Comparison of applied radiation dose to the skull with MSCT, dental-CBCT, and 3D-C-arm devices

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Introduction: Two dimensional x-ray images are not suitable for intraoperative imagery of the complex anatomy of the skull and, in particular, the orbit because the projection of multiple bone structures limits clinical evaluation. The improvement of 3D-c-arm x-ray devices has made possible the implementation of this technology for intraoperative imaging. The generation of a series of x-ray images allows for multi-planar imaging in coronal, sagittal and axial planes. Several studies have shown that the use of intraoperative 3D-c-arm imaging can reduce morbidity during the operative treatment of mid-facial fractures, especially orbital fractures. Furthermore, postoperative imaging with MSCT-scan or dental-CBCT could be made obsolete. However, currently no studies are available that compare the applied x-ray dose of a 3D-c-arm device, a conventional MSCT, or a dental-CBCT. The aim of this study was to compare the equivalence dose of these three devices.

Method: 5 different x-ray devices have been compared (Fig. 1 A-E):

- **3-D-C-arm Ziehm® Vision Vario FD 3D (device 1 & 2)***
- **3-D-C-arm Siemens® Arcadis Orbic 3D**
- **MSCT Siemens® 64 slice Somatom definition**
- **CBCT Sirona® Gallileos**
- **3-D-C-arm Siemens® Siremobil Iso C 3D**

** 2 devices of 3-D-C-arm Ziehm® Vision Vario FD 3D were available – in total 6 devices were available to campare.*

To measure the applied organ dose to the head, multiple TLD-sensors (lithium-fluorid-thermoluminiscence-dosimeters) were attached to a phantom skull "Alderson Rando" (Fig. 1 F-I) in ten different anatomical regions:

- **eye lens (left and right)**
- **optical nerve (left and right)**
- **parotid gland (left and right)**
- **submandibular gland (left and right)**
- **hypophysis**
- **anterior mouth floor (medial)**

To compare the x-ray devices, each device made three scans. Each time the TLD-sensors were replaced. The scanned volume of all three c-arm devices was determined at 12x12x12cm. The scanned volume of the dental-CBCT was 15.4 x 15.4 x 15.4 cm, thus only marginally larger than that of the c-arm-devices. The volume of the MSCT was set at the volume of the 3D-c-arm devices in order to show the sinus frontalis, the orbitae, and the upper jaw. The parameters (KV and mA) of the x-ray devices were set to standard values used on a daily basis in order to mirror typical clinical conditions. After evaluation of the TLD-sensors, the equivalence doses were calculated to compare all measured devices.

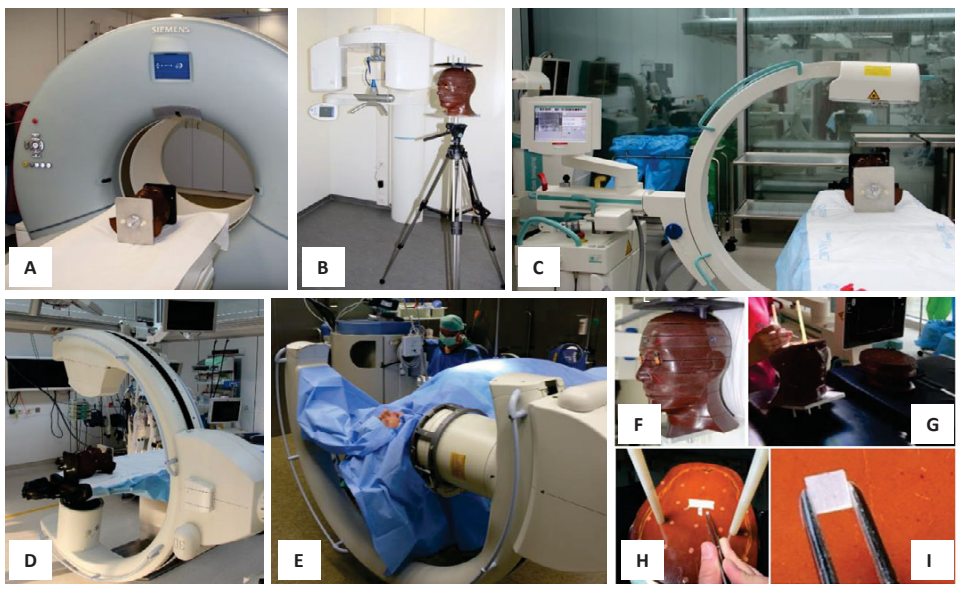

Fig. 1: (A) MSCT Siemens® 64 slice Somatom definition, (B) CBCT Sirona® Gallileos, (C) 3-D-C-arm Ziehm® Vision Vario FD 3D, (D) 3-D-C-arm Siemens® Arcadis Orbic 3D, (E) 3-D-C-arm Siemens® Siremobil Iso C 3D, (F+G) phantom-skull Alderson Rando with 10 horizontale planes, (H) singel plane with chambers in defined anatomical position to pick up TLD-sensor, (I) magnified TLD-sensor for dosimetry.

