RESEARCH ARTICLE

Movement characteristics in young patients and the impact on CBCT image quality

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Objectives: To assess patient movement characteristics in children and young adults and the impact on CBCT image quality.

Methods: During 33 CBCT examinations, the patients (age: average, 14 years; range, 9–25 years) who had moved were identified by video observation [movement group (MG)]. The CBCT data sets were matched with those of 33 non-moving patients according to age, diagnostic task, examined region, field of view and voxel resolution [non-movement group (N-MG)]. Three observers scored the videos of MG, regarding motional state second by second (moving/non-moving), and movement characteristics: duration (in seconds), complexity (uniplanar or multiplanar) and distance ($<3/\geq 3 \leq 10/>10$ mm). The observers blindly assessed axial sections of the 66 examinations individually, categorizing the image quality (appropriate/acceptable/inappropriate). Next, the observers blindly assessed axial sections of the matched-pairs images simultaneously, deciding which image in the pair had the highest image quality or if it was impossible to decide. The relationship between image quality and movement/movement characteristics was evaluated.

Results: When the 66 CBCT images were evaluated individually, no relationship between image quality and movement was found. However, based on the matched-pairs assessment, accumulated number (≤ 2 vs ≥ 3 , $p = 0.039$), duration (≤ 5 s vs ≥ 6 s, $p = 0.024$) and complexity (uniplanar vs multiplanar, $p = 0.046$) of movements had an impact on image quality; the more severe the movement, the more often the image quality was assessed lower in the MG.

Conclusions: Axial CBCT images of young patients who moved during examination did not always present lower quality than images originating from non-moving patients. Image quality was, however, significantly lower in the moving patients when movement occurred several times, had a long duration or was multiplanar.

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Introduction

In dentistry, CBCT may be a resourceful diagnostic tool compared with fan beam CT since it provides a significantly lower effective radiation dose to the patient.^{1–3} In this context the word “lower” must be interpreted with

caution, since there is no low-dose threshold to define the amount of radiation to be considered as safe.^{4,5} This is a major concern, particularly when the patient is a child, children being consistently more susceptible to radiation than adults.⁶

Besides radiation dose, the presence of artefacts in the final reconstructed images is a major shortcoming of CBCT.^{7,8} These artefacts may be related to several unit- or

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patient-related factors.^{7,8} Related to the patient there are motion artefacts, which are speculated to be connected to the relatively long image acquisition time in CBCT.^{9–12} According to the literature, patient motion artefacts in CBCT imaging appear mainly as stripe- and ring-like patterns, double bony contours and overall unsharpness.^{13–15} The impact of patient motion artefacts on the various diagnostic tasks performed based on CBCT imaging is yet unknown.^{16,17}

If patient motion artefacts are present in an image, leading to compromised image quality, a re-exposure of the patient may be necessary. A recent study¹⁷ has shown that being a child (*i.e.* younger than 16 years) is the major factor related to patient movement. The same study showed that approximately 60% of patients in this age group moved to some extent during CBCT examination.¹⁷ In this way, one can speculate that the group of patients, who are more susceptible to ionizing radiation, is also the group in which patient motion artefacts could be more often present, leading to a re-exposure.¹⁷ Until now, no studies have assessed the relationship between the various types and characteristics (number, duration, complexity and distance) of patient movement and the relationship between these characteristics and the severity of degradation in CBCT image quality. An understanding of this relationship could be used to define “thresholds” for when these movements are noxious to image quality. This could lead to the implementation of an examination protocol on when and if the examination should be terminated by the operator, if patient movement is detected.

Therefore, the aim of the present study was to assess patient movement characteristics in children and young adults and the impact of movements on CBCT image quality, testing the hypothesis that image quality is dependent on patient movement and movement characteristics.

Methods and materials

Basic study population

The basic study population consisted of 190 patients (122 females and 68 males; age: average, 32 years; range, 9–84 years), in whom 248 CBCT examinations were performed, at the Section of Oral Radiology, Department of Dentistry, Aarhus University.¹⁷ CBCT examinations were performed using a Scanora[®] 3D unit (Soredex Oy, Tuusula, Finland) by one of the three experienced operators (radiographic technicians). In this unit, patients are seated, with a chinrest 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 [field of view (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.^{17,18} Briefly, a high-definition camera (Canon Legria HSF21, Canon, Japan) was located on each side (right and left) of the patient, at 45° in relation to the patient and with approximately 1-m distance to the patient's 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.^{17,18} 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's clinician, and the video cameras did not interfere with the examination.

