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Abstract

Background. Conversion of images from DICOM format to other image formats affects measuring distances in images.

Materials and methods. Distances in DICOM or JPEG images were measured with different zoom using 1.5T MRI scanning of human diaphragm during spontaneous breathing and during low and high lung volumes.

Results. Correlation between distance measurements in mm and pixels at all zoom factors on DICOM and JPEG images ranged from r=0.9981-1.00 and 95% CI for r of 0.9972 - 0.9986 to 1.00 - 1.00 and the p-value in all correlations was <0.001. Results of comparing the difference in measured dimensions on DICOM and JPEG images in mm for F1.0 indicate that differences in measurements are small (0.1 mm average). Image zooming in JPEG for F1.8 compared to the idealized pixel size values with that zoom on average increases the number of pixels for 1 (range from 5 pixels increase to 4 pixels loss).

Discussion. The values of linear regression equation for all zoom factors (F1.0 - F1.8) indicate that distance measurement on the zoomed JPEG image is not suitable for obtaining accurate results of distance measurements. The distance measurements in JPEG images without zoom are entirely in accordance with distance measurements in DICOM images. In the zoomed images distance measurements differ from the results of distance measurements in DICOM format and for the possible use of the results it is necessary to provide data on zoom factor, physical size of the pixel spacing and the values of the linear regression equation.

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1. Introduction

The image format most currently used in radiology is a DICOM image format. DICOM image is a part of the DICOM standard in accordance with Chapter 10 of the DICOM standard (Varma 2012). DICOM image differs from other image formats since the DICOM file consists of a header with data sets and an image packed into a single file. Header information is organized as a regular and standardized series of tags. By accessing the information, data on patient, device, imaging parameters, etc. become readily available. When DICOM images are transmitted over the Internet for educational and other purposes, it is necessary to remove all personal information that can be used to identify the patient.

Converting images from DICOM image format to other image formats is accompanied by data compression. DICOM viewer and systems for archiving and communication, PACS (Picture Archiving and Communication System) provide procedures for using image compression, such as lossless compression and lossy compression (Radiology 2011). Recommendations for use and usability of the converted files with lossy compression were published by the European Society of Radiology, British Institute of Radiology, the German Radiology Society and the Canadian Association of Radiologists (Koff et al. 2009; Loose et al. 2009; Radiology 2011; Royal College of Radiologists (RCR). Lossy compression may be acceptable in diagnostic radiology, if used in accordance with accepted guidelines (Radiology 2011). Users need to know the ways of irreversible compression such as JPEG and JPEG 2000, and their particular advantages and risks (Radiology 2011). For radiological images used for teaching and interesting cases one of the applications is The Radiology Interesting Case Server. For each case two conversions of DICOM images to JPEG images are carried out. The first conversion generates original JPEG image with established "window levels“ and “window

widths" as the "key image" from the study, while the second conversion allows real time changes of "window levels " and "window widths" (Kamauu et al. 2008).

In terms of image quality, image compression during conversion from DICOM image format to other image formats is acceptable in most areas of radiology on different devices. Conversion to JPEG image format allows different compression ratios (percentages) compared to the original DICOM image format. When converting DICOM image formats to JPEG image format with low compression ratio there is no significant difference in the quality of converted images for interpretation on CT scanner (Koff et al. 2013).

In digital mammography FFDM (Full Field Digital Mammography) loss of 60:1 is potentially eligible for primary interpretation and may depend on other factors such as radiation dose and the object thickness (Kang et al. 2011; Schreiter et al. 2011).

Although conversion and image compression to JPEG image format takes up relatively little visual degradation it is still unclear where irreversible image compression can be used in radiology workflow. As long as it is within the limits recommended by the German Radiology Society, irreversible image compression could be done on the device that generates radiological images (Pinto et al. 2013).

The quality of radiological imaging is based on good spatial and temporal resolution. In physiology that we recognize as a fundamental quantitative science, the imaging methods play an important role by providing possibilities to measure specific physiological parameters (Robertson & Buxton 2012).

