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ORIGINAL ARTICLE

Evaluation of maxillary arch morphology in children with unilaterally impacted incisors via three-dimensional analysis of digital dental casts: a controlled study

Evaluierung der Morphologie des Oberkieferbogens bei Kindern mit unilateral impaktierten Inzisiven mittels 3D-Analyse digitaler dentaler Abformungen: Eine kontrollierte Studie

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Abstract
Objective The purpose of this work was to analyze variations in maxillary arch dimensions in subjects presenting unilaterally impacted maxillary permanent central incisors compared with a control group of subjects without eruption anomalies.
Methods A group of 23 Caucasian children [8 females and 15 males, mean age 9.7 years, standard deviation (SD) 1.6 years] displaying unilaterally impacted maxillary permanent central incisors (impacted incisor group: IIG) were compared with a control group (CG) of 23 subjects (9 females; 14 males, mean age 8.8 years, SD 1.9 years) presenting no eruption disorders. Pretreatment dental casts were taken from each subject and the upper arch was scanned using a three-dimensional scanner. Linear measurements were taken on each digital model to analyze maxillary arch dimensions. Significant between-group differences were tested with the Student's *t* test ($p < 0.05$).
Results The transverse and sagittal upper-arch measurements were significantly smaller in the IIG than in the CG. In particular, the anterior arch was 1.35 mm shorter in the IIG, while intercanine width was decreased by 2.51 mm on the impacted side.
Conclusion Children revealing unilaterally impacted maxillary central incisors demonstrated a significantly constricted maxillary transverse width and shorter arch on the impacted side compared with subjects with no eruption disorders.

Keywords Impacted incisor · Maxillary morphology · Digital dental casts · Pediatric dentistry · Mixed dentition

Zusammenfassung
Ziel Die Zielsetzung der Studie war die Analyse dimensionaler Variationen in den Oberkieferbögen von Kindern mit einseitig impaktierten permanenten zentralen Inzisiven im Vergleich mit einer Kontrollgruppe ohne Durchbruchsanomalien.
Methoden Eine Gruppe von 23 kaukasischen Kindern [8 Mädchen, 15 Jungen, Durchschnittsalter 9,7, Standardabweichung (SD) 1,6 Jahre] mit einseitig impaktierten bleibenden zentralen Inzisiven ("impacted incisor group", IIG) wurde verglichen mit einer Kontrollgruppe ("control group", CG; 9 Mädchen, 14 Jungen, Durchschnittsalter 8,8, SD 1,9 Jahre) ohne Durchbruchsstörungen. Vor der Behandlung wurden von jedem Individuum Zahnabdrücke erstellt, der obere Bogen wurde dreidimensional gescannt. Zur Analyse der Oberkieferbogendimensionen wurde jedes digitale Modell linear vermessen. Signifikante Differenzen ($p < 0{,}05$) wurden mit dem Student-t-Test überprüft.
Ergebnisse In der IIG erwiesen sich die transversalen und die sagittalen Messungen als signifikant geringer als in der CG. Vor allem der vordere Bogen war 1,35 mm kürzer in der IIG, während die intercanine Distanz auf der Seite der Impaktierung 2,51 mm geringer war.

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Schlussfolgerung Bei Kindern mit einseitig impaktierten zentralen Inzisiven im Oberkiefer zeigten sich im Vergleich mit Kindern ohne Eruptionsanomalie eine signifikant verengte Oberkieferbreite und ein kürzerer Bogen auf der Seite der Impaktierung.

Schlüsselwörter Impaktierter Inzisivus · Maxillamorphologie · Digitale Zahnabformung · Pädiatrische Zahnheilkunde · Gemischte Dentition

Introduction

The failure of the permanent maxillary incisors to erupt is a rare pathology in the early phase of mixed dentition, as it occurs in just 0.2–1 % of the population [9]. Primary etiological causes of maxillary incisor impaction include supernumerary teeth, odontomas, trauma to a deciduous tooth, disturbances in tooth eruption sequence, lack of space, and follicular cysts [10]. One of the signs that often attracts the attention of both practitioner and parents is maxillary arch asymmetry and an asymmetric smile arch. During normal eruption, the two permanent central incisors emerge within the arch almost concomitantly. In the presence of only one fully erupted central incisor, the practitioner should examine the potential causes of the contralateral incisor's delayed eruption [5].

The primary goal of treating displaced maxillary incisors is to reposition the tooth within the dental arch whenever possible [4, 8, 22]. Several treatment techniques have been developed [4, 5], and careful planning is required when an impacted tooth is to be moved. However, the treatment mechanics can be modified according to the individual clinician's preferences.

