Low dose computed tomography of the wrist: really for everyone?

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Purpose

Fractures of the wrist and the carpal bones are very common traumas especially in young persons. Unfortunately, in this complex anatomic region fractures are sometimes missed or underestimated on plain film radiographs [1,2,3]. As insufficient treatment of wrist fractures can lead to persistent pain, instability, avascular necrosis or even disability [1,3,4], exact and comprehensive primary diagnostic and treatment is mandatory. Therefore, in a significant number of patients a complementary multidetector computed tomography (MDCT) examination is needed [4,5].

However, MDCT is an x-ray based imaging modality and associated with a significant radiation exposure [6,7]. Especially young patients with wrist trauma generate a conflict situation: on the one hand comprehensive diagnostic is mandatory to avoid insufficient therapy and persistent disability, on the other hand dose exposure must be kept to a minimum. It would be desirable to have MDCT-protocols that combine good image quality with a minimum dose exposure [8,9].

The dimension of radiation exposure in a MDCT scan is mainly correlated to tube current and voltage, pitch factor, collimation, scanned distance and tube rotation time. In turn, image quality is basically determined by spatial resolution, contrast and signal to noise ratio (image noise). All these factors are directly influenced by the scan parameters. Thus, if scan parameters are altered, image quality will be affected, too [10,11].

The primary objective of this multi-observer study was to evaluate, if in multidetector computed tomography (MDCT) of the wrist good image quality can be maintained while radiation dose is substantially reduced. In a second approach the degree of agreement within observer groups of similar training level and among groups with different training levels was investigated.

For this purpose we evaluated the effects of systematically altered scan-parameters (mAs, kV and pitch-factor) in an ex vivo setting and a comprehensive interobserver analysis.
Methods and Materials

Specimens

10 formalin fixed anatomic wrist specimens (from the anatomic institute of the Christian-Albrecht-University of Kiel, Germany; consent to posthumous scientific investigations was given).

Data acquisition

- 16-slice MDCT scanner (collimation 0.75 mm, rotation time 1 second, FOV 200 mm; automatic tube current modulation disabled)

- Tube current, voltage and pitch parameters were altered systematically, so all anatomic wrist specimens were scanned according to twelve resulting protocols, resulting into a total number of 240 MDCT datasets: tube current 100, 70 and 40 electronic mAs (i.e. effective mAs corrected for pitch), voltage 100 and 120 kV, pitch factor 0.9 and 1.5.

- The combination of 120 kV, 100 mAs and pitch 0.9 was designated as the standard reference protocol.

- CTDI\textsubscript{vol} (mGy) and DLP (mGy*cm) were automatically indicated for all CT-protocols by the scanner software. The effective dose (E, mSv) was calculated using a dedicated computer program.

Image reconstruction

- Primary image reconstruction: slice thickness 1 mm, reconstruction increment 0.5 mm, high-resolution kernel

- Secondary image reconstruction: pre-defined MPRs were consistently reconstructed in two axial, one coronal and one (para-)sagittal plane (Fig. 1a-d). 4 reformations of all 240 CT datasets resulted into a total number of 960 images.

Image evaluation

- All 480 images were evaluated by 3 observer groups (3 observers each) of different training levels (2-3 years, 5-6 years and 8-10 years radiologic training) evaluated image quality in a blinded and randomized scheme.
A prototype of an individually customized computer program was installed on a standard workstation and allowed for a randomized and blinded display of all images. In the center and lower part of the graphical user interface (GUI) the reconstructed images were presented in a DICOM format (Fig. 2). A bar to select the quality score (1-4) for each category was placed in the upper part of the GUI: anatomical details of corticalis, spongiosa, articular surfaces and soft tissue could be judged. The observers had to evaluate all categories according to a four-point scale (1=excellent, 2=good, 3=sufficient, 4=poor). A standard bone-window (center 400 HE, width 1500 HE) was used. The window settings and zoom could be adjusted at any time during the evaluation.

Data evaluation

- For descriptive statistics the score proportions of the four-point scale (1 to 4) in percent for all specimens of each category (corticalis, spongiosa, articular surface and soft tissue) were calculated. To identify the CT protocols that were eligible for clinical use the relative proportion of images scored 3 or better was given in percent for all settings. The proportion of scores #3 achieved within the standard reference protocol was the internal standard of sufficient image quality. To allow for an easier comparability of different protocols, the lowest proportions with a score of # 3 including only bone structures (i.e. corticalis, spongiosa and articular surface, MinBoneScore) were considered.

- The level of concordance was calculated for every observer-group regarding again the group specific agreement for score results of # 3 (MinBoneScore).
Fig. 0: Examples of the reconstructed planes (1 mm slice thickness): a) axial I (distal radioulnar articulation) b) axial II (scapholunar joint) c) coronal (radiocarpal articulation as center) d) (para-) sagittal image (radio-scaphoid joint).