The analysis of diaphragmatic movements during breathing without converting images from DICOM format to JPEG format with GRE (Fast Gradient Recalled Echo) sequence during MRI may be useful in studying normal and abnormal breathing mechanisms (Gierada et al. 1995). To measure diaphragmatic movement in Chronic Obstructive Pulmonary Disease patients via MRI

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with MR fluoroscopy a single point of measuring diaphragmatic movement was determined, which was presented as the study limitation (Ünal et al. 2000). Subtraction (overlapping) images obtained by dynamic imaging of diaphragmatic movement may be used for obtaining the differences in diaphragm movement and measuring the distance between the maximum cranial and caudal position of diaphragm (Batinic 2012.; Kolar et al. 2009; Kolar et al. 2010). Currently, there are limited data on the effects of irreversible compression in special images, such as 3D, measurements or CAD (Computer aided detection), so it is recommended to evaluate implementation of data compression prior to clinical application (Radiology 2011). One of the basic features of DICOM viewer is distance measurement on DICOM images, while measuring the distance on JPEG images is not used in everyday practice. Therefore, by measuring distance on DICOM and JPEG images different results/values are obtained. After conversion of images from DICOM format to JPEG format, the data from DICOM header are not transmitted, and distances in JPEG format are expressed in number of pixels on the line between two points which determine the distance you want to measure. Some of the DICOM viewers can import JPEG image format to DICOM viewer, but without data from the DICOM header the distances cannot be expressed in mm or cm, but only in pixels.

Measuring points, angle and distance in various image formats is used in dental radiography as well. Repeatability (reproducibility) of measurement and the impact of various factors of image compression in JPEG format is important for the daily use of non DICOM image format in dental radiography. Comparison of measurements with cephalometric software between the aggregated (compressed) JPEG images and DICOM images on the lateral teleroentgenograms showed the strong correlation on the distances measured on 12 to 13 measured points on the images of the same zoom (Duarte et al. 2014). Effect of image compression and conversion to TIFF and JPEG

image format on measurements in digital panoramic images can result in a statistically significant difference between the results of TIFF and JPEG image formats (Yasar et al. 2012).

For the purpose of visual interpretation and in particular from the point of precise distance measurement on the images in every day practice the experts need selective implementation of the converted images from DICOM image format to other image formats, such as JPEG. Zoomed images in other image formats question the validity of the measurements on these images for both diagnostic and research purposes.

2. Materials and methods

2.1. Ethics statement

All procedures have been approved by the Ethical Committee for medical research, University of Split, Medical School (Approval number: 003-08/11-03/0005, 2181-198-03-04/10-11-0045 from December 9th, 2001).

All research conducted for the study were performed according principles of Declaration of Helsinki. The Ethic committee approved all the procedures as well all the documentation in the research. All procedures and possible risks were in detail explained to every patient, as well as the possibility that in any time they can withdraw their consent for participating in research. All the examinees had to read and sign the informed consent for participating in this research.

2.2. Experimental

2.2.1. Study population and scanning characteristics

Images in DICOM format of matrix size 512 x 512 pixels, made by 1.5T MRI scanner (Avanto, Siemens Medical Solutions AG, Erlangen, Germany) in the supine position were used. The subject was trained free diver that was able to sustain very long apneas lasting for minutes either during rest (static apnea) or exercise (dynamic apnea). During maximal end inspiratory apnoea it is divided into two phases: an initial or easy going phase, where diver has no need for breathing and easily tolerates the absence of air, and the second part of apnoea, struggle phase, where diver resists the increasing urge to breathe (Dujic et al. 2013). During the second phase involuntary movements of major and auxiliary respiratory muscles occur, but without real inspiration. Such movements are called involuntary breathing movements (IBM). Slices were made continuously by dynamic scanning of the right hemidiaphragm during apnoea in each of three phases: total lung capacity (TLC) apnea, functional residual capacity (FRC) apnea and tidal breathing (TB) with dynamic high resolution gradient echo (GE) sequences. The diaphragm was scanned in the sagittal plane in the axial topogram, paravertebrally on the right side, midway between the centre of the vertebral body and the lateral thoracic wall. The thickness of recorded layer was 10 mm, the distance of each sequence was 20 seconds, and it consisted of 60 image slices. The sequences were recorded continuously during apnoea. Slices with minimum and maximum diaphragm position were selected from TLC and FRC apneas and TB. Total number of 14 slices were selected in DICOM format at the beginning, in the middle and at the end of the „struggle phase“, i.e., TLC and FRC apnoea and TB.

2.2.2. Analysis

Markers placed on subject’s body allowed setting up grid on the image (JPEG) and division of distance between markers M_0 and M_1 (DICOM). The measured distance M_0 i M_1 between the marker M_1 on the ventral side of the subject and M_0 on the dorsal side of the subject was divided

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into 12 equally distant sections whose distance (d) is identical at JPEG (Fig. 1) and DICOM (Fig. 2) images. Horizontal line connecting the lower edges of the markers M_0 and M_1 is the starting point of distance measuring and the starting point of G_0 grid (JPEG) (Fig. 1) and the beginning of the first division (DICOM) (Fig. 2) is on the right and bottom edge of the dorsal marker M_0. In this way, the measurement of the distance from the horizontal line (base line) to the diaphragm on the same sections is standardized regardless of the different distance between markers M_0 and M_1, which varies depending on the ventral dorsal movements of the chest during IBM.

