RESEARCH ARTICLE

Detection of patient movement during CBCT examination using video observation compared with an accelerometer-gyroscope tracking system

Rubens Spin-Neto, Louise H Matzen, Lars Schropp, Erik Gotfredsen and Ann Wenzel

Section of Oral Radiology, Department of Dentistry and Oral Health, Aarhus University, Aarhus, Denmark

Objectives: To compare video observation (VO) with a novel three-dimensional registration method, based on an accelerometer-gyroscope (AG) system, to detect patient movement during CBCT examination. The movements were further analyzed according to complexity and patient age.

Methods: In 181 patients (118 females/63 males; age average 30 years, range: 9–84 years), 206 CBCT examinations were performed, which were video-recorded during examination. An AG was, at the same time, attached to the patient head to track head position in three dimensions. Three observers scored patient movement (yes/no) by VO. AG provided movement data on the x-, y- and z-axes. Thresholds for AG-based registration were defined at 0.5, 1, 2, 3 and 4 mm (movement distance). Movement detected by VO was compared with that registered by AG, according to movement complexity (uniplanar vs multiplanar, as defined by AG) and patient age (≤ 15 , 16–30 and ≥ 31 years).

Results: According to AG, movement ≥ 0.5 mm was present in 160 (77.7%) examinations. According to VO, movement was present in 46 (22.3%) examinations. One VO-detected movement was not registered by AG. Overall, VO did not detect 71.9% of the movements registered by AG at the 0.5-mm threshold. At a movement distance ≥ 4 mm, 20% of the AG-registered movements were not detected by VO. Multiplanar movements such as lateral head rotation (72.1%) and nodding/swallowing (52.6%) were more often detected by VO in comparison with uniplanar movements, such as head lifting (33.6%) and anteroposterior translation (35.6%), at the 0.5-mm threshold. The prevalence of patients who move was highest in patients younger than 16 years (64.3% for VO and 92.3% for AG-based registration at the 0.5-mm threshold).

Conclusions: AG-based movement registration resulted in a higher prevalence of patient movement during CBCT examination than VO-based registration. Also, AG-registered multiplanar movements were more frequently detected by VO than uniplanar movements. The prevalence of patients who move was highest in patients younger than 16 years.

Dentomaxillofacial Radiology (2017) **46**, 20160289. doi: [10.1259/dmfr.20160289](https://doi.org/10.1259/dmfr.20160289)

Cite this article as: Spin-Neto R, Matzen LH, Schropp L, Gotfredsen E, Wenzel A. Detection of patient movement during CBCT examination using video observation compared with an accelerometer-gyroscope tracking system. *Dentomaxillofac Radiol* 2017; **46**: 20160289.

Keywords: CBCT; motion artefacts; movement; movement detection

Introduction

In dentistry, CBCT may be an efficient diagnostic tool compared with fan-beam CT, since it provides a higher

spatial resolution at a significantly lower patient dose.^{1–3} Lately, special attention has been paid to provide high-level evidence for the use of CBCT in dentistry-related diagnostic tasks,⁴ focusing also on its major disadvantage, the presence of artefacts.^{5,6} Three systematic

Correspondence to: Dr Rubens Spin-Neto. E-mail: rsn@odont.au.dk

Received 8 July 2016; revised 21 October 2016; accepted 25 October 2016

reviews agreed that artefacts may arise owing to unit- and object-/patient-related factors.^{5–7} Related to the patient, motion artefacts are especially interesting, since no protocol on how the patient should be observed/tracked during examination has been tailored to avoid or minimize this problem.^{4,6,8,9}

The influence of patient motion artefacts on various diagnostic tasks in CBCT imaging is yet unknown.^{6,10,11} One study suggests that even a slight patient movement can lead to a reduction in spatial resolution of the images.¹² On the other hand, another recent study showed that axial CBCT images of impacted teeth of patients who are young with no metal in the field of view (FOV), who had been observed to move during examination, did not always present a subjectively lower quality than images originating from patients who did not move, when blindly assessed.¹⁵ The same study showed that image quality was lower when patient movement had been observed several times during the examination, were long-lasting (i.e., longer than 5 seconds) or complex (i.e., multiplanar).¹³ In any case, if patient motion artefacts are present in an image and compromise image quality, misdiagnosis may occur or a re-exposure of the patient may be decided.^{11,12} This is a major concern particularly (but not only) when the patient is a child, and⁴ being a child is the major factor related to patient movement.¹¹

