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Reliability of panoramic radiographs for the assessment of mandibular elongation after distraction osteogenesis procedures

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Structured Abstract

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Objectives – To determine whether panoramic radiographs could be used for evaluation of changes in the vertical and horizontal dimensions following internal curvilinear mandibular distraction osteogenesis.

Study Design – A retrospective cohort study included 25 patients who underwent bilateral mandibular distraction surgery. Three panoramic radiographs and lateral cephalograms from each patient were available: before distraction, immediately upon termination of the distraction process, and at the end of the follow-up period. The radiographs were traced by plotting Condylion, Gonion, and Menton. The linear distances between Condylion and Gonion and between Gonion and Menton were measured on each side, and the correlation was calculated.

Results – No significant differences were found between the values of the linear measurements determined by lateral cephalograms and panoramic radiographs ($p \geq 0.079$), excluding one measurement. The correlation test for these radiographs showed very high, positive and statistically significant correlations, for both sides of the internal mandibular distraction ($r > 0.77$, $p \leq 0.0001$), apart from three measurements.

Conclusion – Panoramic radiographs, with mandibular length (Co–Go and Go–Me) measurements, can be used as an alternative to lateral cephalograms, i.e. as a reliable tool for assessing vertical and horizontal dimensional changes resulting from internal mandibular distraction achieved by a curvilinear distractor.

Key words: distraction osteogenesis; lateral cephalogram; mandible; panoramic radiographs; radiological assessment

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Introduction

Since the introduction of cephalometrics, by Broadbent (1) in 1931, orthodontists and oral surgeons have used these measurements to analyze the relationship between teeth, bone, and facial soft tissues. Superimposition of different bilateral anatomic landmarks, such as Condylion and Gonion, presents great challenges during their tracing and X-ray analysis. An average of these landmarks is calculated to overcome these problems. However, by doing so, not only bilateral information of the patient is lost, but it is impossible to evaluate any asymmetry of the mandible that may exist. This is extremely important in unilateral or bilateral craniofacial anomalies such as hemifacial microsomia, Goldenhar syndrome, Treacher Collins, and trauma cases, where major discrepancies exist between the unaffected and affected sides or between both affected sides.

The panoramic radiograph was first introduced by Professor Yrjö Paatero of the University of Helsinki in 1961 (2). It presents all anatomic landmarks in a panoramic view, thus demonstrating the right and left landmarks for bilateral structures. In addition, it displays many anatomic landmarks with great detail and enables the diagnosis of mandibular asymmetries. Therefore, the panoramic radiograph is a valuable orthodontic screening tool and a means for planning any type of jaw surgery. However, for many years authors have contemplated about the limitations of panoramic radiographs: image magnification, geometric distortion and superimposed images, which ultimately limit their accuracy (3–7). Consequently, there are very few studies that involve the use of panoramic radiographs in evaluating dentoskeletal measurements (3, 5, 8–10).

Some studies have shown that vertical and horizontal linear measurements in panoramic radiographs are unreliable: Tronje et al. (11) stated that horizontal assessments of linear dimensions on panoramic radiographs are unreliable, but the vertical dimensions are reliable if patients are properly positioned. Likewise, Turp et al. (10) advocated that vertical linear measurements of the condyle and the ramus, obtained by direct measurements of skulls, were poorly correlated with their value obtained from panoramic radiographs. Van Elslande et al. (12) claimed that although vertical measurements were more accurate than horizontal or angular measurements, they were not true representations of the real objects to which they corresponded, and therefore caution is advised when using conventional or digital panoramic images to assess mandibular asymmetry. Larheim and Svanaes (5) found acceptable reproducibility for vertical and angular variables on panoramic radiographs that did not exceed 1% of the total variance; horizontal variables were less reliable. For this reason, many studies have focused only on angular measurements (3, 13, 14).