In the literature, changing the dimensions of the maxillary dental arch has usually been described as dimensional changes in intercanine and intermolar widths and in arch lengths via using traditional measurement methods on dental casts with calipers. Changes measured via traditional approaches might not always reveal the modified arch form [7, 16] and these methods cannot exclude bias when assessing the maxillary arch's transverse dimension due to tooth malposition, such as buccal tooth tipping [1, 18]. To overcome these problems, an optical scanner can be used to obtain three-dimensional (3D) images of dental casts [17]. Recent advances in digital technology have vastly improved the diagnostic workup in orthodontics, and analogue records have quickly been replaced by digital formats [12] Several studies have verified the accuracy of angle and linear measurements on 3D digital models with different software [19, 20]. Finally, 3D images can help us assess linear and angle measurements that describe the arch form [23].

Although numerous working groups [4, 5, 8–10, 22] have investigated the treatment of intraosseous displaced incisors, no study has to date evaluated maxillary morphology in subjects presenting impacted incisors via 3D digital dental casts. The aim of the present study was, therefore, to analyze variations in the maxillary arch in a group of subjects with unilaterally impacted maxillary permanent central incisors compared with a control group of subjects without eruption anomalies in the maxillary permanent incisors using 3D analysis of digital dental casts.

Patients and methods

A total sample of 23 consecutive subjects [impacted incisor group (IIG), 8 females and 15 males] with unilaterally impacted maxillary permanent central incisors who sought orthodontic treatment at the Department of Orthodontics at the University of Rome Tor Vergata were selected. Mean age was 9.6 years [standard deviation (SD) 1.7 years]. The study project was approved by the Ethics Committee at the University of Rome Tor Vergata, and informed consent was obtained from the subjects' parents.

Our additional criteria for enrolling subjects in the IIG were the following: Caucasian ancestry; eruption of the contralateral incisor at least 6 months earlier or deviation from the normal sequence of eruption (lateral incisor erupted prior to the central incisor); no posterior or anterior crossbite; normal overjet and overbite values; intermediate mixed dentition with a Class I or edge-to-edge molar relationship (43.5 % Class I, 56.5 % end-to-end molar relationship); absence of previous orthodontic treatment or tooth extraction; and the absence of sucking habits, craniofacial syndromes, cysts, cleft lip and/or palate, or multiple and/or advanced caries.

The IIG was compared with a control group (CG) of 23 prepubertal subjects (9 females; 14 males) with no eruption disorders in the permanent incisors. The CG subjects' mean age was 8.8 years (SD 1.9 years), and all of them were in intermediate mixed dentition with a Class I or end-to-end molar relationship (52.2 % Class I, 47.8 % end-to-end molar relationship).

We had access to the pretreatment dental casts for all subjects in both groups.

To analyze the maxillary arch form and perimeter, the dental casts of the maxillary arches were scanned by a 3D scanner (D800, 3Shape A/S, Copenhagen K Denmark, Scan time 25 s, Resolution 2 cameras 5.0 megapixels, Ultrahigh point accuracy <15 microns). Each cast was scanned from 10 or more views that were then combined and rendered into three dimensions using specific software (3Shape ScanItOrthodontics^{TM} 2010-2p3, 3Shape A/S, Copenhagen

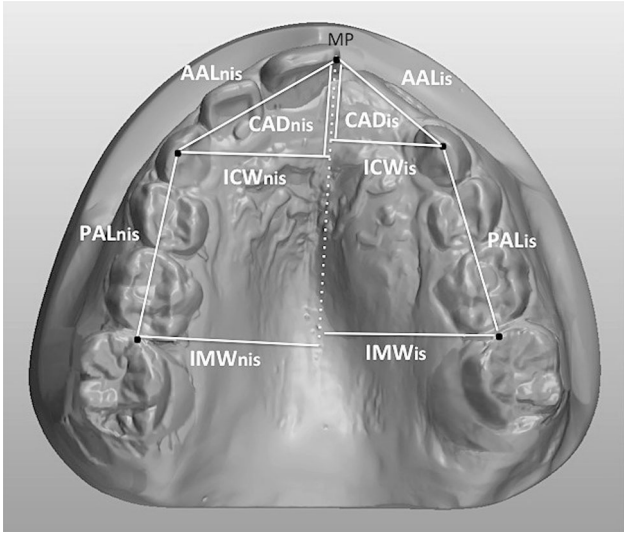

Fig. 1 Transverse and sagittal measurements on the maxillary arch in the impacted incisor group (*IIG*) by using 3D digital model
Abb. 1 Transversale und sagittale Messungen am Oberkieferbogen anhand des dreidimensionalen digitalen Modells, Gruppe der Kinder mit impaktierten Inzisiven (*IIG*)