A possible approach to reducing patient motion artefacts in CBCT imaging is to control patient movement through optimized patient positioning, stabilization, instruction and monitoring, supplemented by stronger operator instruction and guidance protocols.⁹ The SEDENTEXCT guidelines suggest that a proper setting of the CBCT clinic includes that the operator is able to monitor the patient during the full examination.⁴ In most CBCT units, the patient will be covered by the arm of the unit during part of the examination, where s/he cannot be observed. To avoid this, the guidelines appoint the use of cameras as an alternative or supplementary patient monitoring method.⁴ Previous studies included the observation of video recordings by trained observers of patients under CBCT examination, suggesting a prevalence of approximately 20% of patients who move.^{11,13,14}

A drawback of the video camera method may be that movement detection based on watching the videos is to some extent a subjective, operator-dependent method. Further, video recordings provide only a two-dimensional picture of a three-dimensional (3D) movement in space, hampering quantitative estimates of patient movement.⁶ Technologies that are able to register and quantify patient movement in all planes could be a solution, leading to a more objective understanding of patient movement. Therefore, the aim of the present study was to compare video observation (VO) with a novel 3D registration method based on an accelerometer-gyroscope (AG) system to detect patient movement during CBCT examination. The movements were further analyzed according to complexity and patient age.

Methods and materials

Basic study population

The basic study population consisted of 181 patients (118 females/63 males; age average 30 years, range: 9–84 years), in whom 206 CBCT examinations were performed, at the Section of Oral Radiology, Department of Dentistry, Aarhus University. The CBCT examination was performed using a Scanora[®] 3D unit (Soredex Oy, Tuusula, Finland) by one of the two experienced operators (radiographic technicians). In this unit, patients are seated with a chin rest used to stabilize the mandible and two vertical plastic bars (one in each side) to support the position of the head. Patients reported no history of systemic disorders, which could lead to impaired head movement control, such as Parkinson's disease. The settings (FOV and voxel resolution) for each patient were selected based on the region to be examined and on the diagnostic task in question. Scanning time was 23 s, considering the small FOV (6 × 6 cm, 0.13-mm resolution). To fit the CBCT examination protocol of the Section of Oral Radiology, Department of Dentistry, Aarhus University, the patients were video recorded during CBCT examination as previously described.^{11,14}

Video recording

A high-definition camera (Legria HSF21; Canon, Tokyo, Japan) was located on each side (right and left) of the patient at 45° in relation to the patient long axis and at approximately 1-m distance from the patient face. These videos were later cropped to fit the examination time (in which the CBCT arm containing the X-ray tube moves around the patient), synchronized (to show the exact same period of the examination and to last exactly the same time) and saved as audio video interleaved files, keeping the native resolution and speed.^{11,13,14} Patients agreed to be video recorded during CBCT examination. According to Danish regulations, an approval by an ethical committee was not required, since the CBCT examination was requested by the patient clinician and ratified by a radiologist, and the video cameras did not interfere with the examination.

Accelerometer-gyroscope system registration

In addition to video recording, an AG system was used, which can register the patient head position during the examination in all planes. The system consisted of two iPod touch devices (Apple Inc., Cupertino, CA) with their AG synchronized *via* Bluetooth connection to track the movement range on the x-, y- and z-axes in degrees, at a rate of 50 readings/second by using dedicated software (Gyro-kun 3; Medical Informatics Lab., Kitasato University, Tokyo, Japan). One of the devices was attached to the patient head using a plastic tiara ("Patient AG" in Figure 1), while the other was attached to the CBCT arm containing the X-ray tube ("Unit AG" in Figure 1). The synchronization between the two devices (iPods) ensured that AG data represented

Figure 1 Accelerometer-gyroscope (AG) as used in the study: the system consisted of two iPod touch devices (Apple Inc., Cupertino, CA), one attached to the patient head using a plastic tiara (Patient AG) and the other attached to the CBCT arm (Unit AG). The devices were synchronized *via* Bluetooth connection, securing that AG data represented the same time period as shown by the videos, based on the position of the unit CBCT arm.

the same time period as shown by the videos: AG registered when the CBCT arm started and finished moving, allowing comparison between what was seen in the videos and registered by the iPods. AG data containing the synchronized position on the x -, y - and z -axes of both devices were saved as comma-separated values files, which could later be read by the statistical software package. Patients agreed to be AG-tracked during the CBCT examination.