Reference standard for patient movement

As previously reported,¹⁷ three observers (radiologists working with CBCT for several years) had assessed the videos of the selected patients 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 team) in full screen in a blinded and random sequence. The two videos of a patient were displayed as a sequence. Observers were trained in how to detect patient movement in the videos, in particular to distinguish between eye blinking solely and head movement. They scored the videos (left and right camera separately) on a dichotomous scale: the patient moved/did not move. Videos could be stopped, replayed and played in slow motion as many times as the observer found it was necessary. In those cases 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 would lead to the patient being scored as moving. In this way, 52 examinations, in which the patient had moved, were identified, defining the reference standard for patient movement.¹⁷

Patient sample

The present study aimed to investigate children and young adults, since the recent study showed that patients in this age group were more likely to move during CBCT examination than patients above the age of 30 years.¹⁷ In order to minimize the influence of other artefacts (rather than patient motion) on CBCT image quality, patients with metal in the FOV were excluded from the sample. Eventually, 33 CBCT examinations (age: average, 14 years; range, 9–25 years) with no metal in the FOV, in which the patient had been identified as moving, were sampled defining the movement group (MG). 3 examinations were

performed for the diagnosis of impacted third molars, and 30 examinations were performed for the diagnosis of impacted maxillary canines. The principal investigator (RS-N, not part of scoring the videos) matched the data sets of the patients from MG with those of 33 non-moving patients, according to age (same age in years), diagnostic task, examined region, FOV and voxel resolution, defining the non-movement group (N-MG). [Figure 1](#) presents examples of two matched-pairs, as sampled for the study.

Assessment of patient's motional state second by second and movement characteristics

In a subsequent video observation session, the same 3 observers assessed the videos of the 33 patient examinations from the MG individually on a 24-inch flat screen monitor (Dell P2412H, Dell Inc.). The two videos of a patient were displayed as a related sequence, and the order in which the patients were shown was assigned randomly. Videos could be stopped, replayed and played in slow motion as many times as the observer thought it was necessary. Observers were advised to pause the

videos whenever a movement was detected, allowing time for the movement to be scored. The observers scored the patient's motional state second by second (movement/non-movement) throughout the examination, together with movement characteristics: duration (in seconds), complexity (uniplanar, *e.g.* nodding/rotation/tilting, or multiplanar, *e.g.* nodding + rotation + tilting) and distance ($<3/\geq 3 \leq 10/>10$ mm) of each movement.

Assessment of CBCT image quality

The same three observers as those scoring the videos assessed the image quality of the 66 examinations (MG and N-MG in random sequence). The randomization of the sequence was defined by drawing a lot. In the first session, the observers blindly assessed data sets based on the observation of axial sections of the 66 examinations individually, categorizing the overall image quality (appropriate: if the image was considered to be as good as possible; acceptable: if the image was considered to have a few artefacts, but was still diagnostically acceptable; inappropriate: if the image had too many artefacts

Figure 1 Two matched-pairs (MG and N-MG), as sampled for the study. In (a), two multiplanar movements were detected with an accumulated duration of 4 s. In (c), one uniplanar movement was detected with a duration of 2 s. In the (a, b) pair, the image from N-MG was selected as the one with higher image quality. In the (c, d) pair, the image from MG was selected as the one with the higher image quality. MG, movement group; N-MG, non-movement group.

Table 1 Number of movements (count), movements per examination (count range), duration of each movement (range and median, in seconds), complexity of movements (uniplanar or multiplanar) and movement distance (≤ 2 , $\geq 3 \leq 10$ and >10 mm), according to the observer

Observer	Number of movements	Movements per examination	Duration (s)	Complexity		Distance (mm)		
				Uniplanar	Multiplanar	≤ 2	$\geq 3 \leq 10$	>10
1	74	1–5	1–4 (2)	66	8	56	17	1
2	76	1–6	1–7 (2)	66	10	29	45	2
3	70	1–5	1–6 (2)	44	26	28	30	12
Consensus	72	1–4	1–6 (2)	57	15	31	36	5

and should be preferentially retaken) and the appearance of stripe artefact in the images (absent/stripes related to the presence of dental hard tissues/stripes related to movement). The observers were aware that the sample consisted of moving and non-moving patients.