Results: The measured equivalence doses of all six devices regarding the median value of all measured regions are shown in table 1. The corresponding box plot to table 1 is shown in figure 2. The MSCT showed a 4.22 factor increase in equivalence dose compared to the dental-CBCT (Tab. 1). All 3D-c-arm devices showed comparable median equivalence doses. These equivalence doses were a factor of 3-4 times more decreased compared to the MSCT. The Ziehm® Vision Vario FD 3D as well as the Siemens® Siremobil Iso C 3D showed almost equal equivalence doses in comparison to dental-CBCT (Tab 1.). The Siemens® Arcadis Orbic 3D, however, showed the smallest amount of equivalence doses compared to all other devices. These equivalence doses were a factor of 10 times more decreased compared to Sirona® Galileos, 9 times more decreased compared to Ziehm® Vision Vario FD 3D, and a factor of 14 times more decreased compared to Siemens® Siremobil Iso C 3 D. Comparing the Siemens® Arcadis Orbic 3D with the MSCT even showed a 40 factor reduction of equivalence dose compared to the MSCT (Tab 1). The applied radiation dose with the MSCT was statistically highly significantly increased compared to all other devices. The comparison of the Siemens® Arcadis Orbic 3D with the other 3D-c-arm devices as well as the dental-CBCT showed a highly significant decrease in applied equivalence dose. No significant difference in applied equivalence doses could be found comparing the 3D-C-arms Ziehm® Vision Vario FD 3D, the Siemens® Siremobil Iso C 3D and the dental-CBCT (Tab.2).

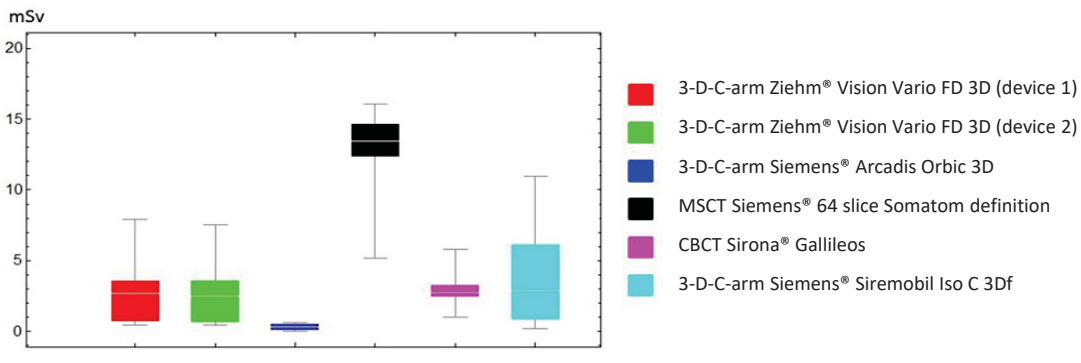

Fig. 2: box plot shows equivalence dose in mSv of the tested x-ray devices regarding the median of all regions of measurement.

in mSv	MSCT Siemens® 64 slice Somatom definition	CBCT Sirona® Gallileos	3-D-C-arm Ziehm® Vision Vario FD 3D (device 1)	3-D-C-arm Ziehm® Vision Vario FD 3D (device 2)	3-D-C-arm Siemens® Arcadis Orbic 3D	3-D-C-arm Siemens® Siremobil Iso C 3D
median	13,58	2,72	2,79	2,56	0,29	2,81
min.	4,35	0,95	0,38	0,40	0,01	0,18
max.	17,73	5,89	8,04	7,58	0,69	11,29

Tab. 1: equivalence doses in mSv of the tested x-ray devices regarding the median value of all measured regions.