Patient movement definition by means of video observation

As previously reported,^{11,13} three observers (radiologists working with CBCT for several years and trained in how to detect patient movement in the videos) assessed the videos of the patients and scored patient movement (yes/no). They assessed the patient videos individually on a 24-inch-flat screen monitor (Dell P2412H; Dell Inc., Round Rock, TX). The videos were displayed in dedicated software (Media Player Classic; MPC-HC) using the full screen and in a blinded and random sequence. The two videos of a patient were displayed as a sequence, but shown separately. Videos could not be zoomed in, but could be stopped, replayed and played in slow motion as many times as the observer found it was necessary. In those cases (nine in total), in which the opinion of one of the observers differed from the others', a consensus among the three observers was reached in a

subsequent session, watching the videos again. Patient movement seen in only one of the cameras implied that the patient was scored as moving. As reported in previous studies, interobserver reproducibility for VO movement detection ranged from moderate to strong.^{13,14}

Patient movement definition by means of accelerometer-gyroscope—threshold and movement type

To define the threshold for movement by the AG (*i.e.* the smallest registered position change, which should be defined as movement), the first step was to assess the standard error of the system. This was performed by collecting data from five dry runs of the CBCT unit, in which the iPod was mounted on a stable desk, placed in the same room as the unit. AG error was observed to be up to 0.25° in all axes; thus, the threshold for defining movement was set to $\geq 0.3^\circ$.

The registered head movements ranged from 0.3 to 3.9° , which represent overall movement distances from 0.5 to 6.9 mm (approximately), measured at the patient nose tip, considering an average distance of 100 mm in the axial plane between the AG and the patient nose tip (Figure 2). Movement type was defined based on which axes/planes were affected by the movement. Movement types were thus defined as nodding, lateral head rotation, head lifting, anteroposterior translation or swallowing. In addition, movements were sorted according

Figure 2 To convert the movement distance registered in degrees (“ α ” angle) to millimetres, as seen at the patient nose tip level (“ d ” distance), an average distance of 100 mm in the axial plane between the patient accelerometer-gyroscope (AG) and the patient nose tip was determined.

to their complexity as: multiplanar (*i.e.* when movement involved more than one plane: nodding, swallowing and lateral head rotation) or uniplanar (*i.e.* when movement involved one plane: head lifting and anteroposterior translation).

Data treatment

Commercially available software (IBM Corp., New York, NY; formerly SPSS Inc., Chicago, IL) was used for data evaluation.

Patient movement prevalence as defined by AG was initially assessed according to movement distance (movement thresholds ≥ 0.5 , ≥ 1 , ≥ 2 , ≥ 3 or ≥ 4 mm). Prevalence of VO movement (dichotomous) was based on consensus among the observers. VO was compared with AG at each threshold and percentage agreement between the two methods was calculated, also according to patient age (≤ 15 , 16–30 and ≥ 31 years).

Movement prevalence as assessed by VO was also compared with that registered by AG at the 0.5 mm threshold according to movement type [nodding, swallowing, lateral head rotation, lifting, anteroposterior translation and complexity (uniplanar vs multiplanar)].

Results

According to AG, movement of at least 0.5 mm in at least one plane was present in 160 (77.7%) examinations. Overall, approximately 56% patients had moved at least 1 mm, 21% patients had moved at least 2 mm, 10% patients had moved at least 3 mm and 6% patients had moved 4 mm or more (Table 1). According to VO, movement was present in 46 (22.3%) examinations. In one case, movement was detected by VO, but not registered by AG.

At the 0.5-mm threshold for AG movement in any axis (*i.e.* movement of any type), VO did not detect 71.9% of the movements that were registered by AG. Approximately 90% of the movements < 1 mm were not detected by VO, while approximately 75% of movements between 1 and 2 mm, and close to 60% of movements between 2 and 4 mm, were not detected. At a movement distance ≥ 4 mm, 20% of the movements were not detected by VO. These results are presented in Table 2.

