

Comparison of Calculated Skin Doses in Cineradiography and Four Dimensional Kinematic Computed Tomography of the Wrist

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Abstract

Background: Previous studies have discussed the diagnostic value of four dimensional kinematic CT in cases of carpal instabilities. This analysis compares calculated skin doses of 4D CT and conventional cineradiography of the wrist in cases of suspected SLL rupture.

Methods: Retrospective calculation and interpolation of skin doses and effective doses for ten consecutive 4D CT examinations and 41 cineradiographies for suspected lesions of the scapholunate ligament. Standardised anterior-posterior and lateral cine sequences using a flat-panel digital subtraction imager and of 4D kinematic CT using a dual-source scanner were acquired and acquisition parameters recorded. We tested if the skin dose of 4D CT is different from cineradiography.

Results: Median dose area product (DAP) of cineradiography was 135.34 cGycm² resulting in a calculated median skin dose of 32.6 mSv (confidence interval 26.86-42.90 mSv) and an estimated effective skin dose of 3.26 µSv. CT dose index (CTDI) for 4D examinations was recorded to be 26.79 mGy and the dose-length product (DLP) was 150 mGy*cm. This resulted in an estimated skin dose of 34 mSv, which is covered by the confidence interval of cineradiography, and an effective skin dose of 3.4 µSv.

Conclusions: Skin dose calculations are comparable for 2D cineradiography in two plains and 4D kinematic CT of the wrist. Calculated effective doses are <0.01 mSv.

Background

Precise carpal kinematics require complex interactions of multiple bony and ligamentous structures [1]. Injuries of the carpal ligaments are common causes for wrist pain and can lead to arthrosis and invalidity if treatment is delayed [2]. Tears of the scapholunate ligament (SLL) are the most common cause of carpal instability [3]. Efforts to detect these injuries at an early stage and to avoid unnecessary arthroscopy have led to various radiological approaches. Conventional radiography solely detects static forms of SLL injuries and therefore has a sensitivity of only 57% for injuries of the SLL [4]. To visualize the SLL directly and improve detection rates, MRI and MR arthrography were implemented with an increased sensitivity of 56–100% [5, 6]. Dynamic approaches aim to illustrate carpal arrangements in motion and detect insufficient stabilization of the joints. As one of these methods, cineradiography has been widely used to analyse carpal kinematics [7]. Sensitivity of 86% and specificity of 95% are high and interobserver reliability is excellent [4]. Nevertheless, cineradiography is time-consuming and requires highly specialised equipment [7]. Cine MRI combines the advantages of dynamic imaging, high soft-tissue contrast, and a radiation free technique [8]. Its biggest disadvantages, susceptibility for artefacts, long acquisition times, and thus a reduced cost-effectiveness, have prevented this method from gaining popularity in clinical routine. Development of super-fast dual source CT scanners created another method of dynamic imaging paired with three-dimensional evaluation. Image quality of 4-dimensional computed tomography (4D) CT of the wrist is excellent [9, 10] and recent studies have shown an excellent interobserver reliability for analysis of wrist kinematics [11]. While modern CT-scanners are expected to be

installed successively, this quick and feasible method might be a reliable tool in hospitals and health care centres. As radiation-based technique, 4D CT yet has to prove its precision whilst undercutting reference levels for diagnostic radiology.

This retrospective study aims to compare calculated skin doses of cineradiography and 4D CT of the wrist in cases of suspected SLL rupture in-vivo.

Methods

Physical parameters of 41 consecutively acquired cineradiographies between 02/2008 and 04/2011 and ten 4D CTs of the wrist acquired between 08/2018 and 02/2020 for suspected carpal instability were included. Retrospective calculations were carried out by one medical physicist and one radiologist. No personal information was stored, analyzed, or processed. Individuals were equipped with lead gowns and thyroid protection. The local institutional ethics committee of the University of Greifswald approved the study (BB 032/20) and stated that there are no ethical or legal concerns regarding this study. The decision was based on the Helsinki declaration. The need for consent for the retrospective use of examination and dosage data was waived by the institutional committee. Written consent was obtained for the presentation of imaging data.

