RESEARCH ARTICLE

Radiographic observers' ability to recognize patient movement during cone beam CT

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Objectives: To assess radiographic observers' ability to recognize patient movement during cone beam CT and to decide early termination of the examination.

Methods: 100 patients were video-recorded during cone beam CT examination. Patients' videos were cropped twice: fitting the active 20-s examination time or the initial non-radiation 3 s of the examination. *x*- and *y*-coordinates of pre-defined points marked on the patient's face were used to define the reference standard for movement in the 20-s videos. A sample of 40 non-moving and 20 moving patients was selected. Eight observers scored the videos. The 3-s videos were scored: 0, the patient did not move; 1, the patient moved and the examination should be terminated. The 20-s videos were scored: 0, the patient did not move; 1, the patient moved. Re-assessment of 15% of the videos provided intra-observer reproducibility. The 20-s videos were compared with the reference standard providing sensitivity and specificity values (movement/non-movement recognition). The scores of the 3-s videos were compared with the scores of the 20-s videos.

Results: Intra- and interobserver reproducibility ranged from substantial to almost perfect for both videos. The 20-s videos allowed patient movement recognition with a high specificity and a medium to high sensitivity. The 3-s videos allowed early termination of the examination with a small number of incorrect positive scores. The majority of the patients scored as moving in the 20-s videos were detected in the 3-s videos.

Conclusions: By observing video recordings, trained observers are able to recognize patient movement during cone beam CT examination with high specificity and to decide an early termination of the examination.

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Introduction

Cone beam CT (CBCT) appears to be a substitute for fan beam CT scanning for three-dimensional visualization of bony structures in the head and neck region, mainly because of its lower radiation dose.^{1–3} However, a foremost disadvantage of CBCT imaging may be the

presence of visible artefacts in the final reconstructed images,^{4,6} such as beam-hardening and extinction artefacts caused by high-density objects (*e.g.* metal), and of motion artefacts caused by patients moving during the examination.^{4,5} Although metal artefacts are inherently present in all types of CT imaging, motion artefacts are particularly present in CBCT because it has a much longer exposure time.^{1,2,5}

Although this is a well-known phenomenon, few studies exist on the prevalence and diagnostic impact of

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artefacts in CBCT images.⁵ There is little evidence on how motion artefacts hamper image quality in dento-maxillofacial diagnosis.^{4,6–8} For medical fan beam and CBCT imaging, the detection of patient movement and the relationship with image quality has been studied regarding examination of the thoracic and abdominal region, because patients' heartbeats, breathing and digestion, as well as muscular movements, may result in image artefacts.^{9–14} The impact of motion artefacts in CBCT images is related to the fact that the examination is long, but time is not considered as a factor when the images are reconstructed.⁵ The range of exposure times is wide (5–40 s), with an average close to 20 s.^{1,2} As possible movements (and the time at which they occurred) are not considered in the volume reconstruction process, the reconstructed image may present artefacts due to geometric errors in the reconstruction process.^{4,5} At present, there seems to be only one study evaluating the impact of patient movements on image quality and the visual characteristics of motion artefacts.⁶ In that study, the authors described that head motion of any type resulted in artefacts in CBCT images, and that stripe-like artefacts were the most commonly seen, followed by ring-like artefacts, double contours and overall unsharpness.⁶ The same study showed that motion artefacts degraded image quality, depending on the performed motion pattern and on the region of interest.⁶

If the loss in image quality is significant, there might be a need for re-exposure, and the major concern in these cases is the extra radiation dose that the patient will receive. Therefore, methods that allow trained observers to recognize patient movement during CBCT examination would be clinically relevant. Implementing a method in the clinical routine that allows the examination to be terminated even before radiation exposure has started (if patient movement is detected) would be useful to keep up with the as low as reasonably achievable principle.¹⁵

To provide background information for the implementation of such a method, the aim of the present study was to assess radiographic observers' ability to recognize patient movement during CBCT examination and to decide early termination of the examination.

Methods and Materials

Sample characteristics

A total of 100 patients (70 females and 30 males; average age, 34 years; range, 10–86 years) referred for CBCT examination at the Department of Dentistry, Aarhus University, Aarhus, Denmark, were screened for the study. CBCT examination was performed using a Scanora® 3D unit (Soredex Oy, Tuusula, Finland). In this unit, patients were seated with a chin-rest, which was used to stabilize the mandible, and two vertical plastic bars (one on each side) to stabilize the position of the head. The settings (field of view and resolution) for each patient were selected based on the region to be evaluated and on the diagnostic task in question. The active scanning

time was approximately 17 s. Patients were consulted and agreed to be video-recorded during the examination. Approval of the methodology by an ethics committee was not required, since the CBCT examination was requested by the patient's clinician, and the video cameras did not interfere with image acquisition.

