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Review Article

Geometric morphometric analysis of palatal form in patients with maxillary anterior teeth impaction-A systematic review

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A B S T R A C T

Introduction: Morphometrics is a rising technology being employed for describing biological structures in terms of quantifying their shape and form. This review explores maxillary palatal vault shape and arch dimensions which are proposed to have a role in the aetiology of maxillary buccal and canine impactions.
Objectives: To analyse the morphological variations in palatal shape in subjects with maxillary anterior teeth impaction using Geometric Morphometric Analysis.
Materials and Methods: Two independent reviewers searched six databases (PubMed, Web of Science, Embase, Google Scholar, Scopus, and Open Grey). The searches were carried out in November 2023 with no restrictions on publication date. Observational studies and Randomised controlled trials (Study design) were included wherein the morphological variations in palatal shape (outcome) in subjects with maxillary anterior teeth impaction (population) studied using Geometric Morphometric Analysis (intervention). The Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) guidelines were applied, and the protocol was registered in PROSPERO (CRD42023449757). The risk of bias was determined using the Anatomical Quality Assessment (AQUA) tool.
Results: Patients with unilateral or bilateral buccal displaced permanent canine showed a vertical extension and a horizontal compression in the lateral area of the palate. Palatal canine impactions had minimal relationship with palatal shape and morphology.
Conclusion: Morphometric variations of the palatal vault can be considered a factor in determining the probability of maxillary anterior teeth impactions.

1. Introduction

Morphometrics refers to the quantitative analysis of form i.e. it encompasses both size and shape. Defined as the fusion of geometry and biology, morphometrics deals with the study of form in two- or three-dimensional space.[1] Three conceptually and statistically separate approaches are:[1] Traditional morphometrics, which analyzes lengths, widths, masses, angles, ratios and areas[2] Landmark-based geometric morphometrics, using the relative position of a few anatomical landmarks, and[3] Outline-based morphometrics, which captures the contour of forms through a sequence of close pseudo-landmarks.[2] Geometric morphometrics (GMM) uses geometric shapes to study and quantify variations in biological forms, and several researchers have applied this method to orthodontics. It

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uses landmark coordinates to analyse shapes objectively, thus removing the size effect.[3] GMM can be used as a specific tool to describe shape variation between individuals and identify patterns of orthodontic interest variation (hypo/hyper-divergency or sagittal relationship of the basal bones). This approach allows orthodontists to study the intricate details of facials and dental structures, aiding in the diagnosis and treatment planning for malocclusions and other orthodontic issues.

Morphometric techniques allow the integration of the distinct information present in cephalometry: geometric location and biological homology.[4] Shape was defined by Kendall (1989),[5] "as the information remaining when location, size, and rotational factors are all removed". Thus, to compare shapes, the non-shape information is removed from the coordinates of landmarks.

Maxillary palatal vault shape and arch dimensions are proposed to have a role in the aetiology of maxillary buccal and canine impactions.[6] The labially unerupted canines and the ectopic labially erupted canines frequently present different degrees of arch-length deficiency.[7] This can be considered the result of a crowded condition in the maxillary bone. McConnell et al.[8] used dental casts to measure maxillary transverse arch dimensions and showed that patients with maxillary canine impactions had maxillary transverse deficiencies compared with controls. Although a distinction between palatal and labial impactions has not always been made in the literature, there is evidence that palatal and labial canine malposition are different phenomena with different aetiology.[9–11]

Several studies have assessed the palatal and maxillary arch dimensions using 2D strategies in patients with various eruption anomalies[6,8,12–15] Though the results were similar in most of the studies, there have also been pieces of evidence contradicting the varying association between space availability and incidence of buccal and palatal canine impactions.[16] One of the most fundamental limitations associated with conventional imaging technologies is their inability to delineate size from shape as it depends mainly on linear and angular measurements.[17] Moreover, the biological structures warrant greater description in terms of shape and form for better comparison of variation in a particular population. To overcome these shortcomings, morphometrics are now being employed for describing the biological structures in terms of quantifying the shape and form.

This systematic review aims to analyse the morphological variations in palatal shape in subjects with maxillary anterior teeth impaction using Geometric Morphometric Analysis.