Cineradiography

Cine sequences were obtained in sitting position [Figure 1] by one radiologist using a flat-panel digital subtraction angiography imager (Allura XPER FD 20/20, Philips Medical Systems, Germany). In standard anterior-posterior (ap) projection, one cycle of maximum radial and ulnar deviation was acquired. Lateral projections documented one cycle of maximum dorsal extension and palmar flexion. Maximum magnification and collimation were used and the central ray was aimed at the SLL. The field of view for ap and lateral projections extended just proximally of the distal radio-ulnar joint to the proximal part of the metacarpals [Figure 2]. An additional movie file gives an example of cineradiography [see Additional file 1]. Acquisition parameters are shown in Table 1.

Table 1
Parameters of cineradiography.

Tube voltage (kV)	75
Tube current (mAs)	2
Number of projections	2
Magnification	15
Image Acquisition Rate	7/second
Source image distance (SID, cm)	90
Flat detector (FD, cm)	15
Filtration	2.5 mm aluminum

4-Dimensional CT

Images were acquired using a 2×192 row detector dual-source scanner (Somatom Force, Siemens, Germany) with standardised acquisition parameters [Table 2]. One cycle of 8 seconds documented one smooth radioulnar deviation cycle without table movement in prone position [Figure 3]. Postprocessing and reconstruction were performed with a designated workstation (Syngo.Via Version VB10B-VB30A, Siemens, Germany) [Figure 4]. An additional movie file gives an example of reconstructed 4D CT [see Additional file 2].

Table 2
Parameters of 4D CT.

Tube voltage (kV)	80
Milliamperage (mAs)	70
Section thickness (mm)	1
Length (mm)	56
Number of slices	1254
Collimation	384×1 mm
Reconstruction matrix	Soft-tissue and bone kernel
Image reconstruction	512×512

Calculations and Statistics

For cineradiography dose area product (DAP), areas of ap (A_{AP}) and lateral (A_{LP}) projections were analysed. A mean area (A_{mean}) was calculated for each examination. Skin doses (SD) were estimated

using a backscatter correction factor of 1.4 for a 15 cm flat panel detector and 2.5 mm aluminum filter in a simplified formula:

$$SD \text{ (mSv)} = DAP / A_{\text{mean}} * 1.4 * 10$$

Estimations of effective doses were based on the tissue weighting factor of the skin of 0.01 [12]. The skin of the hand constitutes for only 1% of the body surface [13], therefore the conversion factor was adapted to 0.0001.

The CT Dose-Index (CTDI) was documented by the scanner and used to determine skin doses. Skin doses were estimated by a software program "CT Expo V2.5" [14].

Skin doses were expressed as absolute values which were tested for normality. As the distribution of skin dose values for cineradiography appeared skewed and non-Gaussian, we decided on the sign-test to estimate the median and calculated the 95%-confidence interval for the median.

Results

Table 3 presents the parameters of each cineradiography exam. Median DAP was 135.34 cGycm² and median areas of ap and lateral projection were 59 cm². These parameters resulted in a median skin dose of 32.6 mSv with a confidence interval of 26.86–42.90 mSv (range 13.3–60.7 mSv). Effective skin dose was calculated to be 3.26 μSv.

Table 3
Dataset cineradiography.

DAP (cGycm ²)	A _{mean} (cm ²)	SD (mSv)
107.9	75.8	19.9
47.6	50	13.3
86.3	50	24.2
170.5	76.4	31.2
92.2	38	34.0
289.4	66.8	60.7
162.8	60.9	37.5
197.4	68.1	40.6
168	57.2	41.1
81.7	53.6	21.4
97.8	52.6	26.0
64.5	66.7	13.5
148.8	66.0	31.6
169.1	55.2	42.9
189.4	59.6	44.5
243.7	69.2	49.3
101.6	52.5	27.1
169.1	65.1	36.4
165.5	52.2	44.4
244.0	55.2	61.9
40.8	64.0	8.9
95.4	58.0	23.0
381.9	51.5	103.8
37.0	51.6	10.0
147.0	59.9	34.4
96.2	61.4	21.9

	DAP (cGy cm^2)	A _{mean} (cm 2)	SD (mSv)
	105.2	77.8	18.9
	197.9	57.6	48.1
	58.0	49.9	16.3
	71.1	51.4	19.4
	366.9	71.5	71.8
	330.9	82.5	56.2
	245.9	77.8	44.3
	271.4	65.9	57.7
	129.8	47.0	38.7
	336.0	55.6	84.6
	247.1	57.6	60.1
	131.7	45.4	40.6
	107.3	41.5	36.2
	108.8	56.7	26.9
	114.7	53.2	30.2
Median	135.4	59.0	32.6

CTDI for 4D CT examinations of the wrist according to the standardised protocol [Table 2] was 26.79 mGy for each examination and the dose-length product (DLP) was 150 mGy*cm. The estimated skin dose of 4D CT was 34 mSv. The calculated effective skin dose was 3.4 μ Sv.