Video recording

All patients were video-recorded during the CBCT examination. A high-definition camera (Legria HSF21, Canon, Japan) was located on each side (right and left) of the patient, at 45° in relation to the patient's long axis, and approximately 1 m from the patient's face (Figure 1). Videos were acquired at a resolution of 1920 × 1080 pixels with a speed of 25 frames per second. Five red paper marks (stickers) were used to map the relation between the position of the patient's head and the CBCT unit: two of them were used as fiducial markers and were placed on a non-moving part of the unit (chin support holder), and these could be seen during the whole examination. The other three marks were placed on the patient's facial skin, one on the central forehead region and one over the anterior part of each zygomatic arch, in such a way that two of them would be seen with at least one of the cameras all through the examination (Figure 2). A cross was drawn in the middle of each sticker to allow a subsequent unequivocal marking of the centre point.

Video editing

Using dedicated software (Easy Video Cutter; AVN® Media, Chatsworth, CA), the videos were cropped twice to fit the active 20-s examination time (in which the

Figure 1 Schematic drawing of the position of the video cameras. They were placed on each side (right and left) of the patient, at 45° in relation to the patient's long axis and at a distance of approximately 1 m from the patient's face.

Figure 2 Using a phantom head as an example in this figure, the five red paper stickers can be seen. These were used to map the relation between the position of the patient's head and the cone beam CT unit. Four of them were displayed in each video [(a) right-side camera, (b) left-side camera] recording: two placed on the patient's face [one on the central forehead region (no. 1) and the other over the anterior part of the zygomatic arch (no. 2)], and two as fiducial markers (3 and 4).

CBCT arm containing the X-ray tube moves around the patient—20 s) and to contain solely the initial non-radiation 3 s of each examination (3 s). Cropped videos were saved as audio video interleaved files, retaining the native resolution and speed. Image snapshots were acquired (two image frames per second) using another piece of software (FrameShots Video Frame Capture; EOF Productions, Sacramento, CA), generating 40 frames from each 20-s video. These images were generated with the resolution of the original video file and saved as tagged image file (TIF) images. In this way, for each patient, there were two 20-s videos (left- and right-side camera), which generated 40 image frames (snapshots) each, and two 3-s videos.

Marking of sticker centre in video snapshots defining a reference standard for movement

The video snapshots were opened using dedicated software (PorDios[®],¹⁶ Aarhus, Denmark), and a trained user marked the centre of the cross in each of the four red stickers in each snapshot using a computer mouse. The same software provided a text table containing the *x*- and *y*-coordinates of each marking.

For each sticker on the patient (right and left camera separately), the averages between the *x*- and *y*-coordinates of the markings in the 40 snapshots constituting a 20-s examination were calculated using commercially available software (SPSS[®] v. 13.0; Apache Software Foundation, Vancouver, BC); that is, the mean *x*-coordinate for each of the four stickers was calculated by adding the 40 *x*-coordinates and dividing by 40. The same was done for the *y*-coordinates. The “distance from the mean” in pixels was then calculated for each of the 40 snapshots in the patient's examination. Roughly, in the video snapshots, 2.5 pixels represented a movement of 1 mm. The largest distance from the mean for each of the markings on the patient's face expressed the magnitude of a patient movement. The largest distance from the mean for each of the fiducial markings defined the error of the method for the observer in that specific case ($Error_1$).

The average $Error_1$ (among all cases) was used to express the general error of the marking method and was defined as $Error_2$ (to take into account variations in manual dexterity, fatigue etc.). The two errors together were used as a threshold to define the reference standard for true patient movement: if at least one of the two markings in at least one of the videos (left or right camera) of a patient's face showed a distance to the mean larger than the sum of the two errors ($Error_1 + Error_2$), it was defined that the patient had truly moved during examination.

By this definition, 20 of the 100 recorded patients (prevalence of 20%) had moved during the examination. For the present motion recognition study, and to obtain a more powerful statistical output, it was decided that the sample should comprise one-third of cases that moved and two-thirds of non-moving controls. Thus, 40 non-moving (26 females/14 males; average age, 41 years; range, 15–86 years) patients were randomly selected (out of the 80) and mixed with the 20 moving (14 females/6 males; average age, 32 years; range, 10–84 years) patients, leading to a final sample of 60 patients.