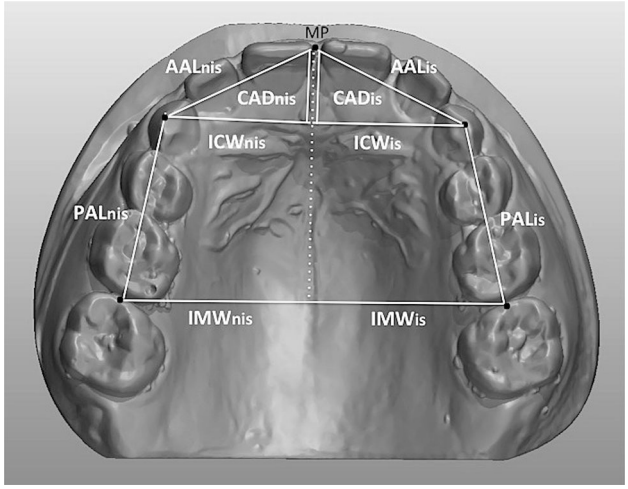

Fig. 2 Transverse and sagittal measurements on the maxillary arch in the control group (*CG*) by using 3D digital model
Abb. 2 Transversale und sagittale Messungen am Oberkieferbogen anhand des dreidimensionalen digitalen Modells, Kinder in der Kontrollgruppe (*CG*)

K, Denmark). The virtual 3D models were measured and analyzed with specific software (3Shape OrthoAnalyzer™ 2010, 3Shape A/S, Copenhagen K, Denmark).

To analyze the transverse and sagittal dimensions of the maxillary arch, a midpoint (MP) was identified in the IIG as the most mesial point on the erupted central incisor's incisal margin (Fig. 1). In the CG, MP was defined as the midpoint between the most mesial points on the incisal margins of both central incisors (Fig. 2). All linear bidimensional measurements were taken on the level of a horizontal plane passing through the cusp tips of right and left deciduous canines and MP.

A midline passing through the MP and through the projection of the center of the third couple of palatine rugae on the horizontal plane was created. The MPs on the mesial margins of the first permanent molars were projected onto the horizontal plane. All conventional linear measurements were taken on the horizontal plane either on the side displaying an impacted central incisor (impacted side) or on the side with the erupted central incisor (nonimpacted side):

- anterior arch length on the impacted side (AALis): distance from the MP to the cusp of the deciduous canine on the impacted side,
- anterior arch length on the nonimpacted side (AALnis): distance from the MP to the cusp of the deciduous canine on the nonimpacted side,
- posterior arch length on the impacted side (PALis): distance from the cusp of the deciduous canine to the mesial marginal crest of the first permanent molar on the impacted side,
- posterior arch length on the nonimpacted side (PALnis): distance from the cusp of the deciduous canine to the mesial marginal crest of the first permanent molar on the nonimpacted side,
- canine arch depth on the impacted side (CADis): distance from the MP to the projection on the deciduous canine's cusp midline, on the impacted side,
- canine arch depth on the nonimpacted side (CADnis): distance from the MP to the projection on the deciduous canine's cusp midline, on the nonimpacted side,
- intercanine width on the impacted side (ICWis): distance from the cusp tip of the deciduous canine to the midline on the impacted side,
- intercanine width on the nonimpacted side (ICWnis): distance from the cusp tip of the deciduous canine to the midline on the nonimpacted side,
- intermolar width on the impacted side (IMWis): distance from the MP on the mesial margin of the first permanent molars to the midline on the impacted side,
- intermolar width on the nonimpacted side (IMWnis): distance from the MP on the mesial margin of the first permanent molars to the midline on the nonimpacted side.

The same measurements were taken in the CG (Fig. 2). The impacted and nonimpacted sides of the IIG were superimposed onto the same sides of the CG.

Statistical methods

To determine method reliability, a single trained examiner took all the measurements on the digital models (M.B.) and repeated them after an interval of approximately 2 weeks.

We applied a paired t-test to compare the two measurements (systematic error). The magnitude of random error was calculated using the method of moments' estimator [21].