2. Materials and Methods

2.1. Registration protocol

The systematic review was conducted following the Preferred Reporting Items for Systematic reviews and Meta-analysis (PRISMA)[18] guidelines and registered with the International Prospective Register of Systematic Reviews (PROSPERO) with registration number CRD42023449757.

2.2. Information sources

The systematic review included the literature search from the electronic databases viz. Pub Med, Embase, Scopus, Google Scholar and Web of Science as the primary sources. This was supplemented by manual searching. The results of the search are listed in Table 1.

The electronic search was supplemented with a manual search in the reference lists of relevant articles. Grey literature was identified by searching OpenGrey and Google Scholar.

2.3. Eligibility Criteria and Study Selection

Table 2 describes the eligibility criteria based on PICOS.

The inclusion criteria included prospective and retrospective studies (case-control, cohort studies), cross-sectional, longitudinal studies, quasi-randomized and randomised controlled trials on orthodontic patients reporting for treatment of impacted canine/incisor(s), and studies that have evaluated palatal shape using Geometric Morphometric Analysis. Exclusion criteria were; case reports, descriptive and preliminary studies, abstract papers, review articles, studies on non-human models, studies of patients with tooth anomalies and severe interproximal caries or attrition, and studies published other than in the English language.

2.4. Search strategy

The PRISMA flow diagram shows an overview of the selection process (Figure 2). Two authors independently identified and reviewed potentially relevant studies by screening the titles and abstracts from the searches. The search strategy was as follows: in the first stage, all articles related to geometric morphometrics and orthodontics were collected by screening the titles followed by the removal of duplicate studies. Articles were excluded by reading the abstracts at the second stage. Finally, articles were included after full-text reading.

2.5. Search strategy

Research Question: What are the effects of maxillary anterior tooth impactions on the palatal shape as studied using Geometric Morphometrics?

Table 1:

Database	Search	Hits
Pubmed	((geometric) and (morphometric)) and ((palatal) and (morphology)) and (orthodontics) and (impaction) and (human) "geometric"[All Fields] and "morphometric"[All Fields] and ("palatal"[All Fields] and "morphology"[All Fields]) and "orthodontics"[All Fields] and "impaction"[All Fields] and "incisor"[All Fields] and "human"[All Fields]	4
Scopus	(Title-ABS-KEY (geometric) and Title-Abs-Key (morphometric) And Title-ABS-key (palatal and shape) and Title-ABS-Key (impacted) and All (human))	3
Embase	('geometric morphometrics'/exp OR 'geometric morphometrics') and 'palatal shape' and 'impacted' and [humans]/lim	1
Web of Science	Geometric (all fields) and morphometric (all fields) and palatal shape (all fields) and impacted (all fields) and (human)	2
Google Scholar	"geometric morphometrics" and "palatal shape" and "variability"	22

Table 2: Eligibility criteria andpicos

Category	Inclusion criteria	Exclusion criteria
Population	Orthodontic patients reporting for treatment of impacted canine/incisor	Patients with genetic syndromes and severe facial malformations, Tooth anomalies and severe interproximal caries or attrition/typhodont models. Studies not involving human subjects
Intervention	Geometric Morphometric Analysis	
Comparison	Subjects with no impacted maxillary canine/incisor	
Outcome	Palatal Shape	
Study Design	Prospective and retrospective studies (case-control, cohort studies) Quasi-randomized, Randomised controlled trials	Reviews Expert Opini Case reports and Case Series
Others	Articles in English language	Other languages