In the second session, the observers assessed data sets of the matched-pairs simultaneously, blinded to which image in the pair was from MG and which was from N-MG. The observers decided which image in the pair had the highest image quality or if it was impossible to decide.

Statistical evaluation

Commercially available software (IBM SPSS® Statistics 21, IBM Corp., New York, NY; formerly SPSS Inc., Chicago, IL) was used for data evaluation. Based on the recordings of the patient’s motional state second by second, the number of isolated movements per patient was counted for each observer. For the assessment of patient’s motional state and movement characteristics, interobserver reproducibility was stated as percentage agreement. A “consensus” observer was then generated to represent the sample. For patient’s motional state, movement in a specific second of the examination was counted if at least two observers

scored so. For movement characteristics, regarding the number and duration of movements, the same approach for consensus was used. Regarding movement complexity and distance, the mode among the observers was used to define the consensus observer. If there were three diverse scores for a specific case, the consensus would be set to represent the “worst possible” scenario: multiplanar (complexity) and the larger movement (size).

For the purpose of inferential statistical evaluation, the accumulated number and duration of movements were divided according to the severity of the movement by the median of the distributions of these variables (number: $\leq 2/\geq 3$; duration: $\leq 5/\geq 6$ s).

For the assessment of CBCT image quality, inter-observer reproducibility was assessed by means of Kappa statistics. Based on the consensus observer, χ^2 statistics were used to assess the differences in image quality and stripe artefacts between MG and N-MG. Similarly, using the consensus observer, the relationship was calculated between images from MG assessed to have the lower/higher image quality of the matched-pairs and number of movements in the examination, accumulated duration of movements, complexity of movements and the largest movement distance. The level of statistical significance was set to 5%.

Figure 2 Diagram of the motional state of 33 patients second by second, according to the consensus observer. Each block represents a second of the examination. A reference line is drawn after the third second of the examination, delineating the non-radiation part of the examination.

Results

Patient's motional state second by second and movement characteristics

In the 33 patients where movement was known to have occurred at some point during the examination (MG), the 3 observers agreed on the patient's motional state second by second in 74.8% of the seconds, considering all 1518 s of the observed videos (23 s per camera, in each of the 33 examinations). Interobserver agreement regarding movement complexity and distance was 51.4% and 40.3%, respectively. Data regarding the number, duration, complexity and distance of movements are presented in Table 1. For the consensus observer, 72 separate movements were identified. A diagram of the patient's motional state second by second according to the consensus observer is shown in Figure 2.

CBCT image quality

Two matched-pairs images, as sampled for the study, are shown in Figure 1. Interobserver agreement (Kappa) for image quality ranged between fair and good (0.30–0.61). For detecting stripes in the image, the agreement ranged between fair and moderate (0.23–0.53). Considering each observer separately, when the 66 CBCT images were evaluated individually, no significant difference between MG and N-MG was seen in image quality. In this case, 15–33% of the images were scored as inappropriate in the MG, while in the N-MG, the percentage ranged from 3% to 21%, depending on the observer. Regarding the appearance of stripe artefacts, the difference between MG and N-MG was significant only for Observer 1 ($p = 0.02$, χ^2 test). In this case, 3–15% of the images were scored without stripe artefacts in the MG, while in the N-MG, the percentage ranged from 18% to 27%, depending on the observer. Considering the consensus observer, when the 66 CBCT images were evaluated individually, no significant difference was seen in image quality or in the appearance of stripe artefacts between MG and N-MG as shown in Table 2 ($p = 0.10$, χ^2 test). In this case, 6% of the images were scored without stripe artefacts in the MG and 24% in the N-MG.