The power of the study for the independent sample *t* test was calculated on the basis of a sample size of two groups and an effect size (Cohen's *d*) equal to 0.9 [6]. The power was 0.80 at an α level of 0.05 (SigmaStat 3.5, Systat Software, Point Richmond, CA, USA).

The χ^2 tests with Yates' correction were used to assess between-group differences in gender distribution and the distribution in molar relationships. Descriptive statistics were calculated for all the measurements in each group. Exploratory statistics revealed that all variables were normally distributed (Kolmogorov–Smirnov test) with equality of variances (Levene's test). Between-group differences were tested with the Student's *t* test. All statistical computations were done using specific software (SigmaStat 3.5, Systat software, Point Richmond, CA, USA).

Results

We observed no systematic error between the repeated measurements. Random error ranged from 0.25 mm (AALis) to 0.58 mm (IMWnis; Table 1). No significant between-group differences were found in gender distribution (χ^2 test = 0.00; $p = 1.000$) or in the distribution in molar relationships (χ^2 test = 0.09; $p = 0.768$). Descriptive statistics and between-group statistical comparisons are given in Table 2.

Tab. 1 Random error (moments' estimator method) for the analyzed variables
Tab. 1 Zufallsfehler (Schätzer nach Momenten-M ethode) für die analysierten Variablen

	Error
AALis	0.25
AALnis	0.28
PALis	0.38
PALnis	0.45
CADis	0.55
CADnis	0.51
ICWis	0.42
ICWnis	0.54
IMWis	0.53
IMWnis	0.58

AAL anterior arch length, *PAL* posterior arch length, *CAD* canine arch depth, *ICW* intercanine width, *IMW* intermolar width, *diff.* difference, *is* impacted side, *nis* non-impacted side

AALis was significantly smaller in the IIG versus CG (−1.35 mm), while in the AALnis was significantly greater in the IIG versus CG (+0.73 mm). No statistically significant between-group differences appeared in either PALis or PALnis. CADis was significantly smaller in the IIG than in the CG (−0.92 mm). No statistically significant between-group difference was identified in CADnis. The IIG revealed significantly narrower transverse arch widths both at the deciduous canines and at the first permanent molars than the CG (ICWis −3.14 mm, ICWnis −0.97 mm, IMWis and IMWnis −1.73 mm).

Discussion

The aim of the present study was to analyze variations in the maxillary arch in a group of subjects with unilaterally impacted maxillary permanent central incisors (IIG) compared with a control group (CG) of subjects with no eruption disorders in the maxillary permanent incisors. There were no differences between the two groups in chronologic age, gender distribution, dentition stage, or molar relationships.

Data from the current study indicate that subjects with impacted maxillary incisors demonstrate a transverse maxillary deficiency compared with the control group. In particular, both intercanine and intermolar widths were significantly smaller on both the impacted and nonimpacted side compared to the control group. The greatest reduction in arch width was documented on the impacted side at the deciduous canine level (−2.51 mm). To our knowledge, no study in the literature has analyzed these characteristics on dental cast in subjects with impacted incisors, but similar analyses were performed in subjects presenting maxillary canine impaction.

McConnell et al. [13] identified 81 impacted maxillary canines in 57 orthodontic subjects. A sample of 103 subjects with no impacted canines was used as control group. Diagnostic casts served to measure both intermolar and intercanine widths. The authors concluded that subjects with impacted maxillary canines exhibit transverse maxillary deficiency in the anterior portion of the dental arch. Baccetti et al. [3] supported the use of rapid maxillary expansion (RME) to decrease the incidence of palatally displaced canines. The use of a banded RME in early mixed dentition was proposed to facilitate successful canine eruption [3]. Accordingly, Pavoni et al. [14] demonstrated that the most effective treatment to prevent maxillary incisor impaction is orthopedic expansion of the maxillary dental arch. Following surgical removal of any obstacles hindering the eruption of permanent maxillary incisors (e.g., supernumeraries, odontomas), RME can help provide space to allow the proper eruption of the

Tab. 2 Descriptive statistics and statistical comparisons. The impacted and non-impacted sides in the Impacted Incisor Group (IIG) were superimposed onto the same side in the Control Group (CG, presenting no impacted incisors)
Tab. 2 Deskriptive Statistik und statistische Vergleiche. Die Seiten ohne und mit Impaktierung in der Gruppe der Kinder mit impaktierten Inzisiven (*IIG*) wurden auf den jeweils gleichen Seiten überlagert in der Gruppe mit Kindern ohne impaktierte Inzisiven (*CG*)