Table 1 Prevalence of cases with patient movement (count and percentage) as registered by accelerometer-gyroscope (AG) for the diverse thresholds for movement

Threshold (mm)	Cases registered by AG	Cases not detected by VO	Cases detected by VO also
≥ 0.5	160 (77.7%)	115 (71.9%)	45 (28.1%)
≥ 1.0	115 (55.8%)	74 (64.3%)	41 (35.7%)
≥ 2.0	44 (21.4%)	22 (50.0%)	22 (50.0%)
≥ 3.0	21 (10.2%)	9 (42.9%)	12 (57.1%)
≥ 4.0	10 (6.2%)	2 (20.0%)	8 (80.0%)

VO, video observation.

Cases not detected and cases detected by VO also (count and percentage) are also shown.

Table 2 Number of cases with patient movement (count) registered by accelerometer-gyroscope (AG) according to movement distance

Distance (mm)	Cases registered by AG	Cases detected by VO also
$\geq 0.5 < 1.0$ mm	45	4 (8.9%)
$\geq 1.0 < 2.0$ mm	71	19 (26.8%)
$\geq 2.0 < 3.0$ mm	23	10 (43.5%)
$\geq 3.0 < 4.0$ mm	11	5 (45.4%)
≥ 4.0 mm	10	8 (80.0%)

VO, video observation.

Cases detected by VO also (count and percentage) are also shown.

According to age, patients younger than 16 years moved more often than patients in older age groups, no matter whether the prevalence was based on AG (at any of the thresholds for movement) or VO. While for VO the prevalence of patients younger than 16 years who move was close to 65%, this number rose to 92% for AG registration at a threshold of 0.5 mm. These results are presented in Table 3.

When movement type and complexity were considered, multiplanar movements such as lateral head rotation (72.1%) and nodding/swallowing (52.6%) were more often detected by VO in comparison with uniplanar movements, such as head lifting (33.6%) and anteroposterior translation (35.6%), at the 0.5-mm threshold. When movement involving all planes (*i.e.* complex movement types, combining the three movement planes) was considered, VO detected approximately 83% of the cases that were registered by AG. These results are presented in Table 4.

Discussion

Patient motion artefacts can influence the quality of CBCT-reconstructed images.^{9,12} Previous studies reported that between 4.5 and 41.5% of CBCT examinations present artefacts suggestive of patient movement.^{10,15,16} Recently, a study suggested that movements with certain characteristics (repeated, long-lasting and multiplanar) are often related to impaired CBCT image quality.¹³ Patients cannot remain perfectly still during the full examination time owing to heart beat, breathing and unintentional movements.^{8,9,17} It is obvious that clinicians should attempt to reduce the

Table 3 Prevalence of cases with patient movement (count and percentage of the total) found by the two methods [video observation (VO) or accelerometer-gyroscope (AG)] and movement distance (ranging from 0.5 to 4 mm) according to patient age group (≤ 15 , 16–30 and ≥ 31 years)

Method—movement distance	≤ 15 years (n = 56)	16–30 years (n = 75)	≥ 31 years (n = 75)
VO	36 (64.3%)	7 (9.3%)	3 (4.0%)
AG ≥ 0.5 mm	52 (92.3%)	52 (69.3%)	56 (74.6%)
AG ≥ 1.0 mm	42 (75.0%)	31 (41.3%)	38 (50.7%)
AG ≥ 2.0 mm	24 (42.9%)	8 (10.7%)	12 (16.0%)
AG ≥ 3.0 mm	12 (21.4%)	2 (2.7%)	7 (9.3%)
AG ≥ 4.0 mm	8 (14.3%)	0 (0%)	2 (2.7%)

Table 4 Number of patients according to motion state (not moving/moving) found by the two methods [video observation (VO) or accelerometer-gyroscope (AG)] (at the 0.5-mm threshold for AG movement) and movement type (as defined by AG)

Movement type	VO	AG (0.5-mm threshold)	
		Not moving	Moving
Any	Not moving	45	115
	Moving	1	45 (28.1%)
All planes combined (complex movements)	Not moving	154	6
	Moving	16	30 (83.3%)
Nodding/swallowing	Not moving	124	36
	Moving	6	40 (52.6%)
Lateral head rotation	Not moving	148	12
	Moving	15	31 (72.1%)
Head lifting	Not moving	73	87
	Moving	2	44 (33.6%)
Head anteroposterior translation	Not moving	86	74
	Moving	5	41 (35.6%)