Observer assessment of videos

The videos were assessed on a 22-inch flat screen monitor (L2250pWD; Lenovo, Morrisville, NC) using dedicated software (UniscorL, designed by senior programmer Erik Gottfredsen, Department of Dentistry, Aarhus University, Aarhus, Denmark). This software displayed the videos in full screen in a blinded manner and random sequence. Eight observers (four radiology dentists, three radiographic technicians familiar with CBCT examination and one information technology technician) individually scored the videos in four separate sessions. The observers were trained in how to score the movements seen on the videos. They were sitting in front of the monitor and were not interrupted during the scoring sessions. The videos could not be stopped or replayed, thus simulating the clinical situation. In the first two sessions, which were at least 1 day apart, observers scored

Table 1 Frequency analysis for the scores, according to observer and camera, for the 20-s videos

Camera	Score	Observer							
		1	2	3	4	5	6	7	8
Right	0	6	2	4	10	11	9	6	8
	1	38	42	41	37	34	38	39	40
	2	3	2	2	1	5	2	2	0
	3	13	14	13	12	10	11	13	12
Left	0	6	1	0	8	5	9	1	5
	1	39	40	43	33	43	36	43	37
	2	2	3	1	6	3	4	2	3
	3	13	16	16	13	9	11	14	15

Scores were defined as: 0, no movement at all; 1, eye movement/blinking; 2, soft-tissue movement; or 3, movement of the head.

the two 3-s videos (left and right camera separately) on a dichotomous scale: 0, the examination started without any observable patient movement and should therefore continue; or 1, the patient moved and the examination should be terminated. In the two last sessions, which also took place at least 1 day apart, observers scored the two 20-s videos (left and right camera separately) on a four-category scale: 0, no movement at all; 1, eye movement/blinking; 2, soft-tissue movement; or 3, movement of the head. Frequency analysis for all observers (Table 1) showed that, in most cases, patients performed eye movement, mostly blinking, making the number of “0” scores small. In addition, it was difficult to differentiate between soft tissue (*i.e.* lips or cheeks) and head (*i.e.* bone) movements. To avoid two of the categories having too few cases, the data were fused to a dichotomous scale: 0, initial scores 0 and 1 into no movement; and 1, initial scores 2 and 3 into movement. In all sessions, 15% of the videos were assessed in duplicate, for intra-observer reproducibility evaluation. The order of the sessions was chosen so that no observer had watched the full examination (20 s) before watching the initial 3 s, to minimize possible memory bias. No observer was aware of the prevalence of truly moving patients as defined by the reference standard.

Statistical evaluation

Commercially available software (SPSS v. 13.0; Apache Software Foundation) was used for data evaluation. Intra- and interobserver agreement was calculated by κ statistics. The 20-s videos were compared with the reference standard providing sensitivity (true positive) and specificity (true negative) values for movement recognition. A false positive was defined as a patient who was not moving according to the reference standard but was scored as moving by the observer. A false negative was defined as a patient who was moving according to the reference standard but was scored as not moving by the observer. Separate values for each observer were calculated, together with values based on a “consensus” observer, defined by the mode among the scores given by the eight observers for each case. The scores given to the 3-s videos were compared with the scores given to the 20-s videos for the same observer, providing the number of incorrect positives and incorrect negative scores.

Results

Reference standard and magnitude of movement

Error₁ ranged from 0.20 to 3.29, and Error₂ was 1.23 pixels. Therefore, the threshold (Error₁ + Error₂) beyond which movement was defined to have occurred ranged from 1.43 to 4.52 pixels, depending on the case. For the 20 patients who were defined to have moved by the reference standard, the mean distance from the mean of the markings was 5.27 pixels, ranging from 2.85 to 22.49 pixels (Table 2). Based on a rough estimation (based on pixel distances), the distance from the mean of the markings ranged from 1.1 to 8.8 mm.

Intra- and interobserver agreement

For the 3-s videos, the average intra-observer agreement was 0.85 (almost perfect), ranging from 0.26 (fair) to 1.00 (perfect). For the 20-s videos, average intra-observer κ was 0.82 (almost perfect), ranging from 0.60 (moderate) to 1.00 (perfect). Mean interobserver agreement was 0.67 (substantial, ranging from 0.32 to 0.95) and 0.78 (substantial, ranging from 0.65 to 0.89) for the 3- and 20-s videos, respectively (Tables 3 and 4). In both sessions, more experienced observers reached higher κ values than the observer (Observer 5) not dealing with patients on a daily basis (information technology technician). The agreement of the less trained observer with the other observers was also lower than the average.