Table 3: Descriptive data from the included studies

Sl. No	Article	Sample	Imaging Tool Used	Software used	Material Methods	Statistical Analysis for removal of shape variation	Results
1	Morphometric analysis of the palatal shape and arch dimension in subjects with buccally displaced canine Mucedero M et. al, (2020) European Journal of Orthodontics	Study Group-50 subjects (16 males and 34 females; mean age 13.9 years ±1.8) divided into unilateral and bilateral. Control (CG)-50 subjects	Model Scanning	Viewbox software	Palatal vault shape and maxillary arch dimensions were studied using Viewbox software (3D GMM analysis) On each digital cast, a total of 240 landmarks were digitized.	Generalised partial least squares Procrustes superimposition was used to extract Procrustes coordinates for shape description. A principal component analysis was performed on the Procrustes coordinates to reveal the main patterns of shape variation	Patients with BDC showed a statistically significant narrower and higher palatal vault. The inter canine width, and the anterior and posterior segment length were significantly smaller in BDC, UBDC, and BBDC subjects when compared with the controls and there were no differences between UBDC versus BBDC groups.
2	Morphometric analysis of the palatal shape and arch dimension in subjects with palatally displaced canine Mucedero M et. al, (2019) European Journal of Orthodontics	Study Group: 46 (18 males and 28 females) patients with one or both canines palatally displaced CG: 26	Model Scanning	View Box 4	The 3D geometric morphometric analysis was used to study the entirety of the shape of the palate. The virtual 3D models were measured with a specific software to analyse the maxillary arch dimension. (VAM, Vectra) Palatal vault shape and maxillary arch dimensions were studied using Viewbox software (3D GMM analysis)	Procrustes analysis was applied and principal component analysis (PCA) was performed	Subjects with palatal canine impactions **do not** present transverse maxillary deficiency in either the anterior or posterior portion of the dental arch.
3	Maxillary dimensions and arch shape with palatally displaced canines Saade M et. al, (2023) European Journal of Orthodontics	SG: 78 orthodontic patients 17.9 ± 8.2 years CG: 78	Cone Beam Computed Tomography	MorphoJ software v.1.07a	Occlusal and skeletal landmarks were plotted using Mimics software. Arch forms were created, and arch width, depth, and skeletal dimensions were measured. T-test ($P < 0.05$) was used to compare the groups. GM analysis was used to compare the groups and to explore the pattern of covariation between two sets of landmarks.	Procrustes superimposition, Discriminant Function Analysis (DFA), Canonical Variate Analysis (CVA), and a two-block Partial Least Squares Analysis (PLS)	The comparison of palatal vault shape showed no difference in patients with PDC relative to a control group. The findings of the GM analysis suggest that significant differences exist in the shapes of dental arch with PDC compared to control groups
4	Geometric morphometric analysis of the palatal morphology in children with impacted incisors: A three-dimensional evaluation. Pavoni C et. al, (2017) Angle Orthod	SG: 26 (10 girls and 16 boys; mean age 9.5 ±1.5 years) CG of 26 subjects (14 girls and 12 boys, mean age 8.7 ±1.6 years)	Model Scanning using a 3D laser scanner.	Viewbox 4 software	To study the entirety of the shape of the palate in any point of the surface, 3D GMM was applied A template for data set/collection of homologous landmarks describing a palate was created with *Viewbox* (dHAL software, Kifissia, Greece) and used to digitise each upper maxillary digital cast of all subjects	Procrustes analysis was applied and principal component analysis (PCA) was performed	SG with impacted maxillary incisors showed skeletal adaptations of the maxilla. In the IIG, both the superior palatal region and lateral palatal surface showed significantly different morphology when compared with CG, with a narrower and higher palatal vault.

Table 4: Quality assessment and risk of bias; aqua tool

SL. No	Study	Risk of Bias (Aqua Tool)		Risk of Bias
Domain 1: Objective(S) and Subject Characteristics				
		Was (Were) the objective(s) of the study clearly defined?	Y	
1	Mucedero M et al (2020)	Was (Were) the chosen subject sample(s) and sample size appropriate for the objective(s) of the study?	Y	Low
		Are the baseline and demographic characteristics of the subjects (age, sex, ethnicity, healthy or diseased, etc.) appropriate and clearly defined?	Y	
		Could the method of subject selection have in any way introduced bias into the study?		
Domain 2: Study design				
		Does the study design appropriately address the research question(s)?	Y	
		Were the materials used in the study appropriate for the given objective(s) of the study?	Y	Low
		Were the methods used in the study appropriate for the given objective(s) of the study?	Y	
		Was the study design, including methods/techniques applied in the study, widely accepted or standard in the literature? If "no", are the novel features of the study design clearly described?	Y	
		Could the study design have in any way introduced bias into the study?		
Domain 3: Methodology Characterization				
		Are the methods/techniques applied in the study described in enough detail for them to be reproduced?	Y	
		Was the specialty and the experience of the individual(s) performing each part of the study (such as cadaveric dissection or image assessment) clearly stated?	Y	Low
		Are all the materials and methods used in the study clearly described, includ- ing details of manufacturers, suppliers etc.?	Y	
		Were appropriate measures taken to reduce inter- and intra-observer variability?	Y	
		Do the images presented in the study indicate an accurate reflection of the methods/techniques (imaging, cadaveric, intraoperative, etc.) applied in the study?	Y	
		Could the characterization of methods have in any way introduced bias into the study?		
Domain 4: Descriptive Anatomy				
		Were the anatomical definition(s) (normal anatomy, variations, classifications, etc.) clearly and accurately described?	Y	
		Were the outcomes and parameters assessed in the study (variation, length, diameter, etc.) appropriate and clearly defined?	Y	Low
		Were the figures (images, illustrations, diagrams, etc.) presented in the study clear and understandable?	Y	