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**Fig. 0:** Screenshot of the graphical user interface (GUI) of the individually customized computer program. This program allowed for a randomized and blinded display of all images. In the center and lower part of the GUI the reconstructed images were presented in a DICOM format. In the upper quarter of the GUI a bar to select the score (1-4) for each quality category was placed: corticalis, spongiosa, articular surfaces and soft tissue. The window settings and zoom could be adjusted at any time during the evaluation.

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Results

- For 480 images all categories were evaluated according to the four-point scale with the dedicated software (fig. 1). The primary results (stratified for protocols, categories and observer groups) are shown in table 1. The list of lowest proportions scored # 3 (extracted from table 1) for bone structures (MinBoneScore) can be found in table 2. Different CTDI\textsubscript{vol}, DLP’s and effective doses are listed in table 3.

- A voltage of 120 kV combined with a pitch of 0.9 and tube currents of 70 and 100 mAs showed the best results (MinBoneScore # 3: 98,1%), while the combination of 40 mAs, 100 kV and a pitch factor of 1.5 was associated with the poorest scoring results (95,8%) (tables 1 and 2). Two protocols achieved a good trade-off between good score results and dose reduction: pitch 0.9, 100kV, 70 mAs (MinBoneScore 98,6%, 0,08 mSv) and pitch 1.5, 100kV, 100mAs (MinBoneScore 98,1%, 0,08 mSv).

Table 1: Proportion of scoring results of 3 or better, stratified for CT-protocols (pitch, kV and mAs), anatomic categories (corticalis, articular surface, spongiosa and soft tissue) and observer groups (3-4years (y), 5-6y and 8-10y). The results of the standard reference protocoll are marked with a grey overlay.

<table>
<thead>
<tr>
<th>Scan parameters</th>
<th>Score #3 (%)</th>
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<td></td>
<td>Corticalis</td>
<td>Articular surface</td>
<td>Spongiosa</td>
<td>Soft tissue</td>
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<td>pitch kV mAs</td>
<td>3-4y 5-6y 8-10y</td>
<td>3-4y 5-6y 8-10y</td>
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Table 2: Poorest proportion with a scoring result of 3 or better derived from table 1, stratified for CT-protocols (pitch, kV and mAs). Only the results for bone structures (corticalis, articular surface, spongiosa (MinBoneScore)) were considered.

<table>
<thead>
<tr>
<th>Scan parameters</th>
<th>Score #3 for bone structures (%)</th>
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<tbody>
<tr>
<td>Pitch</td>
<td>kV</td>
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<tr>
<td>0.9</td>
<td>100</td>
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<td></td>
<td>70</td>
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<td>100</td>
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<td>120</td>
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<td>70</td>
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</table>

Table 3: Computed tomography dose index (CTDI\textsubscript{vol}/mGy), dose-length product (DLP/mGy*cm) and effective dose (E/mSv) at a scan length of 100 mm and various adjustments of pitch, voltage (kV) and tube current (mAs).

<table>
<thead>
<tr>
<th>Pitch</th>
<th>Voltage/kV</th>
<th>Tube current/mAs</th>
<th>CTDI\textsubscript{vol} /mGy</th>
<th>DLP /mGy*cm</th>
<th>E /mSv</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.9</td>
<td>100</td>
<td>40</td>
<td>2.2</td>
<td>36</td>
<td>0.05</td>
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<td></td>
<td></td>
<td>70</td>
<td>3.9</td>
<td>63</td>
<td>0.08</td>
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</tbody>
</table>
In three (corticalis, spongiosa and articular surface) of four categories the group with 5-6 years of professional training achieved the best or maximum degree of concordance (table 4). The group with 8-10 of training could achieve the best agreement in the category "soft tissue" and also the maximum agreement for the category "articul ar surface". The group with 2-3 years of professional experience could not achieve the best or maximum concordance in any category.

Table 4: Concordance for image quality score #3 for bone structures (MinBoneScore, %; mean and standard deviation (SD)) stratified for observer groups (3-4years (y), 5-6y and 8-10y).
Fig. 0: Coronal slices of the same wrist specimen to illustrate image quality of different parameter settings: A) 120 kV, 100 mAs, pitch 0.9 a) 100 kV, 100 mAs, pitch 0.9 B) 120 kV, 100 mAs, pitch 0.9 b) 120 kV, 70 mAs, pitch 0.9 C) 120 kV, 70 mAs, pitch 0.9 c) 120 kV, 40 mAs, pitch 0.9 D) 120 kV, 100 mAs, pitch 0.9 d) 120 kV, 100 mAs, pitch 1.5

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Conclusion

Primary objective

In the presented study two protocols could be identified that allowed for a good trade off between dose reduction and acceptance by observers of all training levels.