In 1991, Levandoski (8, 9, 15–17) was one of the first to introduce a method of panoramic radiographs analysis for evaluating facial asymmetry. In these cases of asymmetry, it is especially challenging to achieve reliable skeletal measurements owing to interference presented by superimposed images of the lateral cephalograms. Since then, few studies have been conducted to investigate the possibility of enhancing the clinical versatility of panoramic radiographs to evaluate changes in craniofacial morphology in comparison with lateral cephalograms (3, 18, 19).

Consequently, we decided to compare the changes in the vertical and horizontal mandibular distances between Condylion–Gonion and Gonion–Menton obtained from cephalometric and panoramic radiographs after internal mandibular distraction osteogenesis and to determine whether the use of panoramic radiographs could be extended to evaluate changes in craniofacial morphology following mandibular distraction. In this respect, we hypothesized that panoramic radiographs could be used as a reliable tool for linear measurements after internal mandibular distraction osteogenesis.

Material and methods

Subjects

For this retrospective cohort study, we included 25 patients (9 men and 16 women) with an age range of 5–55 years (Mean: 18 ± 13.02 years). All patients underwent bilateral mandibular distraction surgery at Lucil Packard Children's Hospital in Stanford, California, between 12/1999 and 07/2008 by the same plastic surgeon, totaling fifty procedures of mandibular distraction (Table 1). The patients were clinically and radiographically diagnosed as suffering from disordered mandibular development resulting in mandibular hypoplasia (Fig. 1). Inclusion was based on the

Table 1. **Distribution of patients by age, gender, and type of distraction surgery**

Age	Sex M	Sex F	Number of distraction surgeries
5–12	3	7	10
13–20	5	6	11
21+	1	3	4
Total	9	16	25

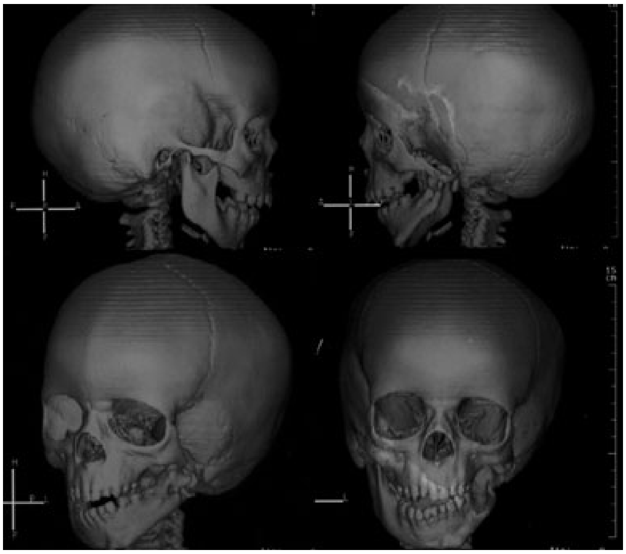

Fig. 1. MS-CT of the skull and mandible in a patient suffering from hemifacial microsomia – a candidate for a curvilinear mandibular distraction osteogenesis.

presence of mandibular asymmetry owing to one of the following reasons: (i) non-syndromic acquired bilateral mandibular hypoplasia, (ii) traumatic unilateral mandibular hypoplasia, (iii) uni/bilateral syndromic mandibular hypoplasia: hemifacial microsomia, Goldenhar syndrome, Pierre Robin Sequence, Nager syndrome, and Treacher Collins.

Exclusion criteria were symmetrical hypoplastic mandible owing to congenital anomaly or acquired disorders and incomplete sets of panoramic and cephalometric radiographs.

Radiographic assessment of mandibular distraction

Three panoramic radiographs and lateral cephalograms of each of the 25 patients were taken: before distraction, immediately upon termination of the distraction process, and at the end of the follow-up period (Figs 2 and 3) which ranged from 3 to 102 months (mean 30.02 ± 22.67 months for the panoramic radiographs and 30.16 ± 22.59 months for the lateral cephalograms).

Panoramic and cephalometric radiographs were taken at the same X-ray laboratory under standard conditions using a cephalostat (Orthoceph 10; Siemens, Munich, Germany) with the clinical Frankfort horizontal plane (FHP) and midfacial planes corrected. The FHP was kept parallel to the floor, while the midfacial plane was kept vertical to the floor.

