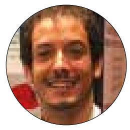
Enhancing the diagnosis of maxillary transverse discrepancy through 3-D technology and surface-to-surface superimposition. Description of the digital workflow with a documented case report



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Abstract

Background Maxillary transverse discrepancy is often diagnosed in childhood. The evaluation of morphological characteristics of the maxilla is crucial for appropriate treatment of this condition, however conventional diagnostic method is based on visual inspection and transversal linear parameters. In this paper, we described a user-friendly diagnostic digital workflow based on the surface-to-surface analysis. We also described a case report.

Case report A 6-year-old female patient presenting mild transversal maxillary deficiency associated with functional posterior crossbite was treated by using maxillary removable appliance. In this respect, the appliance was designed in accordance to the morphological characteristics of the maxilla obtained by using the diagnostic digital work-flow and the maxillary surface-to-surface analysis.

Conclusion The present user-friendly diagnostic digital workflow based on surface-to-surface analysis helps clinicians to detect specific morphological characteristics of the maxilla, such as shape and area of asymmetry, in order to reach a comprehensive diagnosis and choose the correct biomechanics for treating the condition.

KEYWORDS Digital work-flow; Maxillary transverse discrepancy; Surface-to-surface superimposition; 3-D technology.

Introduction

Posterior crossbite is a frequent malocclusion in deciduous and mixed dentition, with a prevalence of 7–23% [Silva Filho et al., 2007; Lo Giudice et al., 2018; Sousa et al., 2014; Leonardi et al., 2018; Lo Giudice et al., 2017a; Mummolo et. al., 2014]. It can be displayed both unilaterally or bilaterally and it is often associated with transversal maxillary hypoplasia. Unilateral posterior crossbite is often caused by a functional shift of the mandible towards the crossbite side and it is often caused by a mild bilateral maxillary constriction, which causes occlusal interference leading to a functional shift of the mandible towards the crossbite in centric occlusion [Leonardi et al., 2018]. This malocclusion is often treated by skeletal expansion of the maxilla, in particular rapid maxillary expansion (RME) is the most effective orthopaedic procedure to increase the maxillary transverse dimension in young patients by opening the midpalatal suture [Allen et al., 2003; Lo Giudice et al., 2018b; Baka et al., 2015]. If left untreated, functional posterior crossbite can modify maxillary morphology due to an adaptative asymmetric compensation of the upper dento-alveolar process that become narrower at the crossbite side compared to the non-crossbite side [Thilander and Lennartsson, 2002; Lauritano et al., 2019; Caccianiga et al., 2019]. In this respect, a previous study [Leonardi et al., 2018] demonstrated that in patients with functional posterior crossbite there is a bilateral symmetrical contraction of the palatal vault and an asymmetric contraction of the alveolar process. This morphological asymmetry can also complicate the biomechanics used since an asymmetric expansion would be required and it could be necessary more at the alveolar process than at the palate.

Nowadays, progress in radiographic techniques and 3D imaging provides new opportunities for a comprehensive evaluation of anatomical characteristics and morphological changes in medical field [Primožic et al., 2013; Ganzer et al., 2017; Isola et al., 2019]. In particular, the use of sophisticated reverse engineering software produces accurate evaluations of the morphological symmetry of any anatomical structure. By using specific software, 3D bone structures such as maxillary and mandibular jaws, obtained from digital scans, can be superimposed to evaluate the Euclidean distances between the surfaces of the superimposed anatomical structures [Kapila and Nervina, 2015]. The morphological differences between the superimposed structures can be displayed in different colors on a 3D color-map by setting different levels of tolerance using a technique called surface-to-surface analysis [Leonardi et al., 2018; Kapila and Nervina, 2015]. This opens a new scenario, since it is possible to three-dimensionally evaluate changes between pre and post-treatment or monitoring changes occurring due to the growth. Moreover, it is possible to mirror and then superimpose maxillary and/or mandibular jaw of the same patients in order to identify anatomical asymmetry as well as asymmetrical changes between the two sides [Leonardi et al., 2018; Kapila and Nervina, 2015; Piancino et al., 2019].