Continued on next page

Table 4 continued

		Were any ambiguous anatomical observations (i.e., those likely to be classified as “others”) clearly described/depicted?	Y	
		Could the description of anatomy have in any way introduced bias into the study?		
Domain 5: Reporting of Results				
		Was the statistical analysis appropriate?	Y	
		Are the reported results as presented in the study clear and comprehensible, and are the reported values consistent throughout the manuscript?	Y	Low
		Do the reported numbers or results always correspond to the number of sub jects in the study? If not, do the authors clearly explain the reason(s) for subject exclusion?	Y	
		Are all potential confounders reported in the study, and subsequently measured and evaluated, if appropriate?	Y	
		Could the reporting of results have in any way introduced bias into the study?		
SL.NO	STUDY	Risk of Bias (Aqua Tool)		Risk of bias
Domain 1: Objective(S) and Subject Characteristics				
		Was (Were) the objective(s) of the study clearly defined?	Y	
2	Mucedero M et al (2019)	Was (Were) the chosen subject sample(s) and sample size appropriate for the objective(s) of the study?	Y	Low
		Are the baseline and demographic characteristics of the subjects (age, sex, ethnicity, healthy or diseased, etc.) appropriate and clearly defined?	Y	
		Could the method of subject selection have in any way introduced bias into the study?		
Domain 2: Study design				
		Does the study design appropriately address the research question(s)?	Y	
		Were the materials used in the study appropriate for the given objective(s) of the study?	Y	Low
		Were the methods used in the study appropriate for the given objective(s) of the study?	Y	
		Was the study design, including methods/techniques applied in the study, widely accepted or standard in the literature? If “no”, are the novel features of the study design clearly described?	Y	
		Could the study design have in any way introduced bias into the study?		
Domain 3: Methodology Characterization				
		Are the methods/techniques applied in the study described in enough detail for them to be reproduced?	Y	
		Was the specialty and the experience of the individual(s) performing each part of the study (such as cadaveric dissection or image assessment) clearly stated?	Y	Low
		Are all the materials and methods used in the study clearly described, includ- ing details of manufacturers, suppliers etc.?	Y	

Continued on next page

Table 4 continued

		Were appropriate measures taken to reduce inter- and intra-observer variability?	Y	
		Do the images presented in the study indicate an accurate reflection of the methods/techniques (imaging, cadaveric, intraoperative, etc.) applied in the study?	Y	
		Could the characterization of methods have in any way introduced bias into the study?		
Domain 4: Descriptive Anatomy				
		Were the anatomical definition(s) (normal anatomy, variations, classifications, etc.) clearly and accurately described?	Y	
		Were the outcomes and parameters assessed in the study (variation, length, diameter, etc.) appropriate and clearly defined?	Y	Low
		Were the figures (images, illustrations, diagrams, etc.) presented in the study clear and understandable?	Y	
		Were any ambiguous anatomical observations (i.e., those likely to be classified N as "others") clearly described/depicted?	Y	
		Could the description of anatomy have in any way introduced bias into the study?		
Domain 5: Reporting of Results				
		Was the statistical analysis appropriate?	Y	
		Are the reported results as presented in the study clear and comprehensible, and are the reported values consistent throughout the manuscript?	Y	Low
		Do the reported numbers or results always correspond to the number of sub jects in the study? If not, do the authors clearly explain the reason(s) for subject exclusion?	Y	
		Are all potential confounders reported in the study, and subsequently measured and evaluated, if appropriate?	Y	
		Could the reporting of results have in any way introduced bias into the study?		
SL.NO	Study	Risk of Bias (Aqua Tool)		Risk of Bias
Domain 1: Objective(S) and Subject Characteristics				
		Was (Were) the objective(s) of the study clearly defined?	Y	
3	Saade M et al (2023)	Was (Were) the chosen subject sample(s) and sample size appropriate for the objective(s) of the study?	Y	Low
		Are the baseline and demographic characteristics of the subjects (age, sex, ethnicity, healthy or diseased, etc.) appropriate and clearly defined?	Y	
		Could the method of subject selection have in any way introduced bias into the study?		
Domain 2: Study design				
		Does the study design appropriately address the research question(s)?	Y	
		Were the materials used in the study appropriate for the given objective(s) of the study?	Y	Low
		Were the methods used in the study appropriate for the given objective(s) of the study?	Y	