The lines perpendicular to the horizontal line $\overline{M_0M_1}$ representing distances between the points $\overline{AA_1}$, $\overline{BB_1}$, $\overline{CC_1}$, $\overline{DD_1}$, $\overline{EE_1}$, $\overline{FF_1}$, $\overline{GG_1}$, $\overline{HH_1}$, $\overline{II_1}$ were drawn through points A-I (9 points) (Figs. 1 and 2). Above explained procedure was made on 14 images, resulting in 126 measurements points. Distance measurements were performed on images with zoom factor F 1.0 (100 %) in DICOM and JPEG formats and on images with zoom factors F 1.2 (120 %), F 1.4 (140 %), F 1.6 (160 %), and F 1.8 (180 %) in JPEG image file format. Measurements and conversion of image file formats (DICOM - JPEG - DICOM) were performed using software (DICOM viewer, Osirix v.3.9.4 Pixmeo, Geneva, Switzerland), and grid was set up on image by Photoshop CS6 software (Adobe Systems, San Jose, USA) and capture was done by Snapashot v.3.7 software (Nicekit). When converting images from DICOM file format to JPEG format, the information about pixel spacing in DICOM format is not transmitted to JPEG format. When a JPEG image (in this case with grid) is imported into DICOM viewer the distances are not obtained in mm but in pixels, which means that the change in the original number of pixels during conversion DICOM-JPEG-DICOM can affect the accuracy and reliability of measurement.

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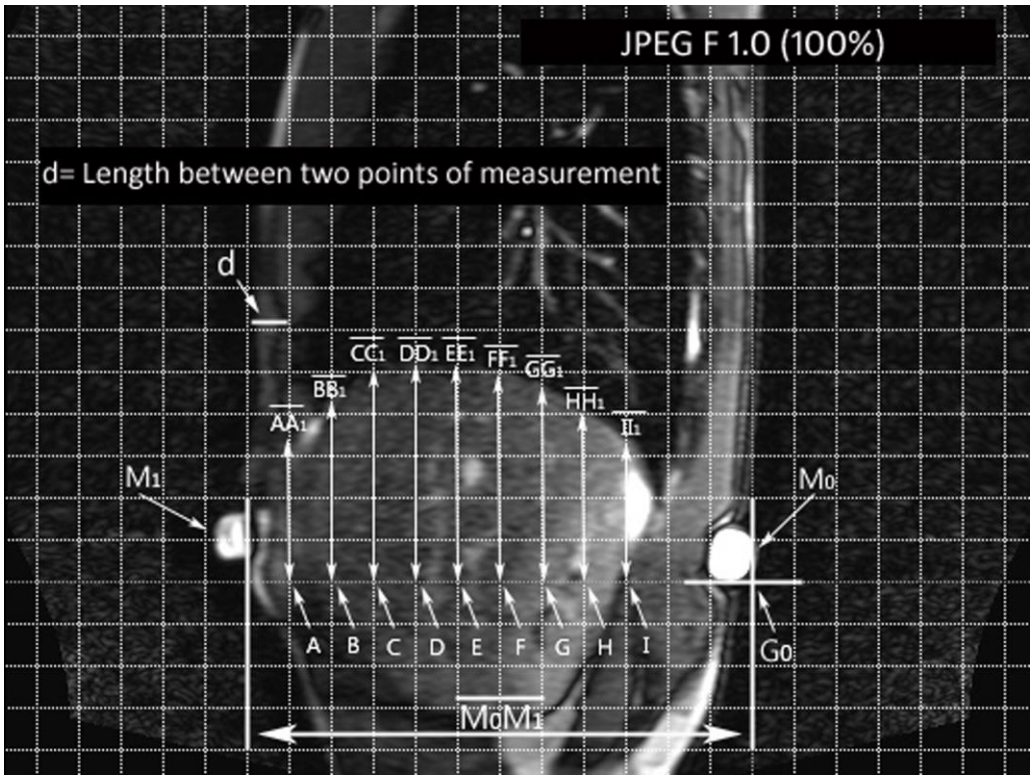

Fig. 1. Setting up the grid and determining the distance of the starting points for distance measuring on JPEG images.