In this respect, the present case report shows the digital work-flow for a preliminary qualitative assessment of maxillary asymmetrical morphology in children with maxillary transversal deficiency associated with functional mandibular shift. Such preliminary evaluation can provide useful information to reach a comprehensive diagnosis and choose the correct biomechanics for treating such condition.

Materials and methods

Patient's clinical charateristics

A 6-year-old female attended consultation complaining an asymmetric mandibular functional pattern upon closure, i.e., during chewing or swallowing. The mother was worried about the negative functional consequences as well as the facial aesthetics related to this aberrant mandibular posture upon closure. Facial analysis revealed a slight prognatism with labial competence, with significant accentuation of cheek-bone profile (Fig. 1) according to Arnett's soft tissue cephalometric analysis [Nucera et al., 2017]. Intra-oral examination revealed deciduous dentition, canine-molar Class II relationship (neutron-occlusion) on the right side and Class I relationship on the left side due to mandibular shift toward the right side in centric occlusion (Fig. 2).

Centric relation obtained with digital models and digital articulator, with coincidence of both maxillary and mandibular midlines, showed mild bi-lateral maxillary contraction with occlusal interferences causing mandibular shift upon closure (Fig. 3). Panoramic radiograph showed the presence of all permanent teeth with no signs of ectopic eruptive pattern (Fig. 4). Considering the patient's age and the absence of relevant skeletal antero-posterior discrepancies, lateral cephalogram was not required in order to avoid useless radiation exposure [Yeung et al., 2019; Lo Giudice et al, 2018c; Cordasco et al, 2013].

To comprehensively evaluate maxillary morphology and to identify the potential area of maxillary transversal restriction, i.e., palatal vault and/or dento-alveolar process, a preliminary digital morphological evaluation was performed by referring to a specific computer-aided workflow.

Creation of 3D virtual models of both maxillary and mandibular arches

The patient received conventional dental impressions using a monophasic polyether impression material (Impregum Penta; 3M ESPE, Seefeld, Germany) with stainless steel impression trays (Hi-Tray Metal; Zhermack SpA, Rovigo, Italy), which was poured, at most, after 4 hours with type IV stone (Ortostone; Techim Group, Milan, Italy). Then, the maxillary cast was scanned using the D500 3D scanner (3Shape A/S, Copenhagen, Denmark) according to a validated and described

FIG. 1 Extra-oral facial examination.

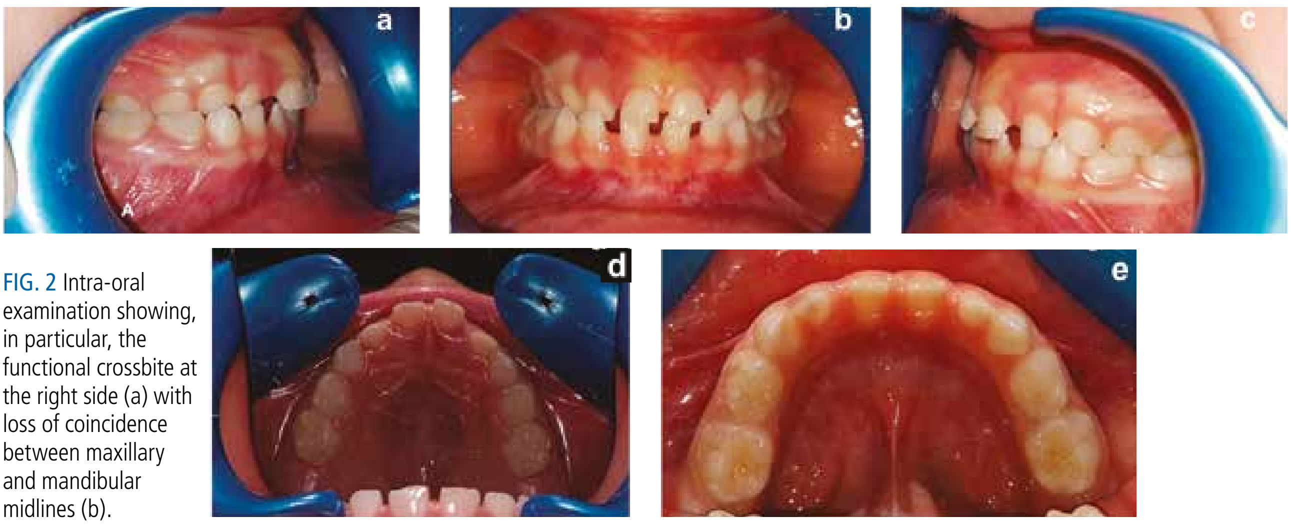

FIG. 2 Intra-oral examination showing, in particular, the functional crossbite at the right side (a) with loss of coincidence between maxillary and mandibular midlines (b).