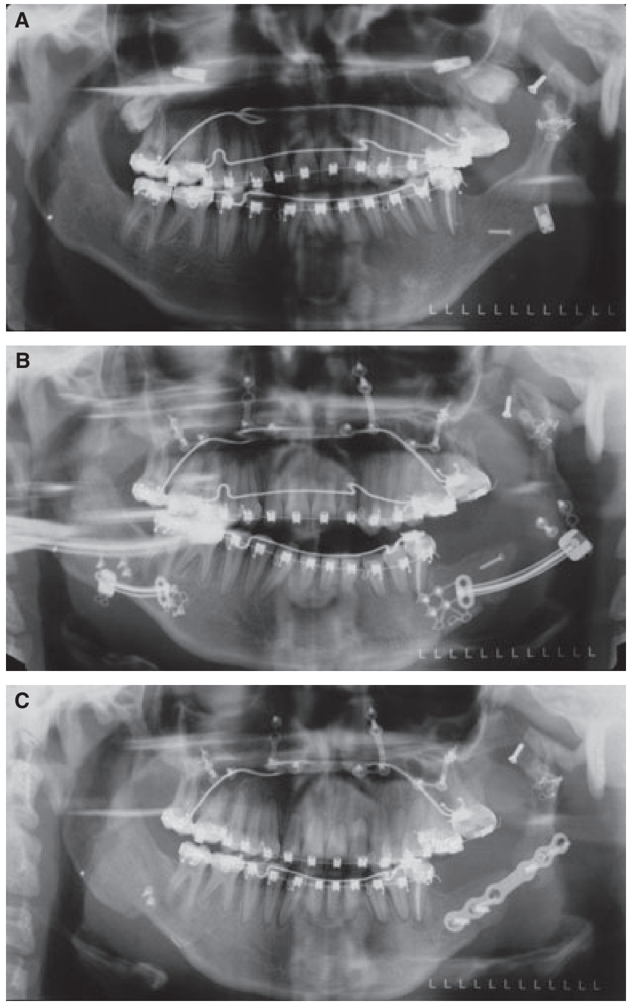

Fig. 2. Panoramic radiograph of the same patient: (A) Pre-distraction. (B) Post-distraction. (C) At the end of the follow-up period.

The printed radiographs (conventional – not digital) were manually traced onto a sheet of cellulose acetate by one operator using a 2H pencil. All skeletal landmarks were first located, identified, and marked on each panoramic radiograph and only then identified and marked on the lateral cephalograph. In some radiographs taken immediately upon termination of the distraction process, the views included uni/bilateral metal distractors. These resulted in ghost artifacts (Fig. 2B) that generally affected both sides of the panoramic image. These artifacts were often superimposed on the images of the maxilla and the mandible, thus interfering with anatomic landmark identification on both panoramic and cephalometric radiographs, making the task of tracing even more challenging (Figs 2B and 3B).

The following skeletal landmarks were traced (Figs 4 and 5):