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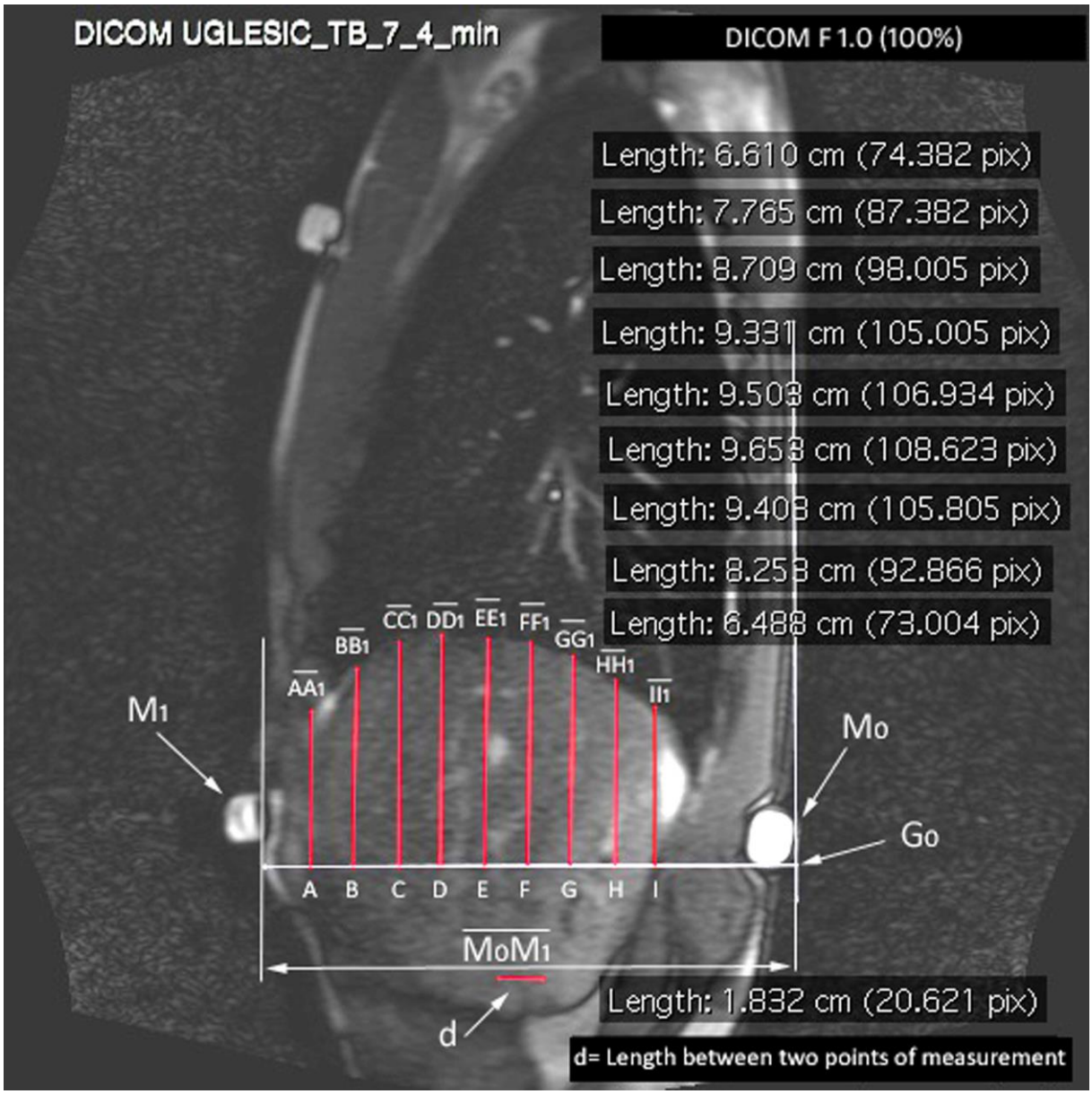

Fig. 2. Determining the distance of the starting points for distance measuring on DICOM images.

A method of obtaining distance measurement data in DICOM and JPEG image file formats is described in the flow diagram (Fig. 3.).