The confidence interval for the median skin dose for cineradiography covers the value 34 mSv for 4D CT. The hypothesis that the median skin dose of cineradiography is equal to the skin dose of 4D CT is not rejected.

Discussion

This retrospective analysis of estimated skin doses of cineradiography and 4D CT showed comparable values of 32.6 mSv (median) for cineradiography and 34 mSv for 4D CT of the wrist in vivo. Standardised imaging couldn't prevent considerable fluctuation in skin doses ranging between 13.3 and 60.7 mSv. The main reasons for this variance were the individual duration of radioulnar and palmo-dorsal motion cycles which were influenced by the speed of the performance and possibly the sample size. In contrast, calculated skin dose values of 4D CT were constant due to a fixed examination protocol.

Calculations of effective doses for imaging of the extremities are controversial and somewhat hypothetical because references and conversion factors are tailored for radiation sensitive organs [12]. The threshold for acute stochastic skin damage has been reported to lie around 2 Gy [15] and thus almost 60x higher than the skin doses of cineradiography (3.26 μ Sv) and 4D CT (3.4 μ Sv) in this study. Nevertheless, concerns about deterministic cells damages by low-dose examinations arise recurrently [16].

In addition, comparison of literature about radiation doses is often imprecise because acquisition protocols and physical approaches can differ significantly which can lead to mathematical uncertainties of up +/- 10–15% for CTDI and 20–40% for effective doses [14, 17]. To date literature about skin doses for cineradiography of the wrist is lacking even though reports about this technique date back to 1966 [18]. In-vivo studies about 4D CT of the wrist calculated effective doses close to zero (0.013–0.26 mSv) [11, 19] and skin doses during 4D CT examinations of cadaveric wrists with 33 mGy [9]. The skin doses in these studies differ from our calculations due to different CT protocols and CT scanners whereas skin doses are comparable to our calculations. However, all studies confirmed that 4D CT applies minimal radiation doses to the skin. Other possible advantages of 4D CT could include the availability of modern dual source CT-scanners in comparison to fluoroscopy especially in the out-patient setting [20]. As opposed to 2D fluoroscopy, secondary 3D reconstructions of the carpus after 4D CT might also increase sensitivity for complex pathologies and improve surgical approaches [19]. Future prospective studies should investigate the diagnostic accuracy of 4D CT for carpal injuries and compare it to the performance of cineradiography, MRI, arthrographic techniques, and arthroscopy.

Conclusion

Skin dose calculations are comparable for 2D cineradiography in two plains and 4D kinematic CT of the wrist (32.6 mSv vs. 34 mSv). Effective doses range between < 0.01 and 0.26 mSv. Acquisition of 4D CT data might improve standardized diagnostics in in- and out-patient settings and enhance our understanding for carpal pathologies through kinematic and three dimensional reconstructions.

Abbreviations

DAP	Dose area product
CTDI	computed tomography dose index
SLL	scapholunate ligament
4D CT	4-dimensional computed tomography
ap	anterior-posterior
SID	source image distance

FD	flat detector
A _{AP}	area of anterior-posterior projection
A _{LP}	area of lateral projection
SD	skin dose

Declarations

Ethics approval and consent to participate: The local institutional ethics committee of the University of Greifswald approved the study (BB 032/20) and stated that there are no ethical or legal concerns regarding this study. The need for consent for the retrospective use of examination and dosage data was waived by the institutional committee.

Consent for publication: Written consent was obtained for the presentation of imaging data.

Availability of data and materials: The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests: All authors declare that they have no competing interests.

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Authors' contributions: LG: data interpretation, manuscript preparation. AA: image acquisition with patient's consent, proof-read manuscript. SK: ethics approval, proof-reading JD statistical analysis, proof-reading, AE: study planning and proofreading, SG: physical calculations and proofreading, SM: study planning and proofreading.