The number in the parenthesis reflects the percentage of patients, among those defined as moving by AG, who were also seen as moving by VO.

incidence of patient motion artefacts by using “best clinical practice techniques” to reduce/avoid patient movement during CBCT examination.⁹ Therefore, attention should be paid to patient positioning, stabilization, instruction and monitoring methods.⁹

The fact that the operator should be able to monitor the patient during the full CBCT examination is listed by the SEDENTEXCT guidelines as mandatory for a proper CBCT clinic setting.⁴ The traditional setup includes lead-glass windows, which allow the patient to be observed from a certain distance outside the examination room.⁶ The problem can be that the window may be placed several metres from the patient and in a place where it is not comfortable for all operators to observe (*i.e.* the operator height, which is variable, is not compatible with the height in which the window is placed), together with the fact that in most CBCT units, the patient will be covered by the arm of the unit in some seconds, where s/he cannot be observed.⁶ To overcome such problems, the same guidelines suggest that cameras (*i.e.* VO) can be used for patient monitoring.⁴

Previous studies, based on the observation of video camera recordings of patients under CBCT examination, have suggested a prevalence of approximately 20% of patients who move.^{11,13,14} It must be borne in mind that in the present study, the observers could stop and replay the videos, which is not the case in the clinical setup. Thus, prevalence may differ if the patient is observed in “real time”, and no study has clarified this. Although easy to implement, VO-based patient movement detection is somewhat subjective, and the fact that 3D movements will be shown as two-dimensional entities may impede accurate quantitative estimates of movement.⁶ An obvious next step for studies on the prevalence of patient movement would therefore be to use a less subjective method to define patient movement. Ideally, technologies which are able to register and quantify patient movement in all planes (and preferably in an automated, real-time manner) would be desirable.⁶

To the best of our knowledge, the present study is the first comparing VO-based patient movement detection with an objective method based on an AG system. Accelerometers and gyroscopes are classified as inertial sensors, a group of microelectromechanical systems (MEMS), which can be used for motion tracking.¹⁸ Presently, owing to smartphones and other personal use gadgets, such as iPods, MEMS inertial sensors are readily available, inexpensive and widespread. An adequate AG should be able to provide the posture angle (calculated from accelerometer readings), the rotation angle (calculated from gyroscope readings) and the position (calculated from both accelerometer and gyroscope readings) of the mass, to which it is attached.¹⁸ In the present study, position changes of diverse distances defined thresholds for patient movement. The precision of MEMS such as accelerometers and gyroscopes are primarily affected by their innate inaccuracy, which induces errors in the derived angular and spatial positions.¹⁸ The innate errors of AG equalized a position variation up to 0.25° in all axes. Therefore, the smallest threshold to define patient movement was set to 0.3°, representing movements of approximately 0.5 mm, measured at the nose tip axial level. One could speculate on the effect of converting movement distances from degrees to millimetres. In the present study, the use of distances in millimetre, although approximate, was decided as a way to enhance the understanding of the movement characteristics. Considering this approach, it is fair to assume that movements in all planes could be represented in an approximate manner.

It may be evident that movement prevalence, type and characteristics will depend on the method used for motion detection.⁶ AG registered movements of at least 0.5 mm in almost 80% of the examinations, while for VO the prevalence of patients who moved was close to 20%, as previously reported in the literature.^{8,11,13,14} The majority of AG-registered movements had a distance between 1 and 2 mm. The prevalence of cases not detected by VO was logically smaller for larger movements. All movements were also identified by VO at a movement distance close to/larger than 5 mm. For VO, not only distance was a determinant factor for when movement could be observed, since the prevalence of video-observed movements was also closely related to movement type and complexity. Complex and multi-planar movements (*e.g.* lateral head rotation, nodding and swallowing) were more often detected by VO than uniplanar movements (*e.g.* head lifting and anteroposterior translation). The explanation for these differences can go in two directions. First, one needs to speculate on how the observers were trained. The observers engaged in the present study have been working for several years as a group, evaluating the prevalence of patients who move during CBCT examination from videos recorded during the examination, and the intraobserver and interobserver reproducibility in detecting patient movement has been shown to be rather high.¹⁴ Second, VO provides a two-dimensional picture

of a 3D movement in space.⁶ This may explain the fact that some movement types are more easily seen than others. As an example, anteroposterior head translation movements, also known as “turtle neck” movements, owing to the fact that they take place in a parallel plane to that shown by the videos (field “depth” changes), seem to be difficult to notice.