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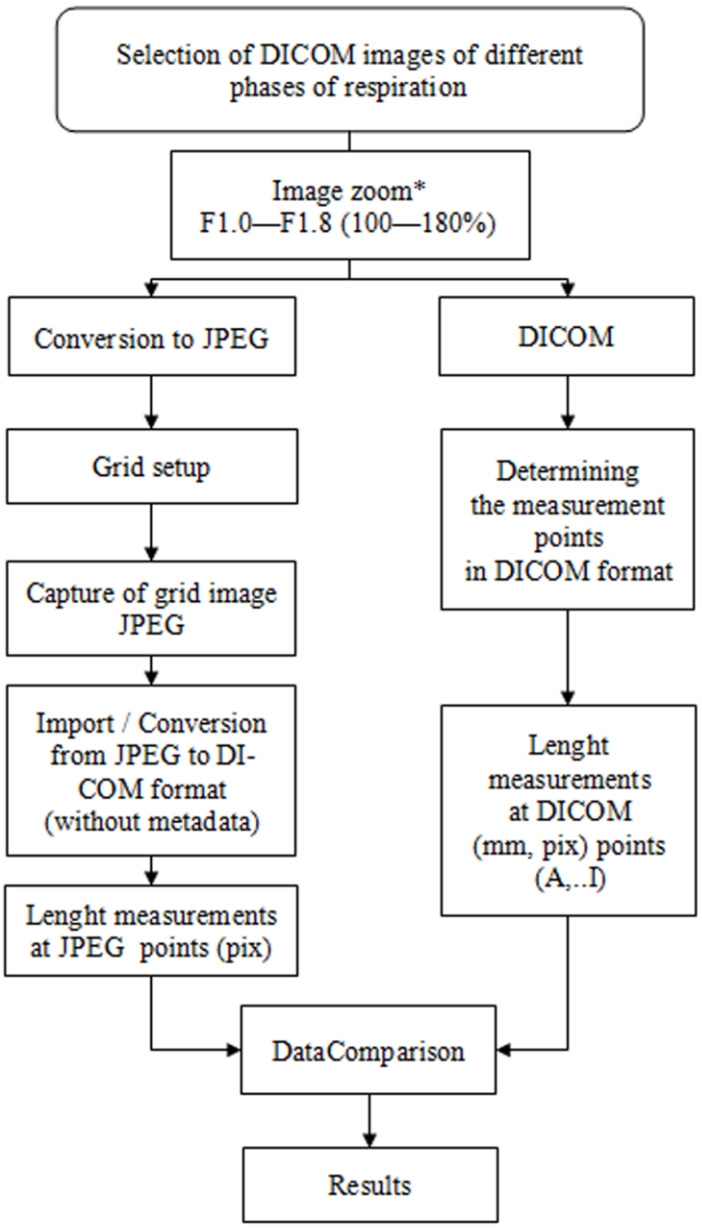

202

203 Fig. 3. Flowchart of conversion and image processing and obtaining measurement data for

204 analysis.

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206 2.2.3. Measuring distance on the images in DICOM image format

Measuring distance between two points on DICOM images is one of the basic functionalities of the DICOM viewer. On images in DICOM format the distance is obtained in millimetres and/or centimetres, and in number of pixels. Data on the physical pixel spacing is found in DICOM metadata under the tag (0028, 0030). Tag contains the information about pixel spacing which multiplied by the number of pixels gives the distance in mm or cm as shown in Fig. 2.

By changing the zoom factor the pixel size on the screen changes but the measured distance between two points in DICOM format does not change. Measurements in DICOM format were performed on the image matrix size of 512 x 512 pixels with a zoom factor of 1.0 (100%) that is a pixel on the monitor presents one pixel spacing on device. Results of distance measuring in DICOM image format are shown in Table 1.

Table 1

Results of distance measuring on images in DICOM format and in JPEG image file format with F1.0, F1.2, F1.4, F1.6, and F1.8 zooms in pixels and millimeters.