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Figures

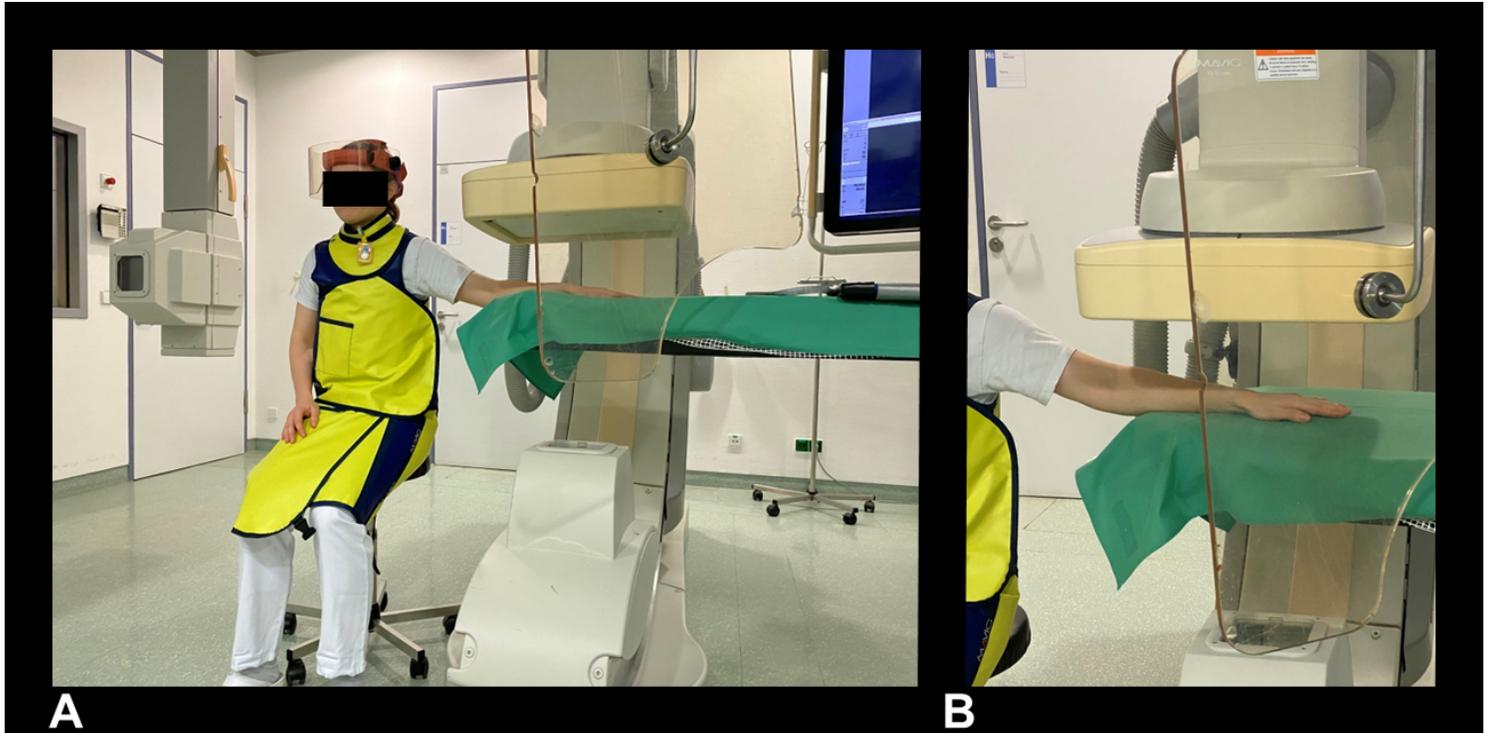


Figure 1

Acquisition of cineradiography. Typical sitting position of patients with radiation protection (A) and positioning of the wrist (B) during acquisition of cineradiography in ap projection.