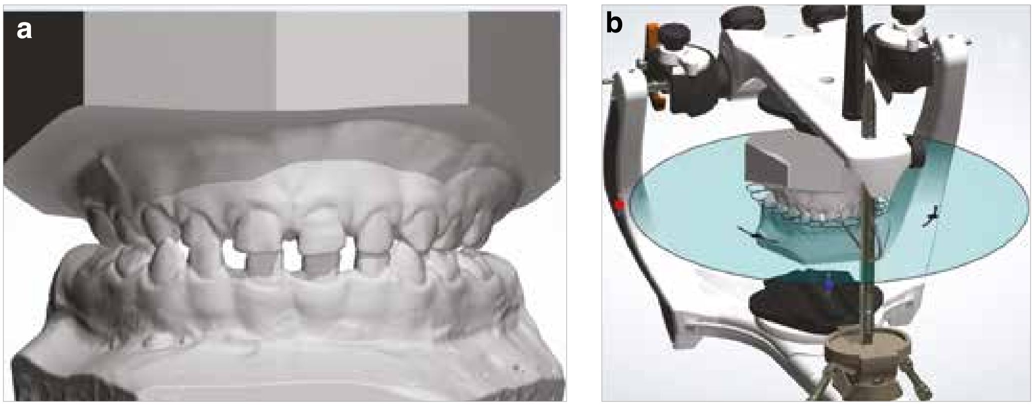

FIG. 3 Centric occlusion, with mandibular and maxillary midlines coincident, showing occlusal interferences leading to mandibular shift upon closure (a) (see intra-oral images). Digital articulator used to simulate centric occlusion of the patient in order to detect occlusal interferences (b).

FIG. 4 Panoramic radiograph.

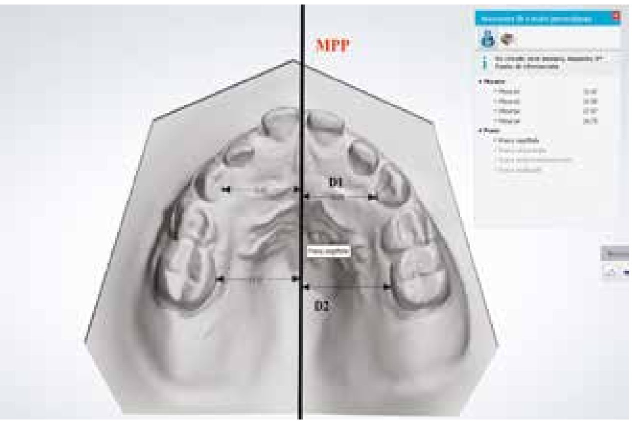

FIG. 5 Median palate plane (MPP) drawn on digital maxillary dental arch. See also emi-linear measurements as distance between the MPP and primary canines (D1) and primary second molars (D2) on both sides.

FIG. 6 Median palate plane (MPP) drawn on digital maxillary dental arch. See also emi-linear measurements as distance between the MPP and primary canines (D1) and primary second molars (D2) on both sides.

system [Leonardi et al., 2018; Quinzi et al., 2019]. After scanning, each dental cast was combined and rendered into a 3D stereo-lithographic model by using a specific software (ScanItOrthodontics™ 2015, version 5.6.1.6, 3Shape A/S, Copenhagen, Denmark). The digital model of the scanned printed model was exported to Geomagic Qualify software (3D Systems, Rock Hill, Washington, DC, USA) to perform model registration and superimposition and exported to Ortho Analyzer software (3Shape) to perform linear measurements.

