line on the midsagittal plane
U1toNB_2D	Projection of the distance between the upper jaw right incisal tooth labial and A-N line on the midsagittal plane
U1toSNAng_2D	Projection of the angle between the upper jaw right incisal tooth apex-crown and S-N line on the midsagittal plane
UpFaceHt(N-ANS)_2D	Projection of the distance between ANS and N on the midsagittal plane
Wits Appraisal_2D	Projection of the distance between A and B in the occlusal plane on the midsagittal plane

Table 2 Comparison of length (mm) and width of the pterygomaxillary fissure according to gender and sides
Tab. 2 Vergleich von Länge (mm) und Breite der Fissura pterygomaxillaris nach Geschlecht und Seite

	Right			Left			Multiple comparisons			
Gender	Male (1)	Female (2)	Total	Male (3)	Female (4)	Total	*p* values			
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	1 vs. 2	1 vs. 3	2 vs. 4	3 vs. 4
PMF length	18.3 (3.4)	17.1 (3.0)	17.7 (3.2)	18.5 (3.4)	17.1 (3.1)	17.7 (3.3)	<0.001	<0.001	<0.001	<0.001
PMF width	7.2 (1.7)	6.7 (1.4)	7.0 (1.6)	6.8 (1.6)	6.5 (1.3)	6.6 (1.4)	<0.001	<0.001	<0.001	0.001

SD standard deviation

Table 3 Comparison of the means and standard deviations (SD) of pterygomaxillary fissure (PMF) length and statistically significant cephalometric parameters
Tab. 3 Vergleich der Mittelwerte und Standardabweichungen (SD) der PMF(Fissura pterygomaxillaris)-Länge und statistisch signifikanter kephalometrischer Parameter

Males	**Cephalometric parameters**[a]	**Mean (SD)**	**Right PMF length (mm)**	***p* value**	**Left PMF length (mm)**	***p* value**
	U1toAperp2D	3.9 (2.2)	17.9 (3.3)	*0.032*	18.3 (2.9)	0.107
	PostFaceHtSGo2D	85.3 (8.1)		0.643		0.900
Females	**Cephalometric parameters**	**Mean mm (SD)**	**Right PMF length (mm)**	***p* value**	**Left PMF length (mm)**	***p* value**
	U1toAperp2D	4.2 (2.4)	16.7 (3.5)	0.342	15.9 (3.3)	0.492
	PostFaceHtSGo2D	75.7 (5.7)		0.324		*0.025*

p value less than 0.05 statistically significant
[a]Cephalometric parameters defined in Table 1

Discussion

Craniofacial soft and hard tissues grow in a synchronized manner [19]. Thus, the organs and cavities in the head are always interconnected, particularly during growth and development [19, 20]. Simultaneous growth processes with shared walls interact dynamically during the ossification of the various components of the head, leading to variations in size, shape, and position. The close adjacency between

Table 4 Comparison of the means (mm) and standard deviations (SD) of pterygomaxillary fissure (PMF) width and statistically significant cephalometric parameters

Tab. 4 Vergleich der Mittelwerte und Standardabweichungen (SD) der PMF(Fissura pterygomaxillaris)-Breite und statistisch signifikanter kephalometrischer Parameter

Males	Cephalometric parameters[a]	Mean (SD)	Right PMF width (mm)	*p* value	Left PMF width (mm)	*p* value
	MaxSkeletal2D	–1 (4.2)	7.9 (1.9)	0.599	7.2 (1.6)	*0.004*
	MandSkeletal2D	–9.5 (8.0)		0.974		*0.027*
	LwLiptoEPln2D	–4 (5.5)		*0.003*		0.205
	LwLiptoHLine2D	0.3 (3.6)		*0.004*		0.108
	OPtoFHAng2D	10.2 (4.2)		*0.039*		0.269
Females	**Cephalometric parameters**	**Mean (SD)**	**Right PMF width (mm)**	***p* value**	**Left PMF width (mm)**	***p* value**
	MaxSkeletal2D	–0.3 (4.2)	7.3 (1.3)	0.386	6.6 (1.3)	0.274
	MandSkeletal2D	–8.1 (8.3)		0.206		0.678
	LwLiptoEPln2D	–4.3 (5.0)		0.651		0.708
	LwLiptoHLine2D	–1.2 (6.8)		0.614		0.507
	OPtoFHAng2D	10.0 (5.0)		0.473		0.697

p value less than 0.05 statistically significant
[a]Cephalometric parameters defined in Table 1

these structures makes many interactions unavoidable during growth [17].

A study of Rhesus monkeys (*Macaca mulatta*) demonstrated that the application of excessive orthodontic forces caused resorption in both the maxillary tuberosity region and in the pterygoid plates. It was observed that the PMF moved posteriorly during distalization of the maxillary molars, and it was also noted that clinical observations were necessary to evaluate alterations in the vital structures in the pterygopalatine fossa [34].

Ghoneima et al. [10] reported that the cranial sutures responded differently to external orthopedic forces depending on location and interactions. In their study, they found that the intermaxillary, internasal, maxillonasal, frontomaxillary, and frontonasal sutures showed statistically significant effects, while expansions in the frontozygomatic, zygomaticomaxillary, zygomaticotemporal, and pterygomaxillary sutures were not significant. However, it should be considered that even minimal expansions at the pterygomaxillary suture will increase the PMF area [10, 33].