Further, one can speculate on possible AG registration errors (*e.g.* instability of the tiara holding the AG). Although the use of a plastic tiara was judged to be acceptable, the possible influence of this holding device leading to imprecise registrations was not quantified. We believe that other approaches (*e.g.* sport headbands) could also be tested in the future. Correspondingly, there was a case in which the movement was detected by VO, but not registered by AG. The patient was biting on a cotton roll and moving only the mandible. As it could be seen from the present results, this mandibular movement did not cause the head to move beyond the AG threshold for movement registration. For VO, this movement was noticed by all observers, since the idea of movement was also emphasized by the movement of the lips when biting the cotton roll. From the present data, we believe that this type of movement will go undetected by AG and therefore be a method-related drawback. Future studies could use a gold standard for movement (*i.e.* a high-precision, head movement simulation robot) to test various methods for motion detection in the clinic.

In the present study, it was also shown that patients younger than 16 years moved more often than patients in the older age groups, no matter whether the prevalence was based on AG or VO. This is in accordance with other studies stating that being a child is the main factor related to movement during radiographic examination.^{11,15,16} We strongly believe that this group of patients should be further studied on the issue of patient motion artefacts, since children are more sensitive to radiation exposure and would be more affected if the examination needs to be repeated owing to movement.⁴

To understand the relevance of the present findings, more knowledge on the relationship between movement distance and type and its impact on image quality must

be provided. One previous study has suggested that small patient movements may not be harmful to diagnostic image quality.¹³ This is related to the fact that the more the originally acquired images of a volume are “out of normality”, the more the reconstructed images will present artefacts.¹³ Even though a much higher prevalence of patients who move was seen when using AG registration, we should therefore not reject the VO method as a method for patient observation in a clinical setting. When to interfere with the examination, *i.e.* stop and reinstruct the patient or repeat the examination, will obviously depend on how image quality is affected. VO allows enhanced, but operator-dependent, patient monitoring, optimizing the workflow for CBCT examination, while AG may be a future method for automatic movement registration, including thresholds for automatic termination of the examination.

To the present, this is the only report of a method which is able to provide 3D patient movement registration during CBCT examination. Further, this method registers movement data synchronizing the patient position with the position of the CBCT unit arm. These two innovative steps are essential for developing image reconstruction algorithms, which could eventually provide automatized motion artefact correction. Developing such algorithms is the next frontier regarding the issue of motion artefacts in CBCT imaging.

Conclusions

AG-based movement registration resulted in a higher prevalence of patient movement during CBCT examination than VO (77.7 and 22.3%, respectively, considering movement ≥ 0.5 mm). VO rarely detected cases not registered by AG, but the smaller the threshold for AG movement detection was, fewer cases were observed by VO. AG-registered multiplanar movements (*i.e.* lateral head rotation and nodding/swallowing) were more frequently detected by VO also than uniplanar movements (*i.e.* head lifting and anteroposterior head translation). The prevalence of patients who move was higher in patients younger than 16 years than that in older age groups.