The individual analysis of the measured doses in the various anatomical regions showed that the spectrum of the equivalence doses did not drastically differ in all six devices, whereas the spectrum of the MSCT proved to be the widest (Fig 3). The equivalence doses in the several measured anatomical regions, however, varied considerably. Measurements also varied depending on which device was used (Fig. 3 and Tab. 3). This is reflected in box plot shown in figure 2. The relation between the doses of several anatomical regions, however, remained constant in all devices. An exception was the applied dose to the eye lens using the Siemens® Siremobil Iso C 3D c-arm, which almost reached the measured doses of the MSCT.

p-value	MSCT Siemens® 64 slice Somatom definition	CBCT Sirona® Gallileos	3-D-C-arm Ziehm® Vision Vario FD 3D (device 1)	3-D-C-arm Ziehm® Vision Vario FD 3D (device 2)	3-D-C-arm Siemens® Arcadis Orbic 3D
MSCT Siemens® 64 slice Somatom definition					
CBCT Sirona® Gallileos	0.000**				
3-D-C-arm Ziehm® Vision Vario FD 3D (device 1)	0.000**	0.535			
3-D-C-arm Ziehm® Vision Vario FD 3D (device 2)	0.000**	0.478	0.784		
3-D-C-arm Siemens® Arcadis Orbic 3D	0.000**	0.000**	0.000**	0.000**	
3-D-C-arm Siemens® Siremobil Iso C 3D	0.000**	0.605	0.375	0.315	0.000**

Tab. 2: p-value (Mann-Whitney U test) for statistical analysis of the tested x-ray devices regarding the median of all measurement. Level of significance after Bonferroni correction (15 groups): p≤0.00333 significant, p≤0.000333 high-significant.

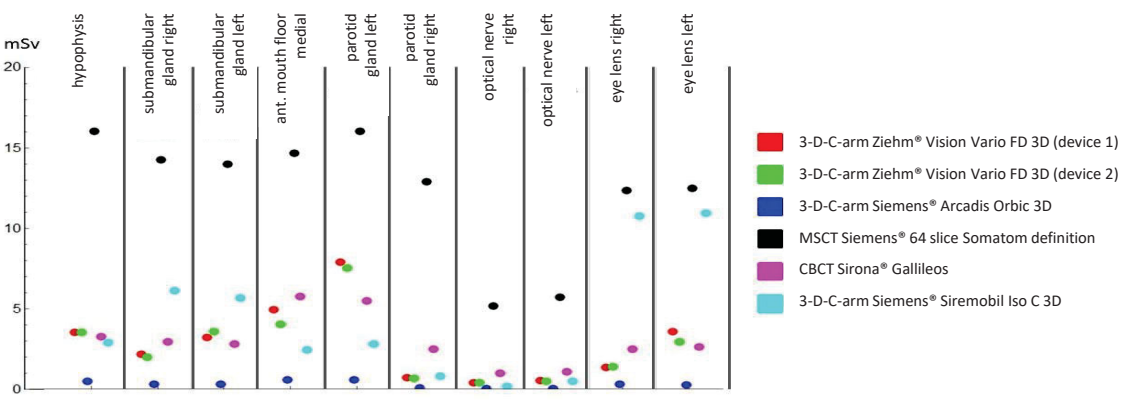

Fig. 3: equivalence doses for each anatomical region seperated for each x-ray device in mSv.

equivalence dose in mSv	hypophysis	optical nerve		parotid gland		ant. mouth floor medial	submandibular gland		eye lens	
		R	L	R	L		R	L	R	L
3-D-C-arm Ziehm® Vision Vario FD 3D (device 1)	3.55	2.10	3.17	5.05	7.93	0.75	0.45	0.57	1.37	3.65
3-D-C-arm Ziehm® Vision Vario FD 3D (device 2)	3.48	1.93	3.61	3.95	7.53	0.67	0.40	0.52	1.40	2.96
3-D-C-arm Siemens® Arcadis Orbic 3D	0.59	0.29	0.30	0.55	0.64	0.07	0.04	0.04	0.32	0.27
MSCT Siemens® 64 slice Somatom definition	16.16	14.13	13.45	14.26	16.22	12.61	4.60	5.53	12.06	12.08
CBCT Sirona® Gallileos	3.27	2.91	2.86	5.82	5.53	2.50	1.02	1.07	2.49	2.63
3-D-C-arm Siemens® Siremobil Iso C 3D	2.87	6.21	5.82	2.47	2.74	0.82	0.18	0.21	10.65	11.18

Tab. 3: median of the equivalence dose in mSv of all 6 x-ray devices regarding each meassurement region.

Discussion and Conclusion: Intraoperative x-ray imaging using 3D-c-arm devices can highly significantly reduce the equivalence dose of radiation compared to postoperative imaging using CT scanning. However, the applied single organ doses still depend on the x-ray device used. Thus, by using a 3D-c-arm device with very low applied radiation, like the Siemens® Arcadis Orbic 3D, the equivalence dose can be reduced to the level of a common dental-CBCT scan. This could be relevant regarding cumulative radiation exposure throughout a patient's lifetime.

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The authors disclose that they have no conflict of interest.