Moreover, during maxillary orthognathic surgical procedures, PMF plays a very important role in achieving vertical maxillary separation [3]. The separation of the pterygomaxillary junction is a blind technique and is therefore very risky for surgeons [3, 6]. During pterygoid osteotomy, the maxilla and the pterygoid plates should remain intact. A serious unwanted separation could result in fracture, or vascular and neural complications. The fissura pterygomaxillaris plays a very important role during surgery; however, the surgical site may occur around the pterygomaxillary suture [6, 18]. Therefore, it is important to distinguish between the terms PMF and pterygomaxillary suture. The pterygomaxillary suture is located inferior to the PMF and represents the contact zone between the maxillary tuberosity and the lateral plate of the pterygoid process of the sphenoid bone [3].

The PMF and pterygopalatine fossa dimensions increase with age [13]. Similarly, in another anatomical study, it was shown that older individuals have larger facial structure cavities including the PMF area depending on their state of edentulousness [7]. In the present study, the PMF length and widths were larger in male subjects than females. Baccetti et al. [2] reported pronounced sexual dimorphism, especially after the age of 13, with males showing relatively longer mandibular, maxillary, and vertical dimensions compared to females. Therefore, we believe that the difference in our study is largely attributable to the longer maxillary and mandibular length in males, as well as the more forward position of the hyoid bone, and muscle elongation consistent with Moss and Salentijn's functional matrix hypothesis [8, 11, 16, 22].

Anatomical studies have shown that the width and length of the PMF are very important during extraoral maxillary nerve block or foramen rotundum block [18, 31]. In a study conducted on dry skulls, it was recommended that the width of the PMF should be larger than 2 mm in order to apply extraoral maxillary nerve injection without any anatomical blockage [31]. According to the current results, the mean width of PMF was larger than 6 mm for both genders and both sides. However, individual variations should always be taken into account for each individual clinical application. In another anatomical cadaver study, the length of the PMF for achieving intraoral maxillary nerve block was investigated [18]. Moiseiwitsch and Irvine [18] suggested that clinicians should use a longer needle (i.e., 35 mm instead of 25 mm) during administration of a maxillary block injection. They determined that a short dental needle with a length of 25 mm would be too short to reach the maxillary hub around the foramen rotundum [18].

PostFaceHtSGo2D values increased with left PMF length in females (Table 3). Considering that PostFaceHtSGo2D is a parameter related to the height of the posterior face, this suggests that individuals with longer PMF also have greater posterior facial height. Males showed greater increases in anterior facial height, while females showed greater increases in posterior facial height.

As the left PMF width increased in males, MaxSkeletal2D and MandSkeletal2D values also increased (Table 4). In addition, the parameters LwLiptoHLine2D and OPtoFHAng2D also increased in line with the right side PMF in males. This suggests that the posteroanterior growth and development of the skeletal unit are associated with increased fissure width.

Furthermore, in the female patients, there were significant positive correlations between right PMF width and SNB, SNBAng2D, SNPogAng2D, PostFaceHtSGo2D, and PAFaceHtRatio2D values. All of these parameters characterize mandibular protrusion and increased posterior facial height, usually with Class III malocclusion [29]. The changes in these parameters suggest that PMF width may be greater in patients with Class III malocclusion and a deep bite. MandSkeletal2D was only significantly correlated with PMF width in males; however, it should be kept in mind that PMF width is also associated with increased mandibular dimensions.

A review of the literature shows that most investigators have used the most inferior point of the PMF as a reference in cephalometric analyses [1, 30]. However, other authors have criticized the use of this landmark as a reference point due to the lack of stability when using external orthopedic forces such as headgear [5, 35, 36]. Cevidanes et al. [5] showed 3D displacement of the PMF during treatment with Fränkel functional therapy. Similarly, several studies have demonstrated posterior movement of the PMF when using headgear [12, 34]. On the other hand, Iseri and Solow demonstrated inferior and posterior movement in the pterygomaxillary region during growth [14]. These studies indicate that PMF shape or position may be altered as a result of any pathologic conditions or external forces.

Based on the current results, we believe that the most inferior point of the PMF is not suitable for an orthodontic reference point, especially in adult patients because the position of the PMF is not stable and could be affected by various factors such as resorption, sexual dimorphism, and pathology.

This study has a number of limitations. First, it was primarily a retrospective study. Even though we found an association between PMF and development of the maxilla and mandible, the results are only based on Cypriot patients. Three-dimensional volumetric results would be more accurate instead of collecting the current data with two dimensional measurements. Therefore, more detailed research should be planned for future studies.

The samples in the study included the data of patients whose CBCTs were taken for various reasons such as implant evaluation, impacted teeth surgery, and orthognathic surgery planning. However, in order to avoid bias with the current recruitment, those subjects who had history of trauma to the head or neck, past sinus or skull base surgery, the presence of systemic conditions, the presence of a genetic disorder, syndrome, or congenital anomaly (craniosynostosis, hemi-facial microsomia) affecting the head and neck region, and pathology or fractures in the relevant region that could also affect the relationship between PMF morphology and maxillary/mandibular position were excluded from the cohort.

Conclusion

The results of this study revealed significant associations between the maxilla–mandibular and the PMF such as that PMF length and width are related to gender and are also correlated with some cephalometric analysis parameters. PMF lengths and widths were larger in males than females. Posteroanterior maxillary and mandibular lengths and posterior facial height are associated with PMF lengths and widths. However, further research with larger study populations is needed to obtain more complete and accurate information about the detailed anatomy of the pterygomaxillary region and the interactions between the anatomical landmarks.

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Compliance with ethical guidelines

Conflict of interest M. Icen, K. Orhan, U. Oz, S. Horasan and H. Avsever declare that they have no competing interests.

Ethical standards All procedures performed in studies involving human participants or on human tissue were in accordance with the ethical standards of the institutional and/or national research committee and with the 1975 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study. Ethical approval was obtained from the Near East University Scientific Research Ethics Committee (IRB approval number 18/2011-16).

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