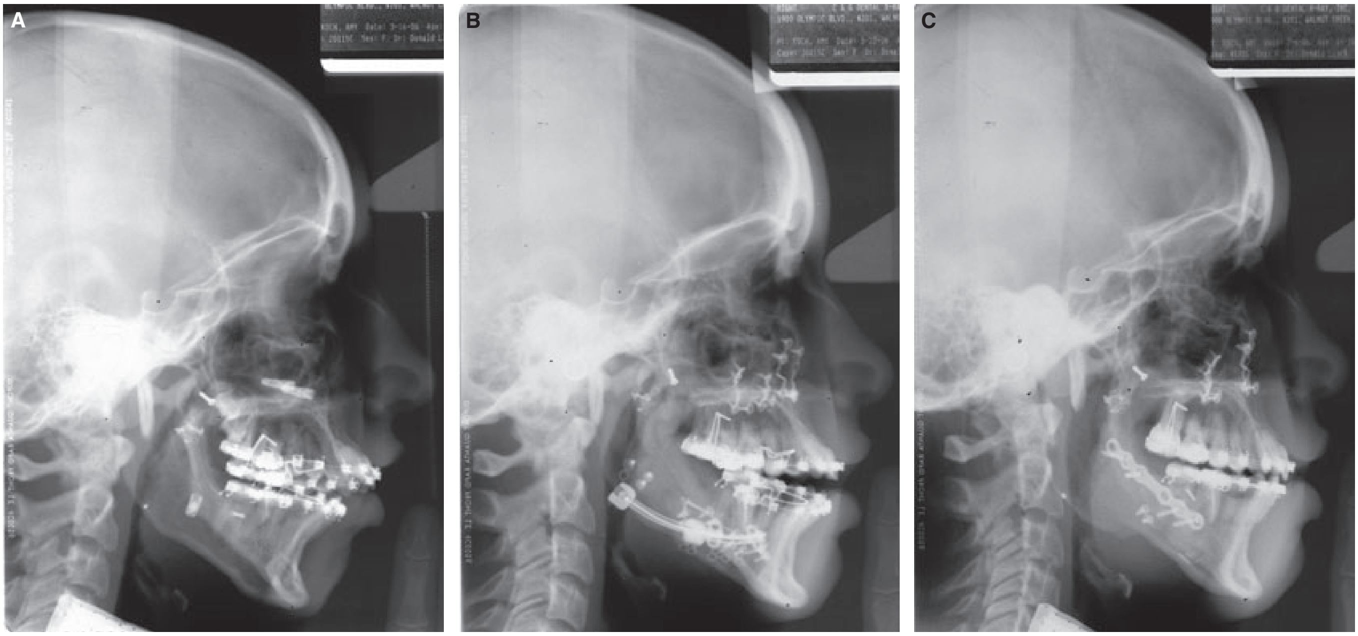

Fig. 3. Lateral cephalogram of the same patient: (A) Pre-distraction. (B) Post-distraction. (C) At the end of the follow-up period.

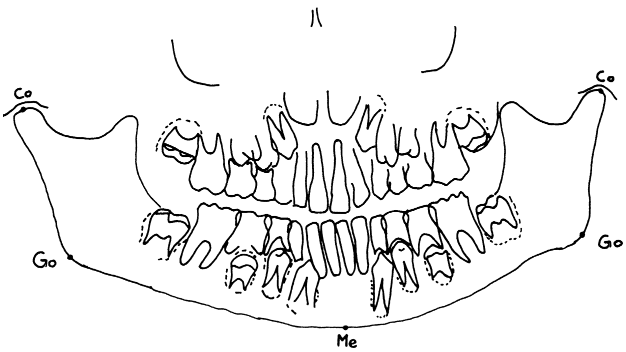

Fig. 4. Tracing of panoramic radiograph demonstrating right and left Condylion, right and left Gonion and Menton.

- Right and left Condylion – the uppermost point of the mandibular condyle (Co).
- Right and left Gonion – the midpoint of the contour connecting the body of the ramus to the body of the mandible (Go).
- Menton – the most inferior point of the mandibular symphysis (Me).

The lines Co–Go and Go–Me were drawn using a cephalometric protractor for each side of the mandible. The linear distances between Co and Go (mandibular ramus height) on each side were measured using a digital caliper (Mitutoyo Co., Kawasaki, Japan) and documented. These distances indicated the change in the vertical dimension, as a result of the newly formed generated bone achieved by the distraction osteogenesis process.