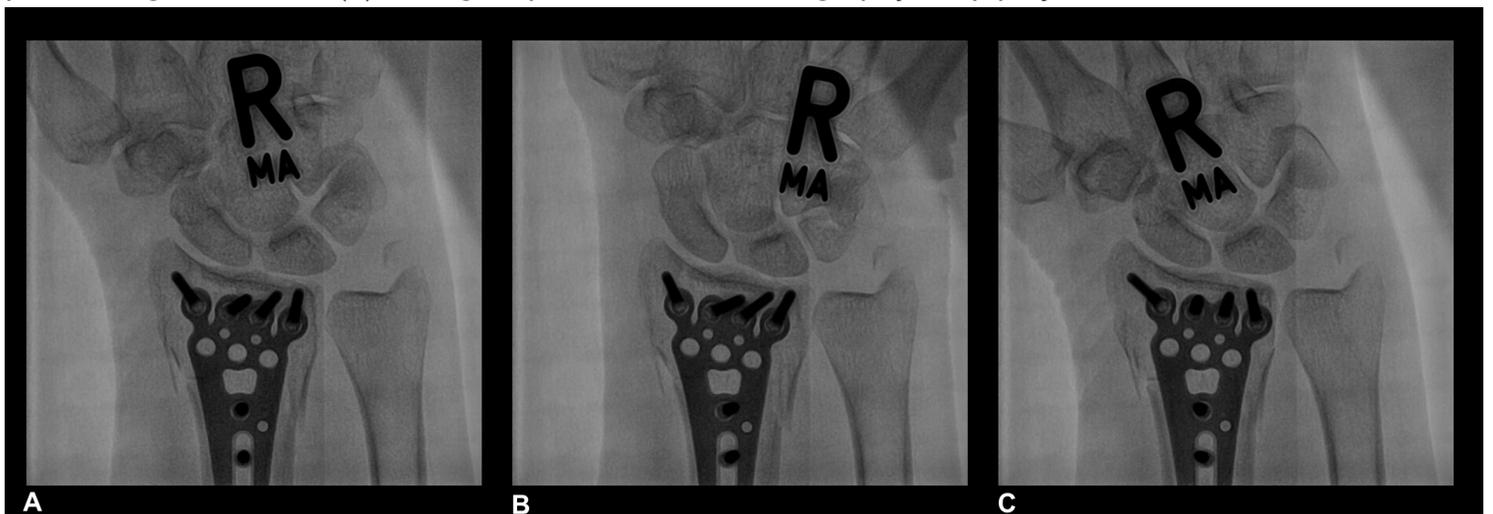


Figure 2

Cineradiography. Snapshots during cineradiography in ap projection of a right wrist in radialduction (A), neutral position (B), and ulnaradduction.