Correct recognition of movement in 20-s videos

For the 20-s videos, specificity was high (0.82–0.95), whereas sensitivity was medium to high (0.60–0.75). This means that, in a few cases, the observers scored movement in a non-moving patient (a false positive, ranging from one to four patients). In more cases, the observers did not recognize a truly moving patient (a false negative, ranging from seven to nine patients). False negatives were mainly related to movements of smaller magnitude (with a distance to the mean ranging from 2.8 to 7.2 pixels, Table 2). All observers and cameras provided comparable results (Table 5). For the “consensus” observer, there was a sensitivity of 0.69 and specificity of 0.87 for the camera on the right and a sensitivity of 0.67 and specificity of 0.93 for the camera on the left.

Recognition of movement from the 3-s videos according to the 20-s videos

When compared with the scores of the 20-s videos, the 3-s videos allowed early termination of the examination with a small number of incorrect positive scores. Between 0 and 2 (mode = 0), patients were scored as moving in the 3-s video, but not in the 20-s video (except for Observer 5). Moreover, the majority of cases which were scored as moving in the 20-s video were also scored as moving in the initial 3 s of the examination. Depending on the observer, the incorrect negative scores ranged between 4 and 12.

Table 2 Sex, age and distance from the mean (in pixels) for both patient stickers for the 20 patients defined as “moved” by the reference standard

Patient	Sex	Age (years)	Camera	Sticker 1	Sticker 2	Observer								Consensus
						1	2	3	4	5	6	7	8	
1	M	22	Right	19.4	14.0	+	+	+	+	+	+	+	+	+
			Left	22.5	17.0	+	+	+	+	+	+	+	+	+
2	M	63	Right	20.0	19.5	+	+	+	+	+	+	+	+	+
			Left	14.5	21.2	+	+	+	+	+	+	+	+	+
3	F	12	Right	9.0	9.9	+	+	+	+	+	+	+	+	+
			Left	10.4	10.8	+	+	+	+	+	+	+	+	+
4	F	59	Right	10.7	7.5	+	+	+	+	+	+	+	+	+
			Left	9.3	8.2	+	+	+	+	+	+	+	+	+
5	F	15	Right	1.9	9.7	+	+	+	+	+	+	+	+	+
			Left	3.3	3.8	+	+	+	+	+	+	+	+	+
6	F	50	Left	7.2	6.9	–	–	–	–	–	–	–	–	–
			Left	4.1	5.1	–	–	–	–	–	–	–	–	–
7	M	57	Left	4.1	5.1	–	–	–	–	–	–	–	–	–
			Right	2.2	3.9	+	+	+	+	+	+	+	+	+
8	M	13	Left	1.8	5.1	+	+	+	+	+	+	+	+	+
			Right	2.4	2.8	+	+	+	+	+	+	+	+	+
9	M	12	Left	3.2	4.9	+	+	+	+	+	+	+	+	+
			Right	2.9	2.7	+	+	+	+	+	+	+	+	+
10	F	15	Left	2.8	4.9	+	+	+	+	+	+	+	+	+
			Right	4.8	3.1	–	–	–	–	–	–	–	–	–
11	F	29	Right	4.3	3.8	–	–	–	–	–	–	–	–	–
			Left	4.1	4.3	–	–	–	–	–	–	–	–	–
12	F	19	Right	1.2	4.1	+	+	+	–	+	–	+	+	+
			Left	3.3	4.0	–	–	–	–	–	–	–	+	–
13	M	12	Right	2.5	3.0	+	+	+	+	+	+	+	+	+
			Left	3.7	3.9	+	–	+	+	–	+	+	+	+
14	F	84	Right	2.8	2.9	–	–	–	–	–	–	–	–	–
			Left	3.0	3.7	–	+	–	–	–	–	–	–	–
15	F	66	Left	2.4	3.6	–	+	+	+	+	–	+	+	+
			Left	2.1	3.4	+	+	+	+	+	+	+	+	+
16	F	10	Left	1.7	2.9	+	–	–	–	–	–	–	–	–
			Right	2.5	2.8	–	–	–	–	+	–	–	–	–

F, female; M, male.

The camera side(s) responsible for assigning the patient to “moved” is/are shown.