Continued on next page

Table 4 continued

		Was the study design, including methods/techniques applied in the study, widely accepted or standard in the literature? If “no”, are the novel features of the study design clearly described?	Y	
		Could the study design have in any way introduced bias into the study?		
Domain 3: Methodology Characterization				
		Are the methods/techniques applied in the study described in enough detail for them to be reproduced?	Y	
		Was the specialty and the experience of the individual(s) performing each part of the study (such as cadaveric dissection or image assessment) clearly stated?	Y	Low
		Are all the materials and methods used in the study clearly described, includ- ing details of manufacturers, suppliers etc.?	Y	
		Were appropriate measures taken to reduce inter- and intra-observer variability?	Y	
		Do the images presented in the study indicate an accurate reflection of the methods/techniques (imaging, cadaveric, intraoperative, etc.) applied in the study?	Y	
		Could the characterization of methods have in any way introduced bias into the study?		
Domain 4: Descriptive Anatomy				
		Were the anatomical definition(s) (normal anatomy, variations, classifications, etc.) clearly and accurately described?	Y	
		Were the outcomes and parameters assessed in the study (variation, length, diameter, etc.) appropriate and clearly defined?	Y	Low
		Were the figures (images, illustrations, diagrams, etc.) presented in the study clear and understandable?	Y	
		Were any ambiguous anatomical observations (i.e., those likely to be classified as “others”) clearly described/depicted?	Y	
		Could the description of anatomy have in any way introduced bias into the study?		
Domain 5: Reporting of Results				
		Was the statistical analysis appropriate?	Y	
		Are the reported results as presented in the study clear and comprehensible, and are the reported values consistent throughout the manuscript?	Y	Low
		Do the reported numbers or results always correspond to the number of sub jects in the study? If not, do the authors clearly explain the reason(s) for subject exclusion?	Y	
		Are all potential confounders reported in the study, and subsequently measured and evaluated, if appropriate?	Y	
		Could the reporting of results have in any way introduced bias into the study?		
SL.NO	Study	Risk of Bias (Aqua Tool)		Risk of bias
Domain 1: Objective(S) and Subject Characteristics				
		Was (Were) the objective(s) of the study clearly defined?	Y	
4	Pavoni C et al (2017)			Low

Continued on next page

Table 4 continued

	Was (Were) the chosen subject sample(s) and sample size appropriate for the objective(s) of the study?	Y	
	Are the baseline and demographic characteristics of the subjects (age, sex, ethnicity, healthy or diseased, etc.) appropriate and clearly defined?	Y	
	Could the method of subject selection have in any way introduced bias into the study?		
Domain 2: Study design			
	Does the study design appropriately address the research question(s)?	Y	
	Were the materials used in the study appropriate for the given objective(s) of the study?	Y	Low
	Were the methods used in the study appropriate for the given objective(s) of the study?	Y	
	Was the study design, including methods/techniques applied in the study, widely accepted or standard in the literature? If "no", are the novel features of the study design clearly described?	Y	
	Could the study design have in any way introduced bias into the study?		
Domain 3: Methodology Characterization			
	Are the methods/techniques applied in the study described in enough detail for them to be reproduced?	Y	
	Was the specialty and the experience of the individual(s) performing each part of the study (such as cadaveric dissection or image assessment) clearly stated?	Y	Low
	Are all the materials and methods used in the study clearly described, includ- ing details of manufacturers, suppliers etc.?	Y	
	Were appropriate measures taken to reduce inter- and intra-observer variability?	Y	
	Do the images presented in the study indicate an accurate reflection of the methods/techniques (imaging, cadaveric, intraoperative, etc.) applied in the study?	Y	
	Could the characterization of methods have in any way introduced bias into the study?		
Domain 4: Descriptive Anatomy			
	Were the anatomical definition(s) (normal anatomy, variations, classifications, etc.) clearly and accurately described?	Y	
	Were the outcomes and parameters assessed in the study (variation, length, diameter, etc.) appropriate and clearly defined?	Y	Low
	Were the figures (images, illustrations, diagrams, etc.) presented in the study clear and understandable?	Y	
	Were any ambiguous anatomical observations (i.e., those likely to be classified as "others") clearly described/depicted?	Y	
	Could the description of anatomy have in any way introduced bias into the study?		