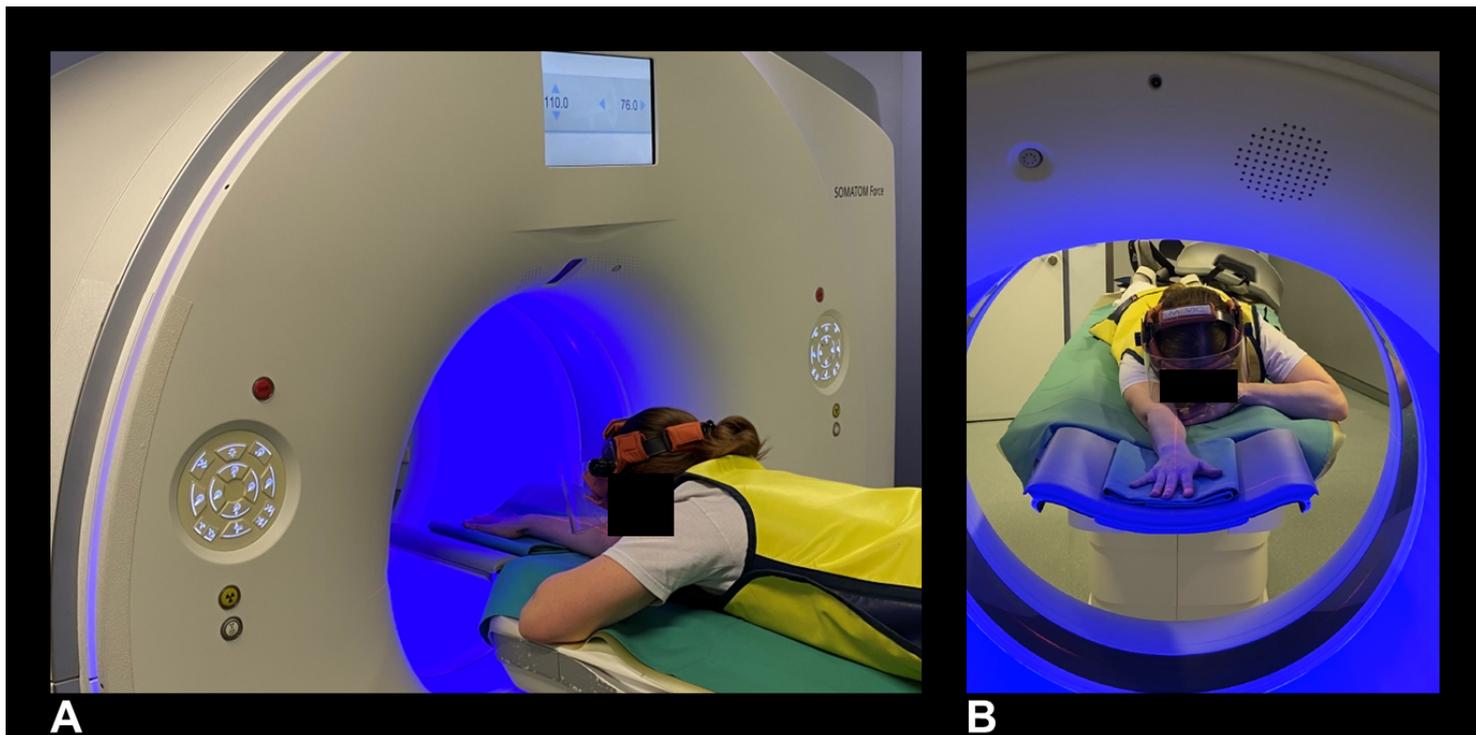


Figure 3

Acquisition of 4D CT. Acquisition of 4D CT in prone position in lateral (A) and cranial view (B).

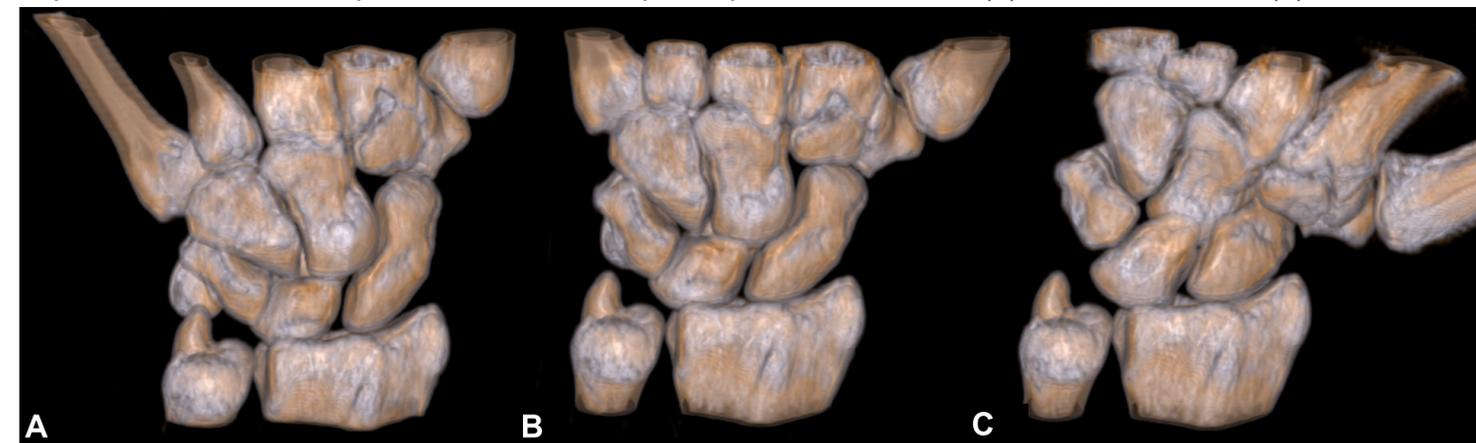


Figure 4

Reconstructed 4D CT. 3-dimensional reconstructions of a 4D CT of a left wrist in ulnar deviation (A), neutral position (B), and radial deviation (C).

Supplementary Files

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- 4DCT.avi