When the images were assessed simultaneously as matched-pairs, no relationship between the observers' selection of the image with the higher image quality and the known reference standard for movement was found ($p = 0.54$, χ^2 test). For four image pairs, the observers had determined it impossible to decide which image had the higher image quality. These image pairs were excluded from the analysis of the relationship between image quality and movement characteristics. There was a statistically significant impact on image quality of number (≤ 2 vs ≥ 3 , $p = 0.039$), duration (≤ 5 s vs ≥ 6 s, $p = 0.024$) and complexity (uniplanar vs multiplanar, $p = 0.046$) of movements; the more severe the movement, the more often the image from MG was assessed to have the lower image quality in the matched-pair (Table 3). No relationship between the lower image quality in the matched-pair and movement distance score was found ($p = 0.659$).

Discussion

The presence of artefacts in the images is a major disadvantage of CBCT.⁷ Artefacts usually appear as streaks/stripes (black and white), double contours and blurring in the reconstructed images.^{7,19} Among the possible artefacts which might be seen in a CBCT image, those related to patient movement (patient motion artefacts) are unique, considering the fact that clinicians can attempt to reduce patient movement during CBCT examination (and therefore the incidence of artefacts) by “best clinical practice techniques” (*i.e.* thorough patient positioning, stabilization and instruction).¹²

It is well known that patient motion artefacts influence the obtainable resolution of the final CBCT reconstructed image, rather than the resolution of the unit's flat panel detector.¹² Very few studies^{13,14,16} in the literature have assessed the image quality and visual characteristics of CBCT examination for the presence of artefacts supposedly related to patient movement. These studies reported that between 4.5% and 41.5% of CBCT examinations show artefacts suggestive of patient movement.^{13,14,16} But, although some studies^{7,8} report on the possible impact of motion artefacts on image quality, knowledge of which types and magnitudes of movements may considerably hamper the diagnostic outcome of a CBCT examination is still a key question.⁸ Moreover, it is unclear whether observed artefacts in some studies^{13,14,16} were in fact due to patient motion.

Being a child is logically one of the main factors related to movement during radiographic examination.^{13,14,17} Considering the fact that children and young adults (between 10 and 25 years) have a larger radiation effect multiplication factor than the older population,⁶ one can understand why this group of patients should be further studied in the issue of patient motion artefacts. We have previously suggested that, when movement is seen during the initial seconds in the examination, which go without radiation, the operator should terminate the examination and re-instruct the patient, avoiding a re-examination.¹⁸ For the unit used in the present study (Scanora 3D), the three initial seconds represent a period in which there is still no radiation. It was seen that 45% of the patients in our study already started to move during the non-radiation phase of the examination. In addition, >85% (13 out of 15) of these patients moved at least one more time during the active time of the examination, when radiation exposure was ongoing (Figure 2). Terminating the examination due to a movement detected at the initial, non-radiation period of the examination costs no harm to the patient; only more time will be spent for re-instruction and resuming the examination. The next speculative step could be to estimate whether stopping the examination at a later phase, in which a certain radiation dose has already been given to the patient, is beneficial. To provide background for such a speculation, one should first understand the causal relationship between patient movements and image quality degradation.

Table 2 Image quality (IQ: appropriate/acceptable/inappropriate) and stripe artefacts (absent/related to the presence of dental hard tissue, enamel/related to movement), according to the known reference standard [non-movement group (N-MG)/movement group (MG)] and observer (blind assessment of 66 patients)

Observer	Reference standard	IQ			Stripe artefacts		
		Appropriate	Acceptable	Inappropriate	Absent	Enamel	Movement
1	N-MG	12	14	7	6	10	17
	MG	4	18	11	1	5	27
2	N-MG	14	14	5	9	5	19
	MG	13	12	8	5	9	19
3	N-MG	17	15	1	6	21	6
	MG	20	8	5	3	21	9
Consensus	N-MG	13	15	5	8	8	17
	MG	13	13	7	2	12	19

IQ: $p = 0.788$, χ^2 test, considering the consensus observer; stripe artefacts: $p = 0.105$, χ^2 test, considering the consensus observer.