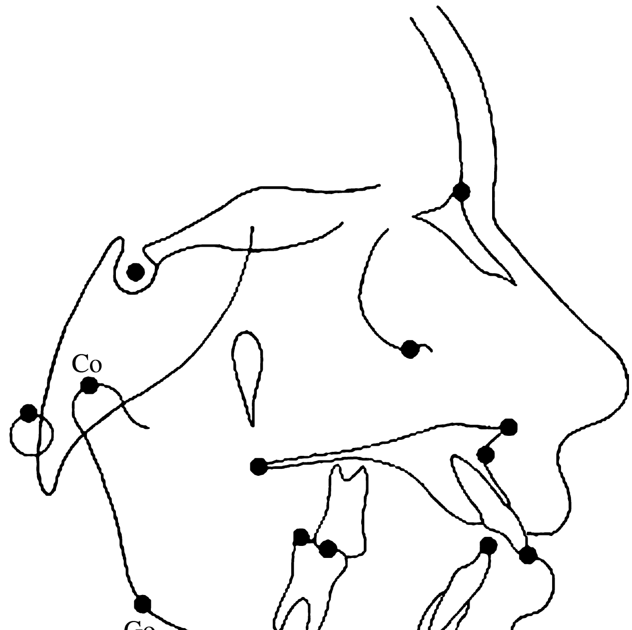

Fig. 5. Tracing of lateral cephalogram demonstrating right and left Condylion, right and left Gonion and Menton.

The linear distances between Go and Me (mandibular body length) on each side were measured using a digital caliper (Mitutoyo Co.) and documented. These distances indicated the change, as a result of the newly formed generated bone achieved by the distraction osteogenesis process of the horizontal dimension.

To eliminate interexaminer variability, the same examiner carried out the tracing procedure. The same examiner repeated the tracing of all panoramic radiographs and lateral cephalograms within 4 weeks. Then, repeatability coefficients were calculated for the initial and final measurements to test for intra-observer variability.

Statistical analysis

Statistically significant differences between the linear distances of the mandible, i.e. right and left panoramic measurements and their cephalometric correspondents (Right Co–Go; Go–Me; Left Co–Go; Go–Me), were evaluated with the Student's t-test. A regression analysis was also performed to indicate a predictive relationship or dependence that can be exploited in practice. These analyses were performed using the statistical package SPSS (SPSS statistics v.17; SPSS Inc., Chicago, IL, USA). A probability level of $p < 0.05$ was considered to be statistically significant.

Results

The repeatability coefficients were above 0.90 for all the parameters, confirming the reliability of the measurements.

There were no significant differences between the values of the linear measurements determined by the lateral cephalograms and panoramic radiographs ($p \geq 0.079$), except for the measurement of the right side Co–Go between the pre-operative and post-operative periods (Table 2).

Linear regression analysis for the measurements on the panoramic radiograph and the lateral cephalogram showed very high, positive and statistically significant correlations, for both sides of the internal mandibular distraction in most of the measurements ($r > 0.77$, $p \leq 0.0001$) except for three measurements, all between the post-operative and follow-up periods: right-side Co–Go and left-side Go–Me with moderate positive and statistically significant correlations ($r = 0.45$, $p = 0.043$ and $r = 0.65$, $p = 0.003$, respectively) and right-side Go–Me without any correlation ($r = -0.09$, $p = 0.698$).

Discussion

The goal of this study was to evaluate the potential clinical use of panoramic radiographs that are routinely

Table 2. **Mean linear measurements**

Vertical linear measurement	Mean (mm)	Standard deviation	p	Horizontal linear measurement	Mean (mm)	Standard deviation	p
Right side							
Pre–post							
Panoramic Co–Go	11.43	5.50	0.008	Panoramic Go–Me	9.04	5.49	0.091
Ceph Co–Go	10.00	5.30		Ceph Go–Me	7.86	3.82	
Post–follow-up							
Panoramic Co–Go	−2.45	4.23	0.079	Panoramic Go–Me	−0.50	3.94	0.766
Ceph Co–Go	−0.80	3.20		Ceph Go–Me	−0.80	1.73	
Left side							
Pre–post							
Panoramic Co–Go	9.82	5.45	0.167	Panoramic Go–Me	9.60	6.66	0.101
Ceph Co–Go	9.00	4.74		Ceph Go–Me	8.73	5.25	
Post–follow-up							
Panoramic Co–Go	−2.05	5.02	0.545	Panoramic Go–Me	−0.68	2.49	0.905
Ceph Co–Go	−1.60	3.06		Ceph Go-Me	−0.63	1.53	