Continued on next page

Table 4 continued

Domain 5: Reporting of Results			
	Was the statistical analysis appropriate?	Y	
	Are the reported results as presented in the study clear and comprehensible, and are the reported values consistent throughout the manuscript?	Y	Low
	Do the reported numbers or results always correspond to the number of sub jects in the study? If not, do the authors clearly explain the reason(s) for subject exclusion?	Y	
	Are all potential confounders reported in the study, and subsequently measured and evaluated, if appropriate?	Y	
	Could the reporting of results have in any way introduced bias into the study?		

2.6. Data extraction

To extract data from the selected articles a table was used to report the study details, control group, study group, sample size considered, tools and software used for geometric morphometric analysis, parameters evaluated in the studies and their conclusion (Table 3). Each study was assessed separately for result derivation and quality assessment. The primary data collected from included studies were (1) Author, journal name, and year of publication; (2) sample size; (3) Imaging Tool Used (4) Algorithm/software employed (5) Material Methods (6) Statistical Analysis for removal of shape variation (7) Results and (8) Conclusion.

2.7. Quality (risk of bias) assessment of the selected studies

The anatomical quality assessment (AQUA)[19] tool was used for risk of bias and quality assessment. Quality assessment was done independently by two investigators. Studies were assessed under 5 domains which were (i) Objective(s) and subject characteristics, (ii) Study design, (iii) Methodology characterisation, (iv) Descriptive anatomy and (v) Reporting of results. Each domain has a set of signalling questions to help assess and judge the ROB pertaining to it. The signalling questions were answered as "Yes", "No", or "Unclear". The question was rated as "Unclear" when the reported data was insufficient. The ROB for each individual domain was judged as "Low" and "High". If all the signalling questions for a domain were answered as "Yes," then the ROB for that domain was judged as "Low." If a signalling question had a "No" or "Unclear" rating, the respective domain was judged as having high ROB.

3. Results

3.1. Study selection

The PRISMA flow diagram gives an overview of the selection process (Figure 2). The search strategy yielded a total of 32 studies. Four studies were finally included in this systematic analysis after two-stage selection criteria which included title and abstract reading followed by full text reading. Twenty-eight studies were excluded which included case reports, non-comparative studies and due to lack of consideration of palatal characteristics**.** No randomised clinical trials were found on this topic.

4. Risk of Bias Assessment in Included Studies (Table 4)

No article was excluded after the AQUA tool application. All the included studies were adjudged to have a low risk of bias.