False-negative (–) and true-positive scores (+) are shown for all observers and for the consensus.

Discussion

It is known that head movements may result in motion artefacts in CBCT images, leading to degraded image quality, and the severity of artefacts depends on the movement pattern and on the region of interest.⁶ This means that patient movement should be avoided, and the patient should be thoroughly instructed before CBCT examination. The SEDENTEXCT guidelines state that a proper arrangement of the CBCT clinic should be worked out, “in such a way that the position of the operator must always be such that they can clearly see the patient and the room entrance(s) and be able to interrupt the scan using the emergency stop, if required”.¹⁷ However, there are no studies on observers’ ability to monitor the patient during a CBCT

examination to detect head movement most accurately.^{5,6}

In this study, our objective was to assess radiographically the observers’ ability to recognize movement in patients who undergo CBCT and further to assess if observers can recognize patient movement from the initial seconds of the examination to terminate the examination and re-instruct the patient before radiation exposure has started.

In the present study, the sample was built to comprise one-third of patients who moved during examination, providing a more powerful statistical output for sensitivity and specificity values. This proportion does not reflect the prevalence of movement during CBCT examination, since 100 patients were monitored to find 20 patients who moved. None of the included patients had a re-examination.

We found that trained observers were reasonably accurate in recognizing patient movement on video recordings during CBCT examination. For the full-examination videos (20 s), a high specificity was found, *i.e.* the observers rarely scored movement, when the reference standard defined the patient as non-moving. In those few cases where it occurred, one explanation could be that the movement was actually restricted to soft tissues since these scores were also included in the

Table 3 Intra-observer agreement (κ) regarding the video session (3 or 20 s)

Session	Observer								Average
	1	2	3	4	5	6	7	8	
3 s	1.00	0.77	1.0	1.00	0.26	1.00	1.00	0.77	0.85
20 s	1.00	0.60	0.60	1.00	0.77	0.60	1.00	1.00	0.82

Table 4 Interobserver agreement (κ) regarding the video session (3 or 20 s) and the camera side

		Observer pair																												Average
		1-2	1-3	1-4	1-5	1-6	1-7	1-8	2-3	2-4	2-5	2-6	2-7	2-8	3-4	3-5	3-6	3-7	3-8	4-5	4-6	4-7	4-8	5-6	5-7	5-8	6-7	6-8	7-8	
Session																														
3 s		0.80	0.79	0.71	0.33	0.95	0.84	0.67	0.78	0.78	0.40	0.76	0.82	0.80	0.69	0.39	0.74	0.74	0.73	0.49	0.74	0.67	0.73	0.35	0.32	0.37	0.79	0.69	0.77	0.67
20 s		0.79	0.85	0.81	0.68	0.84	0.87	0.85	0.77	0.77	0.65	0.72	0.83	0.77	0.79	0.69	0.78	0.89	0.87	0.66	0.82	0.85	0.78	0.69	0.73	0.70	0.80	0.77	0.89	0.78

observers' movement scores, but if the head/jaws had not moved, it would not be defined as movement by the reference method. The reference method for motion detection and quantification was based on digitization of the fixed points (fiducials) and the patient-related points seen in the video image frames, in two snapshots per second. Although the measurement error for the method was small, some drawbacks are inherent in this method. Since two snapshots per video-second were digitized, fast movements that last less than 0.5 s could theoretically be missed by the reference method. While it may be less likely, however, that the naked eye will catch such short-lasting movements, another important pitfall in the reference method is that the image frames provide only a two-dimensional picture of a three-dimensional movement in space. Therefore, a technology that is able to track and quantify movement in all planes is desirable and should be developed for future studies.

A medium to high sensitivity for movement was found for most observers, *i.e.* the observers missed motion in some of the patients who were defined to move by the reference method. Two cameras, on the right and left side of the patient, were used to cover the whole patient examination with the videos, as one camera will have some seconds of “blind angle”, in which the patient is covered by the CBCT unit arm/tube. Movement seen in one of the videos is therefore not always seen in the video on the other side, which explains the difference in scores in the left and right video. As can be seen from Table 2, the missed movements were relatively small in magnitude although detected by the reference method. No studies seem so far to have assessed the relationship between the magnitude of patient movement and the severity of degradation in the CBCT images. It is known that image quality will be hampered by motion artefacts, but the diagnostic impact of a possible loss of quality is as yet unknown. Such studies are of extreme importance and should be an area of future research.