	Impacted incisor group IIG		Control group CG		Mean diff.	95 % Confidence interval of the difference		*t* tests
	Mean	SD	Mean	SD		Lower	Upper	*P*
AALis	14.53	0.90	15.87	1.22	−1.35	−1.99	−0.71	0.000
AALnis	16.43	1.04	15.70	1.27	0.73	0.04	1.42	0.038
PALis	19.44	0.39	19.42	0.82	0.02	−0.36	0.40	0.907
PALnis	19.43	0.60	19.40	1.26	0.02	−0.56	0.61	0.936
CADis	5.84	0.66	6.76	0.78	−0.92	−1.35	−0.49	0.000
CADnis	6.85	0.79	6.70	0.63	0.15	−0.28	0.57	0.499
ICWis	12.60	0.80	15.12	1.26	−2.51	−3.14	−1.89	0.000
ICWnis	14.11	1.02	15.08	1.26	−0.97	−1.65	−0.29	0.006
IMWis	18.93	0.85	20.66	1.12	−1.73	−2.32	−1.13	0.000
IMWnis	18.96	0.92	20.69	1.15	−1.73	−2.35	−1.11	0.000

AAL anterior arch length, *PAL* posterior arch length, *CAD* canine arch depth, *ICW* intercanine width, *IMW* intermolar width, *diff.* difference, *is* impacted side, *nis* non-impacted side, *SD* standard deviation

permanent incisor within the arch. When the space to be gained on the arch perimeter is minor, dentoalveolar expansion via a fixed (e.g., quad helix or a transpalatal bar) or removable appliance can be considered.

We noted significant differences in this study between the IIG and CG in sagittal arch length, suggesting that impacted incisors affect the sagittal dimension of the maxillary arch. The group with impacted incisors displayed significantly smaller AAL and CAD on the impacted side compared to the control sample. The absence of a tooth can reduce the space required for succeeding teeth because adjacent teeth may occupy or move into the available space. In particular, the absence of a permanent incisor is usually accompanied by a shift of the adjacent incisors and/or canine toward the affected side and a resultant midline discrepancy [11]. In our study, AAL on the impacted side in the IIG was significantly smaller than in the CG. This result can be attributed in part to a mesial shift of posterior teeth toward the edentulous space (CADis −0.92 mm in the IIG vs CG) and in part to a drifting of the erupted contralateral central incisor into the edentulous area (AALnis +0.73 mm in the IIG vs CG). The mechanism of space preservation or space gain in the maxillary arch's anterior segment is probably an important factor associated with more positive outcomes such as the spontaneous eruption of delayed incisors. Conversely, loss of space in the anterior region accounts for many of the cases that failed to demonstrate erupted impacted incisors [14]. In these cases, the clinician must choose a therapeutic protocol to correct the anterior space deficiency and to improve the intraosseous positions of the impacted teeth. RME often has favorable effects at the dentoalveolar and skeletal level that facilitate tooth eruption [15], though comprehensive orthodontic treatment with fixed appliances to complete the occlusion is often necessary. The maintenance of or improvement in the perimeter of the upper arch as an intervention in cases with displaced maxillary incisors can be effective in preventing their becoming impacted, as Armi et al. [2] reported for PDCs. Wearing cervical pull headgear can help prevent the distal segment of the upper dental arch from moving mesially, thus, keeping the space available for incisor eruption.

Conclusion

- Children with unilaterally impacted maxillary permanent central incisors displayed a significant transverse constriction of the maxillary arch compared with a control group of subjects without impaction.
- Significant differences were noted between the impacted incisors group and control group in terms of sagittal arch length, suggesting that unilaterally impacted maxillary permanent central incisors affect the maxillary arch's sagittal dimension.
- The absence of a maxillary permanent central incisor can result in a reduction in the maxillary arch's transverse width and in a loss of anterior arch length with potentially negative effects on occlusion and alignment, and may evoke the need for orthodontic treatment.

- Interventions aiming to facilitate the eruption of impacted maxillary permanent central incisors should include orthodontic treatment to maintain or increase maxillary arch's length or perimeter.

Compliance with ethical guidelines

Conflict of interest Chiara Pavoni, Lorenzo Franchi, Marco Buongiorno, and Paola Cozza have no conflict of interest.
All studies on humans described in the present manuscript were carried out with the approval of the responsible ethics committee and in accordance with national law and the Helsinki Declaration of 1975 (in its current, revised form). Informed consent was obtained from all patients included in studies. In the case of underage patients, consent was obtained from a parent or legal guardian.

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