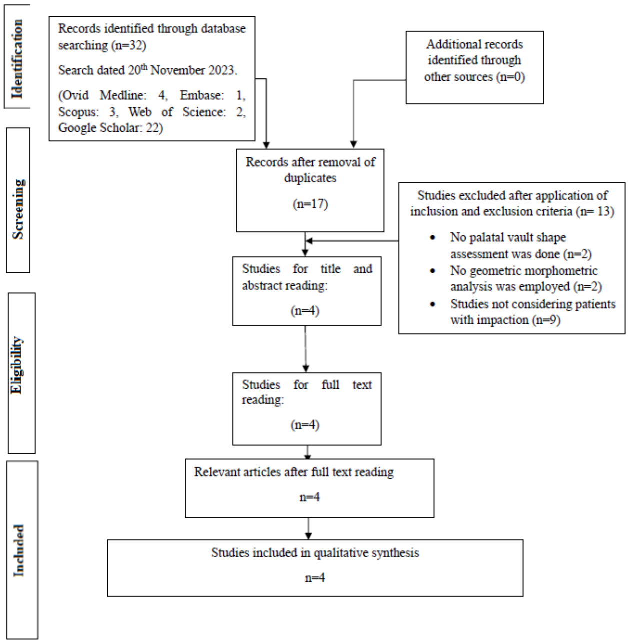

Figure 1: Prisma flow duagram of study selection

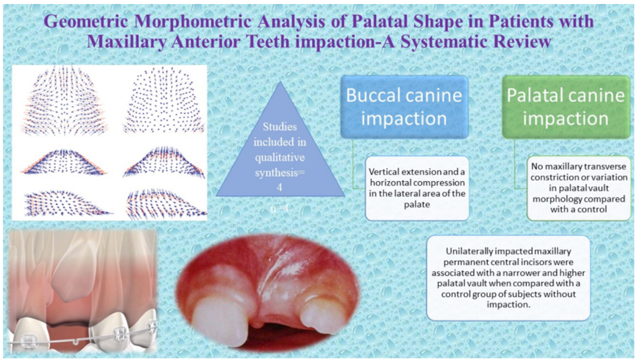

Figure 2: Prisma flow diagram of study selection

4.1. Study characteristics

A summary of the characteristics of all studies is displayed in Table 3. All the selected studies were published between 2017-2023. Pavoni et al.[20] (2017) analysed variations in palatal morphology in subjects presenting unilaterally impacted maxillary permanent central incisors. Mucedero et al. (2019)[21] analysed morphological variations of the palate shape and maxillary arch dimensions in subjects with unilaterally or bilaterally buccally impacted maxillary canines. Mucedero et al. (2019)[22] and Saade et al. (2023)[23] explored the effect of palatally displaced canines on maxillary dimensions and arch shape. All authors studied palatal morphology by comparing it with that of a control group with no eruption anomalies. All studies evaluated the palatal dimensions on scanned models of patients except for the study by Saade et al.[23] in which the morphology was assessed on CBCT images.

4.2. Qualitative analysis

Pavoni et al.[24] (2017) used GMM to study the effects of eruption disorders of upper central incisors on the development of the palate. Comparisons were made between palatal shape variations in subjects with incisor impaction and those without any eruption anomaly. The palate was described in terms of homologous landmarks on digital casts. A total of 240 points (Procrustus coordinates) were registered for each palate. Principal Component Analysis was applied to the coordinates to study the shape variations. Palatal deformation was found to be the greatest in the lateral and superior regions. The palate was found to be narrower, longer, and higher in the impaction group compared with the control group.

Mucedero et al.[22] (2019) studied the palatal morphological variations in patients with unilateral or bilateral buccal canine impactions (BDC) by comparing it with a control group. Maxillary digital models were developed using a tri-dimensional scanner. On each digital cast, 240 landmarks were marked and the palatal template was used as a reference for comparison. View Box software was used for the superimposition of the digitised palatal templates with an iterative closest point procedure for the inter-group comparison. BDC palates were found to be higher and narrower than the control group, especially in the canine regions.

Palatal shape variations were assessed in patients with unilateral or bilateral palatal canine impactions by Mucedero et al.[21] (2019) using a similar methodology as above. The colour map tool in the View Box software was used to visualise the differences in palatal shape in both groups. GMM analysis revealed no statistically significant differences between the palatal vault shapes in both groups.

In a recent 3D study conducted by Saade et al.[23] (2023), CBCT images were used to study the palatal shape variations in subjects with palatal canine impactions and compare them with a control group. 10 landmarks were identified on the maxillary bone as well as on the maxillary arch to define morphological variations between the 2 groups. MorphoJ software was used to detect the shape characteristics using the 3D digitised landmarks. After Procrustes superimposition, these estimations were implemented through Discriminant Function Analysis (DFA), Canonical variance analysis (CVA), and a two-block Partial Least Squares Analysis (PLS). The sagittal and vertical maxillary dimensions showed no significant difference between the two groups except for the distance between the zygomaticomaxillary suture and the coronal plane on the left side. Although all the transverse widths were greater in the impaction group, only the inter-piriform aperture and inter-greater palatine foramen widths were significantly higher.

Results of the present systematic review thus showed that palatal vault morphology can be considered a primary factor in the genesis of buccal canine impactions and maxillary incisor impactions. Palatal canine impactions had minimal relationship with palatal shape and morphology.