taken during the distraction process and follow-up, for accurate appraisal of changes in craniofacial dimensions achieved after an internal mandibular distraction process, as Ongkosuwito et al. (18) suggested in their study on linear mandibular measurements in which they compared measurements on orthopantomograms and lateral cephalograms. To minimize the aforementioned limitation associated with studies involving panoramic radiographs, all radiographs in the current study were obtained at the same X-ray laboratory using the same X-ray machine and were performed under identical standardized conditions customarily used in that laboratory. Thus, the image magnification was identical and enabled a reliable comparison of the radiograph tracing. This also accounted for minimization of the geometric distortion effect, which is one of the most eminent limitations of panoramic radiographs resulting mainly from different positioning of the object relative to the focal through (20) and variation in the cant of the occlusal plane (21). Furthermore, during the entire research only one examiner conducted the measurements and repeated them twice. Vertical, horizontal, and oblique linear measurements can be taken accurately if they are done on only one side and do not cross the midline of the mandible (15). These also contributed to the reduction in variability and magnification errors.

In light of the discussed limitations of the panoramic radiograph, linear measurements could be taken on a posterior anterior (PA) cephalogram and compared with a lateral cephalogram. Leonardi et al. (22) claimed that the mean interexaminer error was the greatest for bilateral skeletal landmarks. Athanasiou et al. (23) concluded in their study that the anatomic landmarks left and right Co were the least accurately detected landmarks in a PA cephalogram and therefore were the most unreliable in both horizontal and vertical directions. Similarly, Trpkova et al. (24) found that the linear measurement Co–Me had the least correlation between actual asymmetry and the asymmetry measured relative to the reference line on PA films. As these are the relevant anatomic landmarks of this study, PA cephalograms were not chosen as comparison radiographs. Furthermore, the popularity of panoramic radiographs and the fact that they are used as an acceptable diagnostic tool in routine orthodontic diagnosis, follow-ups, pre- and post-distraction procedures (rather than PA cephalometric radiographs) made them the X-ray of choice subject to the aforementioned efforts to overcome and minimize their interpretation limitations.

During the last few years, cone beam CT (CBCT) has become a popular imaging tool in orthodontic practice and nowadays is also the state-of-the-art imaging technique for mandibular distraction procedures. While the panoramic radiograph provides an image of only one dimension, namely a mesio–distal or antero–posterior perspective, CBCT imaging provides cross-sectional, axial, coronal, sagittal, and panoramic views, with the ability to separate the various anatomic structures in case of superimposition (25). However, keeping in mind that this long-term follow-up retrospective cohort study presents radiographs taken as early as 1999, at the time CBCT was not available in routine clinical use and therefore was not available for all the patients included in the study. A future study is warranted to compare measurements taken from CBCT, cephalometric and panoramic radiographs to determine the best imaging alternative currently available.

A comparison assessment of anatomic landmarks of symmetrical faces on cephalometric radiographs is often challenging because of the superimposition of both sides of the mandibular body and ramus. In a study recently published on mandibular internal distraction by means of an internal curvilinear distractor performed on 40 patients, Aizenbud et al. (26) examined both lateral cephalometric and panoramic radiographic measurements. Their measurements of both types of X-rays suggested that curvilinear distractors significantly affect both the vertical and the horizontal dimensions of the mandible. Interestingly, they found a high level of similarity for both dimensions on the right and left sides, between the lateral cephalograms and panoramic radiographs of the achieved generated bone as well as for the relapse rates.