References

1. Ludlow JB, Timothy R, Walker C, Hunter R, Benavides E, Samuelson DB, et al. Effective dose of dental CBCT—a meta analysis of published data and additional data for nine CBCT units. *Dentomaxillofac Radiol* 2015; **44**: 20140197. doi: <https://doi.org/10.1259/dmfr.20140197>
2. Pauwels R, Beinsberger J, Collaert B, Theodorakou C, Rogers J, Walker A, et al. Effective dose range for dental cone beam computed tomography scanners. *Eur J Radiol* 2012; **81**: 267–71. doi: <https://doi.org/10.1016/j.ejrad.2010.11.028>
3. Pauwels R, Theodorakou C, Walker A, Bosmans H, Jacobs R, Horner K, et al. Dose distribution for dental cone beam CT and its implication for defining a dose index. *Dentomaxillofac Radiol* 2012; **41**: 583–93. doi: <https://doi.org/10.1259/dmfr/20920453>
4. SEDENTEXCT Project. Radiation protection no 172: cone beam CT for dental and maxillofacial radiology; 2012.
5. Schulze R, Heil U, Gross D, Bruellmann DD, Dranischnikow E, Schwanecke U, et al. Artefacts in CBCT: a review. *Dentomaxillofac Radiol* 2011; **40**: 265–73. doi: <https://doi.org/10.1259/dmfr/30642039>
6. Spin-Neto R, Wenzel A. Patient movement and motion artefacts in cone beam computed tomography of the dentomaxillofacial region: a systematic literature review. *Oral Surg Oral Med Oral Pathol Oral Radiol* 2016; **121**: 425–33. doi: <https://doi.org/10.1016/j.oooo.2015.11.019>
7. Kim DG. Can dental cone beam computed tomography assess bone mineral density? *J Bone Metab* 2014; **21**: 117–26. doi: <https://doi.org/10.11005/jbm.2014.21.2.117>
8. Hanzelka T, Dusek J, Ocsek F, Kucera J, Sedy J, Benes J, et al. Movement of the patient and the cone beam computed tomography scanner: objectives and possible solutions. *Oral Surg Oral*

- Med Oral Pathol Oral Radiol* 2013; **116**: 769–73. doi: <https://doi.org/10.1016/j.oooo.2013.08.010>
9. Hanzelka T, Foltán R, Horká E, Sedý J. Reduction of the negative influence of patient motion on quality of CBCT scan. *Med Hypotheses* 2010; **75**: 610–2. doi: <https://doi.org/10.1016/j.mehy.2010.07.046>
 10. Schulze RK, Michel M, Schwanecke U. Automated detection of patient movement during a CBCT scan based on the projection data. *Oral Surg Oral Med Oral Pathol Oral Radiol* 2015; **119**: 468–72. doi: <https://doi.org/10.1016/j.oooo.2014.12.008>
 11. Spin-Neto R, Matzen LH, Schropp L, Gotfredsen E, Wenzel A. Factors affecting patient movement and re-exposure in cone beam computed tomography examination. *Oral Surg Oral Med Oral Pathol Oral Radiol* 2015; **119**: 572–8. doi: <https://doi.org/10.1016/j.oooo.2015.01.011>
 12. Sun T, Kim JH, Fulton R, Nuyts J. An iterative projection-based motion estimation and compensation scheme for head X-ray CT. *Med Phys* 2016; **43**: 5705–16. doi: <https://doi.org/10.1118/1.4963218>
 13. Spin-Neto R, Matzen LH, Schropp L, Gotfredsen E, Wenzel A. Movement characteristics in young patients and the impact on CBCT image quality. *Dentomaxillofac Radiol* 2016; **45**: 20150426. doi: <https://doi.org/10.1259/dmfr.20150426>
 14. Spin-Neto R, Matzen LH, Schropp L, Liedke GS, Gotfredsen E, Wenzel A. Radiographic observers' ability to recognize patient movement during cone beam CT. *Dentomaxillofac Radiol* 2014; **43**: 20130449. doi: <https://doi.org/10.1259/dmfr.20130449>
 15. Donaldson K, O'Connor S, Heath N. Dental cone beam CT image quality possibly reduced by patient movement. *Dentomaxillofac Radiol* 2013; **42**: 91866873. doi: <https://doi.org/10.1259/dmfr/91866873>
 16. Nardi C, Borri C, Regini F, Calistri L, Castellani A, Lorini C, et al. Metal and motion artifacts by cone beam computed tomography (CBCT) in dental and maxillofacial study. *Radiol Med* 2015; **120**: 618–26. doi: <https://doi.org/10.1007/s11547-015-0496-2>
 17. Brullmann D, Schulze RK. Spatial resolution in CBCT machines for dental/maxillofacial applications-what do we know today? *Dentomaxillofac Radiol* 2015; **44**: 20140204. doi: <https://doi.org/10.1259/dmfr.20140204>
 18. Kos A, Tomažič S, Umek A. Suitability of smartphone inertial sensors for real-time biofeedback applications. *Sensors (Basel)* 2016; **16**: 301. doi: <https://doi.org/10.3390/s16030301>