5. Discussion

In this systematic review, strict selection criteria were used to include articles related to geometric morphometric analysis of palatal shape in patients with eruption anomalies affecting the anterior maxillary teeth. Qualitative analysis of the included studies revealed that buccal canine impactions influence palatal morphology, while palatal canine impactions don't have any significant influence on the same. Moreover, failure of eruption of central incisors beyond their physiological age of eruption led to maxillary transverse deficiency, especially in the anterior region.

Quality Assessment and Risk of bias assessment using the AQUA tool revealed a low risk of bias in the included studies across all the domains. The methods used to perform the measurements were very clear and comprehensive enough to allow the reviewer to answer the review question in all studies.

A comprehensive evaluation of palatal morphology has been attempted by various studies using 2D transverse measurements on dental and digital casts. However, palatal morphology can be accurately studied only by 3D evaluation and Geometric morphometrics is one modality which makes this possible.

Buccal displacement of one or both canines often exhibited a transverse maxillary deficiency compared with the control group. The superior palatal region and the lateral maxillary surface were different between the groups.[22] The palatal vault was higher and narrower in comparison to those with no canine impaction. This is in agreement with the comprehensive literature review and study by Jacoby et al.[7] (1983) which stated that arch length deficiency is the primary reason for labially unerupted canines. The labial failure of eruption or the ectopic eruption of the maxillary canine can be considered the result of a crowded condition in the maxillary bone which can further be manifested as a high and narrow palatal vault. This claim was further supported by other well-documented studies[6,10,11,14]

Palatal vault analysis in patients with palatal canine impactions revealed no significant changes in morphology when compared to the control group.[21,23] The information gathered from previous studies regarding palatal vault morphology in patients with palatal canine impactions is incomplete as 2D analysis is inferior to 3D analyses such as GMM. The findings of our systematic review are in contradiction to the study by Kim et al.[13] who examined the morphology of the palate on digital dental casts through the ratio between palatal vault depth and intermolar width. The results of their study revealed a narrower and longer maxillary arch in the group with palatally impacted canines. However, the majority of other studies are in agreement with our findings suggesting no morphological variations in the palatal vault of patients with palatal canine impactions. According to Jacoby et al.[7] (1983), palatally impacted canines do not show the same arch-length deficiency as buccally unerupted ones with some even present in arches with excessive space which further supports our findings. The morphometric analysis in the studies included in this systematic review showed that the maxillary shape could not be considered a primary factor in the genesis of the PDC anomaly.[21,23]

Morphometric analysis of palatal vaults in patients with incisor eruption anomalies showed significant transverse maxillary deficiency.[24] Maxillary growth occurs in the forward and downward direction as a result of cortical drift, displacement and remodelling of alveolar bone. Cortical drift at the alveolar bone level occurs due to the eruption of teeth and contributes to the overall growth of the maxillary arch and palatal vault development. Thus, the absence of maxillary central incisors over the physiological age of eruption influenced the development of a different maxillary morphology with a narrower and higher palatal vault compared with subjects without eruption anomalies.

It can be gathered that it is possible to predict and prevent buccal/palatal canine impactions by early geometric morphometric analysis of the palatal vaults. The clinician must choose a therapeutic protocol to correct the anterior space deficiency and to improve the intraosseous positions of the impacted teeth whenever possible. The results also further strengthen the genetic basis of etiology of palatal canine impactions and how they are more linked to adequate or excess space in the maxillary arch rather than crowding.

6. Conclusion

1. Geometric morphometric analysis is an invaluable tool for the three-dimensional assessment of palatal vault morphology.
2. Patients with unilateral or bilateral buccal displaced permanent canine showed a vertical extension and a horizontal compression in the lateral area of the palate.
3. Patients with unilateral or bilateral palatally displaced permanent canine showed no maxillary transverse constriction or variation in palatal vault morphology compared with a control group.
4. Unilaterally impacted maxillary permanent central incisors were associated with a narrower and higher palatal vault when compared with a control group of subjects without impaction.
5. Morphometric variations of the palatal vault can be considered a factor in determining the probability of maxillary anterior teeth impactions.

7. Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author upon reasonable request.

8. List of Abbreviations

GMM	Geometric morphometrics
ROB	Risk of Bias
BDC	Buccally displaced canines
PDC	Palatally displaced canines

9. Ethics Approval and Consent to Participate

Not applicable.

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11. Consent for Publication

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12. Conflict of Interest

None.

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