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	DICOM F1.0		JPEG F1.0		JPEG F1.2	JPEG F1.4	JPEG F1.6	JPEG F1.8		DICOM F1.0		JPEG F1.0		JPEG F1.2	JPEG F1.4	JPEG F1.6	JPEG F1.8
N	**mm**	**No. of pixels**	**mm**	**No. of pixels**	**No. of pixels**	**No. of pixels**	**No. of pixels**	**No. of pixels**	**N**	**mm**	**No. of pixels**	**mm**	**No. of pixels**	**No. of pixels**	**No. of pixels**	**No. of pixels**	**No. of pixels**
1	66.860	75.231	65.166	73.330	90.960	104.000	119.186	132.799	**64**	87.240	98.173	87.755	98.748	116.702	138.801	158.003	181.725
2	69.960	78.725	68.254	76.804	91.891	112.000	128.172	142.784	**65**	103.670	116.659	103.745	116.742	139.060	160.368	184.000	202.693
3	75.980	85.500	78.200	87.997	107.076	127.004	144.152	160.756	**66**	122.200	137.507	122.077	137.370	165.453	192.000	221.002	247.625
4	79.530	89.496	76.485	86.067	106.802	126.000	142.155	160.756	**67**	132.070	148.614	132.218	148.782	179.895	207.000	238.002	267.595
5	80.220	90.271	78.646	88.498	108.666	125.000	143.153	162.756	**68**	138.380	155.715	138.069	155.365	187.286	219.528	252.000	278.578
6	75.700	85.181	75.798	85.294	101.211	118.000	136.163	153.767	**69**	141.780	159.538	141.968	159.753	190.772	224.668	257.000	288.563
7	66.560	74.897	65.852	74.102	90.302	105.000	120.184	135.794	**70**	139.030	156.441	140.407	157.997	188.780	220.555	252.002	281.573
8	58.980	66.364	57.278	64.453	73.529	91.000	102.211	118.824	**71**	134.200	151.014	134.557	151.414	181.310	213.328	244.000	271.590
9	40.870	45.990	38.310	43.109	50.236	66.000	76.251	82.874	**72**	127.320	143.275	127.537	143.514	172.845	203.587	232.002	258.608
10	62.690	70.547	62.694	70.548	83.680	105.000	122.183	142.784	**73**	87.280	98.215	87.092	98.002	115.120	134.990	156.003	181.725
11	67.160	75.570	66.888	75.267	90.621	108.005	130.169	145.799	**74**	97.480	109.688	97.704	109.944	137.271	159.401	182.000	203.691
12	78.850	88.724	78.428	88.253	107.395	126.000	145.146	161.755	**75**	119.450	134.408	119.660	134.650	164.138	192.000	218.002	247.625
13	80.900	91.034	80.177	90.221	106.463	128.000	147.143	163.752	**76**	130.690	147.065	130.637	147.003	177.992	207.000	236.002	265.598
14	81.580	91.796	80.527	90.615	108.327	128.004	147.146	163.755	**77**	135.630	152.617	135.395	152.357	183.898	213.777	243.000	276.581
15	78.180	87.978	79.133	89.046	103.668	123.000	142.151	158.759	**78**	138.340	155.665	137.957	155.239	187.344	216.929	246.992	279.576
16	69.850	78.604	68.639	77.238	91.552	111.000	124.178	138.790	**79**	134.210	151.020	134.663	151.533	181.759	210.626	242.998	272.587
17	58.980	66.363	57.798	65.039	75.711	92.000	107.204	118.824	**80**	128.720	144.849	128.809	144.945	174.977	202.621	233.013	260.613
18	42.100	47.378	41.010	46.148	52.413	68.000	77.249	85.876	**81**	121.160	136.336	122.222	137.533	165.802	191.717	221.034	244.631
19	71.450	80.397	71.339	80.276	101.135	118.000	137.158	152.769	**82**	85.220	95.892	84.852	95.482	114.639	135.317	153.136	175.737
20	75.490	84.949	75.754	85.244	103.931	123.000	144.148	155.764	**83**	97.480	109.688	97.379	109.578	137.271	157.041	175.102	201.694
21	77.690	87.419	78.132	87.920	108.589	124.000	147.143	160.756	**84**	117.710	132.454	117.449	132.162	164.138	191.895	210.051	241.634
22	79.060	88.964	75.754	85.244	106.929	122.000	140.158	159.758	**85**	130.010	146.299	130.457	146.800	177.992	207.000	236.002	265.598
23	75.990	85.514	74.396	83.716	103.931	118.000	137.158	151.770	**86**	136.310	153.392	136.775	153.910	183.868	214.917	245.000	276.581
24	69.970	78.741	67.942	76.453	94.611	109.000	125.176	139.792	**87**	139.710	157.214	140.492	158.092	188.486	219.156	251.000	281.575
25	61.040	68.685	59.788	67.278	82.496	93.000	108.202	121.815	**88**	136.270	153.343	137.518	154.746	184.708	215.859	247.000	276.581
26	49.300	55.478	48.577	54.663	64.062	77.000	85.244	94.856	**89**	132.860	149.503	134.173	150.982	178.831	211.000	237.000	269.592
27	30.030	33.787	31.593	35.551	40.764	49.000	55.282	55.915	**90**	126.660	142.532	127.855	143.872	170.855	199.373	227.002	256.611
28	74.380	83.701	73.608	82.829	98.265	114.000	140.154	148.775	**91**	84.420	95.000	85.000	95.648	113.763	135.215	152.136	177.731
29	77.680	87.409	77.516	87.227	106.653	123.000	149.140	157.764	**92**	107.170	120.598	107.333	120.779	145.037	170.053	194.072	220.666
30	81.400	91.593	80.123	90.160	108.520	129.000	153.134	165.749	**93**	126.450	142.286	125.666	141.409	168.493	197.018	223.031	252.617
31	85.290	95.973	85.007	95.656	114.260	134.000	155.131	172.738	**94**	134.460	151.306	133.667	150.412	179.990	210.882	241.001	272.587
32	82.970	93.364	83.053	93.458	111.315	130.000	151.137	166.747	**95**	139.640	157.130	139.666	157.163	189.608	219.810	249.989	282.572