The combinations of 100 kV, 70 electronic mAs and a pitch 0.9 and 100kV, 100mAs and pitch 1.5 achieved an image quality that equals that of the standard reference protocol (120 kV, 100 mAs, pitch 0.9). As a pitch of 0.9 potentially allows for a better spatial resolution the authors prefer the protocol with pitch 0.9, 70 mAs and 100 kV.

Compared to the standard reference protocol this radiation exposure represents a reduction of approximately 55 %. For both low dose protocols the corresponding effective dose for the carpal region is 0.08 mSv. For comparison: the effective dose of a standard digital radiographic examination of the wrist is 0.01 mSv and if special radiographs are necessary it potentially increases to 0.02 - 0.03 mSv. This illustrates that skeletal low dose MDCT almost approaches the dose level of radiography.

To the best of the authors` knowledge only one comparable study can be found in the literature. Bonel et al. [12] examined 30 anatomic wrist specimens with a MDCT and different parameter settings for collimation, rotation time, pitch factor, voltage and tube current. All images were reconstructed in axial and coronal planes with an increment of 60 % and a high-resolution kernel. Images were viewed by three observers blinded and in random order. The evaluation focused on gross anatomic delineation and fine anatomic detail. Bonel et al. concluded that wrist anatomy was best presented with a collimation of 0.5 mm and a reconstructed slice thickness 1.0 mm. A pitch of 1.5 and a rotation time of ³0.75 sec offered the optimal trade-off between radiation exposure and image quality. The authors recommended a voltage of 80 kV and a tube current of 100mA as this allowed for a distinct reduction in radiation dosage and a simultaneous slight improvement in bone contrast, because lowering tube voltage increased the attenuation effect of bone tissue. The associated CTDI\textsubscript{w} was 4.8 mGy. The peculiar effect of voltage reduction on image quality and dose could be confirmed in the presented study. Bonel et al. preferred a pitch of 1.5 to smaller pitch factors. In the presented study all protocols using a pitch of 0.9 achieved a better image quality than protocols with a pitch of 1.5. Consecutively, the protocol with the best trade-off between dose and image quality had a pitch factor of 0.9 but in combination with 70 mAs and 100 kV. The resulting CTDI\textsubscript{w} was 3.5 mGy (CTDI\textsubscript{vol} 3.9 mGy). Thus, an even further dose reduction of 27 % was possible.

Secondary objective:
The group with 5-6 years of professional experience achieved the best concordance followed closely by the group with the longest professional training. The group with the poorest training level showed the lowest concordance in all categories.

The authors could not find a comparable result in the literature. As the difference between the groups of 5-6 and 8-10 years are very small it can be assumed that this can be caused by a statistical problem like a small sample size. Though it can be concluded that from a certain degree of training onwards concordance can not be further improved.

Study limitations:

- This study is an ex vivo approach without traumatic lesions like fractures or dislocations. All findings can only be carefully transferred to the clinical situation.

- All scans were performed with optimally positioned specimens. In the clinical situation ideal positioning of fractured extremities can be difficult or impossible.

- All scans were performed with one MDCT, one reconstruction protocol and kernel. Image impression can depend on scanner type and reconstruction algorithms. Thus the presented data should be carefully transferred to different scanner systems.

- This study did not evaluate any postprocessing to improve image quality [10,13]. If for example the image quality of the discarded MDCT protocols could be further improved, effective doses of 0.05 to 0.03 mSv were achievable.

- The applied mAs are electronic mAs and not effective mAs (effective mAs = electronic mAs / pitch, or rather electronic mAs = pitch * effective mAs). Following this, an increase of the pitch factor will also increase the tube current, resulting into a constant dose and image noise. Nevertheless, an increased pitch factor can be expected to impair spatial resolution along the z-axis. MDCT manufacturers also use mAs in different ways (e.g. effective mAs, mAs or mA). Therefore, the recommended 70 electronic mAs at a pitch of 0.9 (i.e. 78 effective mAs) should not be applied to a MDCT-scanner without previous consideration of the individual scanner settings. Furthermore, in this investigation the automatic tube curent modulation was disabled.

The authors conclude:

- The presented study identified a MDCT scan protocol (pitch 0.9, 70 mAs and 100 kV) that allows for good diagnostic image quality of the wrist and a concurrent significant dose reduction of 55 % compared to a standard CT protocol.

- Using a broadly accepted MDCT protocol radiation dose could be considerably reduced without eminent loss of image quality.

- Concordance did not increase with higher training levels.
References

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