Digitial work-flow for anatomical morphological evaluation of maxilla

A median palatal plane (MPP) was drawn on the maxillary digital cast by identifying two landmarks along the median palatal raphe (Fig. 5): 1) the point on the median palatal raphe adjacent to the second ruga, 2) the point on the median palatal raphe 1 cm distal to point 1.

After identification of MPP, the following measurements were performed (Fig. 5).

D1: the distance between the midpoint at the dento-gingival junction of the primary canine from the crossbite and non-crossbite sides compared with the MPP.

D2: the distance between the midpoint of the dento-gingival junction of the first molar from the crossbite and non-crossbite sides compared with the MPP.

D3: the distance between the midpoint at the dento-gingival junction of the two primary canines (Fig. 6).

D4: the distance between the midpoint at the dento-gingival junction of the two primary second molars (Fig. 6).

These measurements provide information about the transversal diameter of the maxillary arch (D3-D4) and about the emi-transversal diameters to identify a potential linear asymmetry between both sides (D1-D2).

To check for crossbite/non-crossbite symmetry, digital casts from each patient were superimposed through a semi-automatic surface-to-surface matching technique, using 3D reverse modelling software (Geomagic Control™ X, version 2017.0.0, 3D Systems, Rock Hill, USA), which also calculated the deviation between the mirrored and un-mirrored 3D palatal models.

To define the palate surface of the 3D model to be analysed, a gingival plane had to pass through all the most apical points of the dento-gingival junction of all the teeth (from 1st right molar to 1st left molar) (Fig. 7A).

The workflow for the superimposition of the palate can be divided in four steps.

Step 1. Mirroring: It consists in converting the image orientation from right-left, antero-posterior, and infero-superior to left-right, antero-posterior, and infero-superior (Fig. 7B–C).