In the present study, we evaluated the similarity between the changes achieved in both dimensions on panoramic and cephalometric radiographs. This study was possible, owing to the fact that all patients in the study group had mandibular asymmetry, enabling anatomic differentiation of the right and left Co and Go when tracing the lateral cephalograms without superimposition (27). Consequently, the location of Co and Go was first established on the panoramic radiographs and was then examined on the lateral cephalograms. However, the asymmetry in the condyle region (including its atypical morphology in some of the cases) might have led us to a less reliable identification of Co on the panoramic radiographs, as Akcam indicated (3), thus leading to the result that all values of the linear measurements had no statistically significant difference between the lateral cephalograms and panoramic radiographs, apart from the measurement of the right-side Co–Go between the pre-operative and post-operative periods. Furthermore, this linear measurement represents the highest average of vertical mandibular elongation achieved in the distraction surgery both on the panoramic radiograph and on the lateral cephalograms with the greatest variance. There is a possibility that over a certain amount of linear change, achieved by different means such as distraction, there is a difference between the two radiographs. Both issues need to be further investigated, perhaps by means of a similar study on patients who underwent only unilateral mandibular distraction surgery. Then, the intact side may serve as an internal control.

These findings supported our hypothesis that panoramic radiographs could be used as a reliable tool for the assessment of linear measurements after internal mandibular distraction osteogenesis. This probably accounts for the reason that both sides of the mandibular and ramus could be clearly identified on the cephalometric radiographs in these selected cases with mandibular asymmetry compared with the superimposition of the bilateral mandibular structures often found in symmetrical faces. We also evaluated the similarity between the changes achieved in both the horizontal and vertical dimensions using Pearson's coefficient. Vertical measurements (Co–Go) revealed a better correlation than the horizontal measurements (Go–Me) in accordance with the findings of Ongkosuwito et al. (18). The findings showed a very high positive and statistically significant degree of correlation between the lateral cephalogram and panoramic radiograph measurements Co–Go and Go–Me both for the right and left sides and for the immediate distraction and long-term effect of the distraction process (after 32 weeks in average) in reference to all the measurements, except three, conducted between the post-operative and the follow-up periods (right-side Co–Go, left-side Go–Me, and right-side Go–Me). Catic et al. (15) showed that it is possible to precisely measure any vertical or horizontal distance on panoramic radiographs as long as the distance is only on one side of the mandible, either the left or the right. Nonetheless, measurements that extended across the midline of the mandible were greatly enlarged owing to large magnification factors, and therefore such measurements should not be made. We assume that the fact that our measurements on both sides did not cross the midline in any of the studied cases contributed to the high degree of correlation found between the radiographs. Similarly, Ongkosuwito et al. (18) and Shahabi et al. (19) reported high correlation rates for linear (Co–Go, Co-Me and Go–Me, with an intraclass correlation coefficient of approximately 0.70) and angular (gonial angle, $r = 0.562$) measurements, respectively. However, low correlation scores were found in the measurements taken between the post-operative and follow-up periods.

Many authors (28–31) have reported high relapse rates during the period after mandibular distraction osteogenesis, as Condylion, Gonion, and Menton landmarks move back to their normal anatomic position. In addition, Shetye et al. (31) suggest that these anatomic landmarks are also remodeled as a result of the changes in the direction of soft tissue muscle pull on the mandible. Thus, the surrounding soft tissue, i.e. the functional matrix, is gradually distracted during the process of distraction osteogenesis. This may account for the high relapse rates and the remodeling processes of these anatomic points during the period of distraction and therefore might contribute to the low-to-moderate correlation coefficient rates that we revealed.

Conclusion

The panoramic radiograph is a valuable tool in orthodontics and mandibular surgery as a result of its ability to display bilateral mandibular anatomic landmarks without superimposition. Measurements of mandibular lengths (Co–Go and Go–Me) can be used as a reliable tool for assessing vertical and horizontal dimensional changes resulting from mandibular distraction, especially in the pre- and post-operative periods.

Clinical relevance

Superposing bilateral anatomic landmarks on cephalometric radiographs presents considerable challenges for tracing and analysis. One of the difficulties is the evaluation of mandibular asymmetries in craniofacial anomalies. The panoramic radiograph presents all anatomic landmarks in a panoramic view, thus showing clearly the right and left landmarks for bilateral structures. The findings of this study may indicate a routine use of panoramic radiograph to evaluate changes in craniofacial characteristics following mandibular distraction. This may facilitate differentiation between right and left mandibular structures that are very difficult to identify on the lateral cephalogram superimposed image.

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