No previous studies have assessed the relationship between the magnitude of patient movement and the severity of degradation in the CBCT images. Two *ex vivo* studies, in which head movements were simulated using robots, tested only a very small range of possible movements and therefore could not provide much information on the topic.^{15,20} In the present study, it was our intention to understand which characteristics of patient movement might hamper image quality. The observers engaged in the present study have been working for several years as a group, evaluating CBCT image sets, and were considered to be calibrated to “good/acceptable image quality” in the daily clinic. Nevertheless, the relatively low κ values reported emphasizes the fact that image quality assessment is a rather subjective task. The observers were used to work within the “patient motion artefact” topic and were therefore especially trained for detecting artefacts connected to patient motion. No “atlas” or other visual method was, however, presented to the observers to define the image quality categories. It cannot be ruled out that this could have increased their agreement rate.

To avoid the influence of the various types of artefacts, which could be simultaneously present in the image (e.g. beam hardening and extinction artefacts related to metal),^{7,8} the study considered only images of young patients with no metal inside the FOV, which relate to the majority of the child populations in Western countries. To provide a strong control group for image quality evaluation, the CBCT images of the moving patients were matched to those of non-moving patients according to age, diagnostic task, examined region, FOV and resolution. To the present, such study design is unprecedented. Since stripes were the most

commonly observed artefacts in a previous robot study,¹⁵ this artefact was evaluated. The results showed that when the images from the two groups were individually evaluated, the overall image quality and the appearance of stripe artefacts in the images were not significantly different between moving and non-moving patients. The vast majority of the images were scored with stripe artefacts, and it was not possible for the observers to distinguish enamel-related stripes, also present in the non-moving patients, from motion stripe artefacts. In this child population, most of the CBCT examinations (90%) were performed owing to impacted upper canines. In axial sections of impacted canines, stripe artefacts are often present owing to the thick enamel layer in the cusp of the canine. These artefacts are commonly located in the same axial plane in which possible resorption of the maxillary lateral incisors roots should be evaluated, thus hampering image quality. Therefore, our results on image quality may not be identical for other diagnostic tasks.

However, when the MG was divided according to number, duration and complexity of the movements, significantly lower image quality was seen in patients moving more than two times during the examination, with an accumulated duration of movements more than 5 s, or performing complex, multiplanar movements. This may be logical from a technical perspective. The more the originally acquired images of a volume are “out of normality”, the more the reconstructed image will present artefacts. One may speculate that a large number of isolated movements and a long duration of movements will substantially interfere in the image reconstruction process. The same can be stated about the existence of multiplanar movements, which will also lead to changes in the originally acquired sections, and

Table 3 Distribution of images from the known movement group (MG) according to the lower/higher image quality (IQ) score (considering 29 matched-pairs) in relation to number of movements in the examination, accumulated duration of movements, complexity of movements and the largest movement distance as determined by the consensus observer

Reference standard MG	Number of movements		Duration (s)		Complexity		Largest movement distance (mm)		
	≤2	≥3	≤5	≥6	Uniplanar	Multiplanar	≤2	≥3 ≤ 10	>10
Lower IQ	6	12	7	11	10	8	3	11	4
Higher IQ	8	3	9	2	10	1	2	8	1
p -value (χ^2 test)	0.039		0.024		0.046		0.659		

this will not be easily overcome by the algorithms used by the unit to reconstruct the images.

It may be tempting to speculate that if a difference in image quality among moving and non-moving patients cannot be observed; when subjectively evaluated, there will hardly be a diagnostically significant difference. The results may thus imply that small patient movements may not be considered harmful to diagnosis. If the operator is aware of precise characteristics of patient movement, which would jeopardize diagnostic image quality, thresholds may be defined for when an examination should be terminated and resumed. Even though our study suggests that such thresholds must exist, we believe that it would be premature to advise clinicians merely on the basis of the results from the present study.

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Therefore, further research in the form of accuracy studies facing pre-defined diagnostic tasks are necessary to elucidate in more detail the relationship between movement characteristics and diagnosis.

Conclusions

Axial CBCT images of young patients with no metal in the FOV, who moved during examination, did not always present lower quality than images originating from non-moving patients when blindly assessed. Image quality was, however, significantly lower when patient movement had occurred several times during the examination, had a long duration or was complex.