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33	76.660	86.266	76.539	86.127	103.858	122.000	139.155	153.767	**96**	138.960	156.363	138.667	156.038	187.309	218.753	247.998	281.575
34	65.860	74.109	67.420	75.866	91.743	102.000	121.187	130.802	**97**	135.810	152.825	136.000	153.037	184.708	215.052	243.998	275.582
35	55.400	62.341	54.392	61.206	74.040	86.000	99.216	111.835	**98**	129.100	145.276	129.334	145.536	175.351	204.420	233.015	261.604
36	36.320	40.868	38.758	43.613	51.671	62.000	69.261	78.880	**99**	120.130	135.176	121.333	136.533	163.393	193.374	217.037	244.629
37	68.540	77.131	68.281	76.835	90.881	107.000	127.173	139.788	**100**	83.160	93.573	82.582	92.927	113.978	133.904	156.003	177.731
38	71.400	80.347	71.338	80.275	95.359	113.000	130.169	147.776	**101**	100.850	113.482	100.846	113.479	143.293	170.230	182.000	224.660
39	72.090	81.117	72.697	81.804	99.087	115.000	132.166	145.779	**102**	124.960	140.613	124.873	140.516	168.670	199.432	225.028	261.604
40	72.380	81.442	70.658	79.510	99.087	111.000	129.175	142.784	**103**	136.650	153.772	136.522	153.625	184.859	214.917	245.993	279.578
41	69.360	78.045	69.300	77.981	93.677	108.000	124.178	138.790	**104**	140.400	157.985	140.162	157.721	190.996	220.098	251.984	285.567
42	63.340	71.273	63.185	71.101	84.176	101.000	113.199	125.809	**105**	143.150	161.086	143.439	161.408	193.154	224.808	256.977	290.561
43	53.040	59.687	53.334	60.015	72.994	84.000	96.220	104.841	**106**	140.400	157.992	140.891	158.541	190.996	218.685	253.981	282.572
44	40.800	45.911	40.764	45.871	57.152	64.000	75.252	84.871	**107**	136.960	154.115	136.886	154.034	186.153	214.033	244.995	276.581
45	27.600	31.057	27.855	31.345	34.791	43.000	49.291	55.915	**108**	130.760	147.145	131.425	147.889	176.965	203.612	235.013	261.604
46	64.330	72.389	64.638	72.735	88.401	106.000	118.187	132.803	**109**	64.880	73.004	64.438	72.511	92.218	106.953	118.003	136.793
47	71.730	80.712	72.242	81.292	96.794	111.000	129.170	146.781	**110**	82.530	92.866	81.913	92.175	113.113	131.063	147.143	169.743
48	77.590	87.315	78.580	88.424	103.311	123.000	138.157	158.592	**111**	94.030	105.805	93.563	105.284	130.758	150.705	171.111	195.703
49	80.980	91.120	81.114	91.275	107.039	126.000	146.145	162.756	**112**	96.530	108.623	96.839	108.971	132.151	156.060	176.099	199.700
50	80.620	90.720	79.847	89.850	105.233	124.000	142.151	158.763	**113**	95.030	106.934	95.019	106.923	128.856	153.733	174.102	194.705
51	72.650	81.750	73.932	83.194	98.653	115.000	134.163	148.775	**114**	93.310	105.005	93.563	105.284	125.606	147.972	167.113	184.720
52	62.490	70.320	63.370	71.309	87.470	100.000	115.196	129.803	**115**	87.090	98.005	87.738	98.729	118.176	139.306	156.132	176.732
53	52.580	59.164	53.231	59.900	73.264	86.000	100.214	107.841	**116**	77.650	87.382	77.910	87.670	102.853	121.241	133.164	151.770
54	34.800	39.154	34.220	38.507	50.851	57.000	65.267	77.888	**117**	66.100	74.382	65.895	74.150	84.744	100.598	112.196	125.813
55	87.240	98.173	87.574	98.545	117.252	136.000	159.758	181.725	**118**	85.310	96.000	86.172	96.967	116.702	136.000	154.137	175.734
56	95.790	107.789	95.675	107.661	138.816	158.003	179.728	201.694	**119**	92.290	103.854	91.981	103.504	123.057	143.003	166.114	184.720
57	120.480	135.578	120.366	135.445	165.770	192.000	218.669	247.625	**120**	112.690	126.805	112.315	126.385	153.579	178.003	204.057	230.651
58	130.610	146.975	130.011	146.298	177.001	207.000	235.643	265.598	**121**	127.630	143.624	127.160	143.090	173.624	201.000	234.011	261.604
59	135.850	152.868	135.412	152.376	184.638	218.002	246.626	276.581	**122**	134.860	151.755	134.583	151.443	183.868	211.002	241.003	272.587
60	139.740	157.243	139.657	157.152	189.580	221.000	250.620	281.575	**123**	137.260	154.453	137.488	154.712	184.976	216.002	244.995	276.581
61	136.320	153.401	136.569	153.678	185.088	217.000	247.625	275.582	**124**	136.370	153.454	137.165	154.348	184.708	213.000	242.998	275.582
62	132.220	148.785	132.326	148.903	179.247	211.000	238.638	266.598	**125**	131.540	148.014	132.324	148.901	178.598	207.000	235.012	266.598
63	125.620	141.355	126.925	142.825	170.712	200.000	228.656	254.614	**126**	125.650	141.386	126.192	142.001	169.487	195.000	224.027	251.619