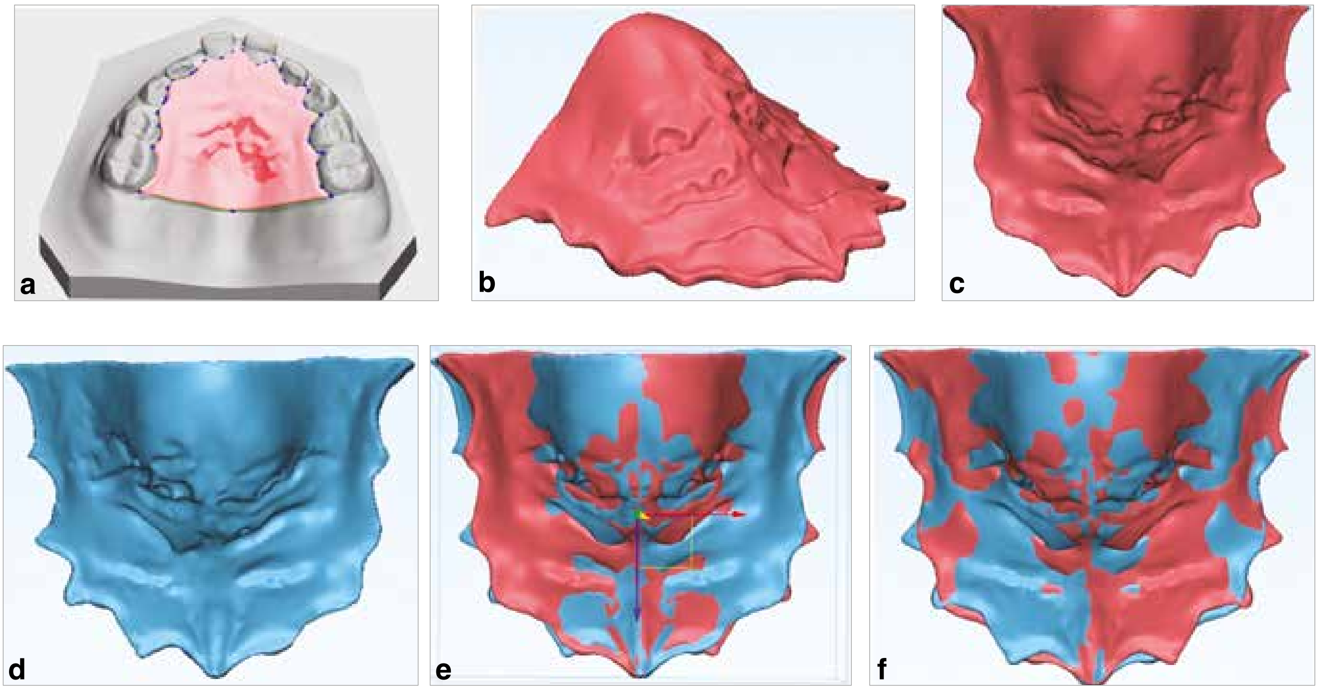

FIG. 7 The gingival plane (a) was assessed by linking the most apical point of the dento-gingival junction of all teeth at the palatal tooth face. Then the palatal vault model was created (b), mirrored (c), and roughly superimposed using the MPP plane and its perpendicular plane (d). Then a 'best-fit' alignment was done to enhance the superimposition (e) quality.

Step 2. First registration: Initial manual superimposition of the two models; Pairs of models (the original and the mirrored one of the same patient) were oriented and approximately registered by using the MPP and a line drawn perpendicularly through point 2 of the MPP (Fig. 7D).

Step 3. Final registration: Final registration was made using the 'Best-fit alignment' option in the Geomagic Control X software. The precision of the registration was set to at least 0.3 mm (tolerance type: '3D Deviation') with a maximum of 100,000 polygons for surface representation. The corresponding polygons from selected reference areas were automatically superimposed (Fig. 7E);

Step 4. Superimposition and 3D analysis: The distances between corresponding areas of the original maxillary cast and the corresponding mirrored one were compared to obtain colour-coded maps (Fig. 8). The yellow-to-red fields indicated that the definitive casts were larger than the master model and the turquoise-to-dark blue fields indicated that the definitive casts were smaller than the master model. The 3D deviation analysis has a tolerance range (green) of ±0.50 mm with a maximum of 2 mm. All the values in this range indicated the matching percentage between the two specular 3D models.

Diagnosis and treatment plan

The analysis of transversal diameter of the maxilla showed a distance of 23.31 mm between primary canines and 27.57 mm between primary second molars. According to McNamara and co-authors [2000], a clinical value of inter-molar distances $\leq$ 31 mm would reflect a narrowed maxilla requiring treatment by maxillary expansion. However, considering that the patient was only 6 years old and that she presented full primary dentition, this cut-off could be higher considering the potential growth of the patient [Maurice and Kula, 1998; D'Apuzzo et al., 2019; Isola et al., 2018; Piancino et al., 2017; Ferro et al., 2016]. Thus, the maxillary contraction could not be considered severe.

Emi-lateral distances to the MPP at the primary second molars level was 17.57 mm at the right side and 18.70 mm at the left side, i.e., it was smaller at the crossbite side

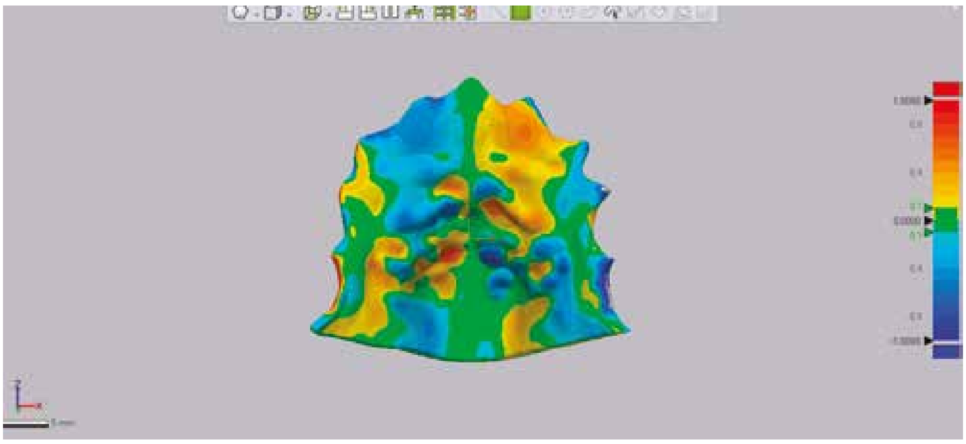

FIG. 8 3D deviation analysis between the two specular models. RGB colored scale bar (millimeters) is reported on the right side: the top (red colored) and the bottom (blue colored) of the scale indicate total mismatching. Green indicates matching percentage. As shown, the areas with most mismatching (intense blue and intense red contours) are located along the alveolar process (at levels of primary molars) suggesting asymmetry in this region.