The examination time in CBCT units is not the same as the exposure time.¹⁸ For many units, the initial seconds in the examination, where the arm starts to move, go without radiation, and the examiner thus has some seconds to terminate the examination if the patient seems to be restless or anxious. For the unit used in the present study (Scanora® 3D; Soredex, PaloDEX Group, Tuusula, Finland), the initial 3 s represents a period in which there is still no radiation. The scores of the 3-s videos showed that the observers in general had already identified that a patient moved at the very start of the examination, since few disagreements between the 3-s and 20-s videos were found. To terminate the examination because of an incorrect interpretation of movement in a patient who had really not moved would cause no harm to the patient since no radiation had occurred, and only somewhat more time would be spent for re-instruction. It is important to emphasize that stopping the examination at a later phase, in which a certain radiation dose had already been given to the patient, was not considered as an option in the

Table 5 Sensitivity and specificity by observer for the 20-s video session

Camera	Parameter	Observer								Average
		1	2	3	4	5	6	7	8	
Right	Sensitivity	0.73	0.67	0.67	0.60	0.73	0.60	0.68	0.60	0.66
	Specificity	0.89	0.87	0.89	0.91	0.91	0.91	0.89	0.93	0.90
Left	Sensitivity	0.62	0.69	0.69	0.69	0.62	0.62	0.69	0.75	0.67
	Specificity	0.89	0.82	0.86	0.82	0.95	0.89	0.89	0.86	0.87

present study. This specific situation must be further considered based on the cost/benefit for the patients. Moreover, it was interesting that the majority of patients who were scored to move at some point during the full 20-s examination were already detected as moving in the initial 3 s. This means that the theory that the patient is tiring and therefore cannot sit still during the whole examination may not hold true but that unrest is a parameter which is more likely inborn in the patient. Further studies with a higher number of patients should assess patient characteristics in relation to motion patterns to be able to predict which patients are more likely to move during the examination. Providing more detailed patient instruction (with the suggestion of eye-closure, as an example) before the examination could also be beneficial, but also demands further studies. In our methodology, when defining the reference standard, it was not possible to evaluate precisely when a movement had occurred; thus the definition of a moving patient was based only on a yes/no answer from the full 20-s examination. However, our results seem to justify that, when movement is seen initially, the examination should be terminated since unnecessary radiation can be avoided and the patient re-instructed before exposure. This would be in keeping with the as low as reasonably achievable principle.¹⁵ Whether the examination should be terminated also at a later phase, when radiation is ongoing and motion is noted by the examiner, cannot be advocated from our results but must await findings that relate time, type and magnitude of patient motion to image quality. Various types of patient fixation devices (such as a chin-rest and a bite piece) and the position of the patient during an examination (seated, standing or supine) should also be considered in relation to the prevalence and magnitude of patient movement. In the present study, as only one unit was used, no judgments on that topic can be made.

The importance of having a well-trained team working in a radiology service is described in the standard guidelines of CBCT imaging. The SEDENTEXCT guidelines state that “all those involved with CBCT must have received adequate theoretical and practical training for the purpose of radiological practices and relevant competence in radiation protection”, adding that “continuing education and training after qualification are required, particularly when new CBCT

equipment or facilities are adopted”.¹⁷ It should be emphasized that higher intra- and interobserver agreements were seen for consistently trained observers than for a non-trained observer in this study.

In many countries, regulations state that a CBCT unit should be positioned in a separate room and that the examiner should be standing outside the room during the exposure.¹⁷ This means that the clinician observes the patient through a window and may be placed several metres from the patient.¹⁸ Moreover, in most CBCT units, the patient will be covered by the arm of the unit for some seconds, where she/he cannot be observed. In the SEDENTEXCT guidelines, the idea of using cameras is suggested as an alternative patient monitoring method,¹⁷ which agrees with the approach tested in this study as a possible “real life” clinical situation. Based on the present findings, we suggest therefore that video cameras, a left-side camera and a right-side camera, be mounted to the unit, and that a monitor adjacent to the exposure button situated outside the examination room display a video of the patient during the full CBCT examination. The left-side camera should take over automatically whenever the right-side camera is covered by the arm of the unit and vice versa. This approach would facilitate the observation of the patient and increase quality control in CBCT examination. We are implementing such a set-up in our CBCT clinic.

Conclusion

Our results suggest that trained observers are able to correctly recognize patient movement during CBCT examination with high specificity based on the observation of video recordings. Moreover, most patients who moved were already identified as moving during the initial non-radiation 3 s of the examination, thus early termination and re-instruction can be decided.

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