compared to the non-crossbite side. Moreover, the surface-to-surface analysis of mirrored superimposed models of the maxilla showed a slight asymmetry of maxillary morphology, being more narrowed at the alveolar bone level, as revealed by means of the mirroring technique and the colored map. In this respect, Figure 8 shows the area of most mismatching (intense blue and intense red contours) between the original and specular model being located along the profile of the dento-alveolar processes. Thus, according to information obtained, the patient presented a slight bilateral symmetric contraction of the palatal vault and an asymmetric contraction of the alveolar process of the upper arch, in accordance with previous findings on young subjects with functional posterior crossbite [Leonardi et al., 2018].

Our treatment goal was to increase transversal maxillary diameters eliminating occlusal interferences in order to restore a physiologic posture of the mandible. Moreover, to obtain this by expanding more the maxillary crossbite side compared to the non-crossbite side.

Despite maxillary expander represents the gold standard appliance for treating transversal maxillary deficiency in young subjects, we decided to not use this appliance for two reasons: 1) skeletal expansion would have been excessive for treating a slight maxillary contraction, 2) maxillary expander works in a symmetrical pattern that would have produced over-expansion at the non-crossbite side generating potential new occlusal interferences. In this respect, we opted for a maxillary removable appliance with built-in Hyrax screw and with an asymmetric cut of the resin that could have provided much anchorage at the non-crossbite side, thus favouring the expansion at the crossbite side. The screw was slowly activated, i.e., 2 times a week up to the clinical assessment of crossbite resolution and correction of mandible posture in centric relation, with both maxillary and mandibular midlines coincident.

FIG. 9 Removable appliance with built-in Hyrax screw and with an asymmetric cut of the resin that could provide anchorage at the non-crossbite side, thus favoring the expansion at the crossbite side.

Results

Figures 10 and 11 show the clinical outcomes obtained after treatment, with the complete resolution of the unilateral crossbite. In particular, the patient shows bilateral Class I occlusion with coincidence of both midlines upon closure (Fig. 11). This condition restored a physiological functional pattern during chewing and swallowing. Also, the aesthetics of the patient improved due to the disappearance of pre-treatment lateral mandibular deviation, with a correct centric posture of the mandible (Fig. 10). The total active treatment time was 3 months, while the same appliance was worn as retention for

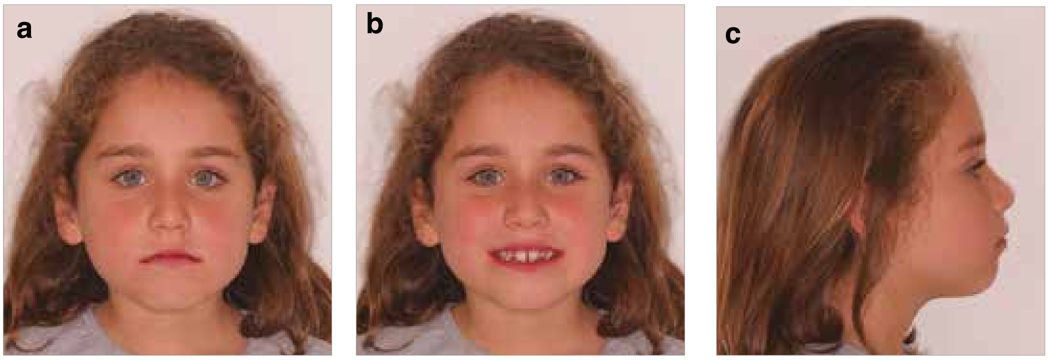

FIG. 10 Extra-oral examination.

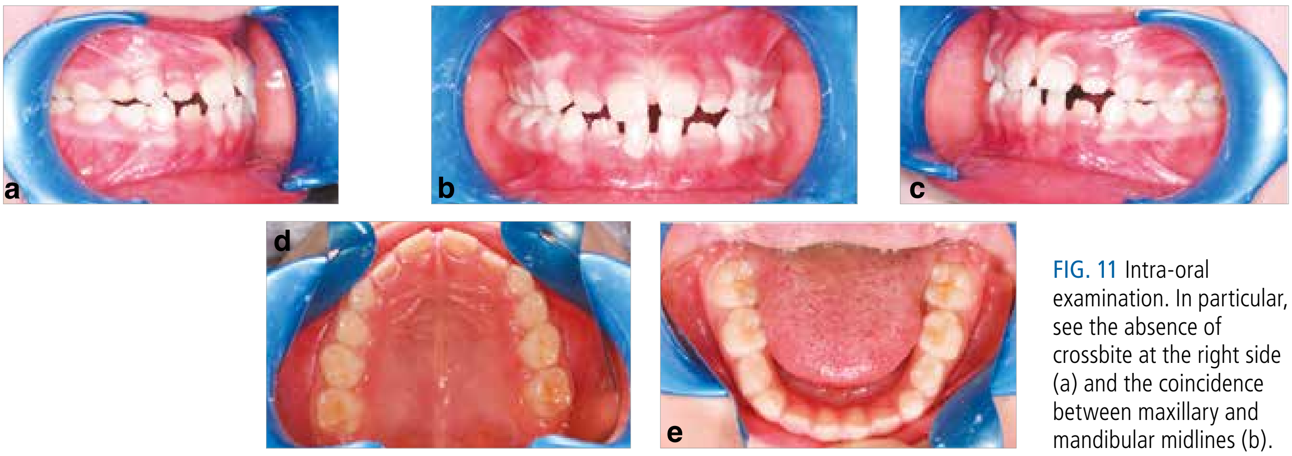

FIG. 11 Intra-oral examination. In particular, see the absence of crossbite at the right side (a) and the coincidence between maxillary and mandibular midlines (b).

other 4 months. Post-treatment radiographic examination such as dental panorex was not required considering the young age of the patient and the short overall treatment time (7 months), thus avoiding useless radiation according to the ALARA principle [Ganzer et al., 2017; Cordasco et al., 2013; Nucera et al., 2017].

Discussion

Shape analysis has gained increasing interest to the medical community, due to its potential for precisely locating and quantifying morphological changes between healthy and pathological structures [Gkantidis et al., 2015].

The present paper shows a digital diagnostic workflow which can help clinicians in thoroughly evaluate maxillary morphology, especially in those cases requiring early intervention such as maxillary expansion. In particular, the assessment of maxillary morphological characteristics, such as shape and potential asymmetry, can be helpful for the appropriate treatment of this condition.

We evaluated the palatal size and morphology of a 6-year-old female patient affected by unilateral functional crossbite by using digital linear assessment of maxillary transversal diameters and by surface-based superimposition of mirrored maxillary models. According to this reverse engineering, each virtual palate can be mirrored at an arbitrary point. This procedure allows to detect morphologic differences, between the two emi-palatal halves, moreover the 3D differences of the registered models are usually translated into color codes that represent the distance between corresponding points [Ho et al., 2016; Leonardi, 2019]. By means of this method, we were able to detect an asymmetric contraction of the maxilla in this young female patient, localised in the area of the alveolar process of the crossbite side (Fig. 7). If not detected three-dimensionally, such asymmetry would have been underestimated and we would have probably treated this patient by conventional approach, i.e., by using maxillary expander. However, this therapeutic approach would have produced specific unwanted effects such as hyper-expansion at the non-crossbite side leading to determine new occlusal interferences, thus preventing a physiologic posture of the mandible upon closure. Otherwise, we should have used a new orthodontic appliance with asymmetric bio-mechanics to encourage relapse on the over-expanded side.

Conclusion

The present diagnostic digital workflow can be a helpful user-friendly tool to analyse the morphological characteristics of the maxilla in children affected by maxillary transverse deficiency, and can aid clinicians in choosing the correct appliance design for treating such condition.

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