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2.2.4. Measuring the distance on images in JPEG image file format

DICOM viewer has the functionality for converting image to JPEG format. When DICOM image file format is converted into JPEG format, DICOM metadata are not registered (pixel size, pixel spacing) so distance measurement is presented by number of pixels on the measured distance (http://dicom.nema.org/standard).

As information on the physical size of pixel spacing is not available in JPEG format, distance measurements are based on the number of pixels and do not match the actual distance in mm / cm. To obtain the distance the number of pixels of distance should be multiplied by physical size of pixel spacing specified in DICOM metadata. This procedure was made for F1.0 zoom factor on JPEG images. Conversion of the enlarged image in DICOM format to JPEG format increases the pixel number of image matrix depending on the zoom factor. So in JPEG format for F1.2 zoom the image matrix is 616 x 616 pixels, for F1.4 the image matrix is 718 x 661 pixels, for F1.6 the image matrix is 821 x 661 pixels, and for F1.8 image matrix is 923 x 661 pixels.

IBM cause chest movements in ventro dorsal and dorso ventral direction at different stages of apnoea. Distance between markers M0 and M1 is different on the recorded dynamic sequences of selected images. In order to ensure equal spacing of points A-I on the line between markers M0 - M1, a grid is added to the images converted to JPEG format. The grid size is determined based on the distance measured between the markers M0 and M1, which is divided into 12 parts, as in DICOM format. The distance of one part is the size of the grid as well. Image with a grid in JPEG format is imported to DICOM viewer to measure the distances expressed in number of pixels on the distances between the points $\overline{AA_1}$, $\overline{BB_1}$, $\overline{CC_1}$, $\overline{DD_1}$, $\overline{EE_1}$, $\overline{FF_1}$, $\overline{GG_1}$, $\overline{HH_1}$, $\overline{II_1}$ for zoom factors F1.0 , F1.2 , F1.4 , F1.6 and F1.8.

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Results of distance measuring in JPEG image file format with F1.0 zoom in pixels and millimetres obtained by multiplying the number of pixels with pixel spacing (DICOM tag 0028, 0030) are shown in Table 1. Results of distance measurements in JPEG image file format with F1.2, F1.4, F1.6, and F1.8 zooms in pixels are shown in Table 1.

2.3. Statistical analysis

Statistical analyses were performed using MedCalc software version for Windows (MedCalc Software, Mariakerke, Belgium). Quantifying variables were described as mean and standard deviation, with 95% confidence interval (95% CI) and minimum and maximum values. In assessing the strength of correlation in DICOM and JPEG image file formats the Pearson correlation coefficient was used, while Bland-Altman plot was used in graphical illustration of correspondence between DICOM and JPEG measurements. Linear regression was conducted to evaluate the relationship between the measured distances in DICOM format [mm] with a) distances [mm], and b) the number of pixels measured in JPEG with various zooms (from F1.0-F1.8). Statistical significance was set at $p<0.05$.

3. Results

Distances were measured in mm and pixels (N = 126) in eight different image formats and zoom factors. Overall results of descriptive statistics of the distances measured in mm and pixels for F1.0 zooming in DICOM and JPEG formats, and for zooming from F1.2 to F1.8 for measurements in pixels in JPEG format, are presented in Table 2.

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Table 2

Overall results of descriptive statistics.

Image	N	Mean	95% CI for Mean	SD	Minimum	Maximum
F1.0 DICOM_mm	126	96.16	90.54 - 101.79	31.90	27.60	143.15
F1.0 DICOM_pix	126	108.20	101.88 - 114.54	35.90	31.06	161.09
F1.0 JPEG_mm	126	96.10	90.43 - 101.76	32.12	27.86	143.44
F1.0 JPEG _pix	126	108.13	101.76 - 114.50	36.14	31.35	161.40
F1.2 JPEG _pix	126	130.30	122.63 - 137.99	43.56	34.80	193.15
F1.4 JPEG _pix	126	152.26	143.40 - 161.11	50.22	43.00	224.81
F1.6 JPEG _pix	126	174.10	164.07 - 184.14	56.90	49.30	257.00
F1.8 JPEG _pix	126	195.81	184.43 - 207.18	64.52	55.91	290.56

The analysis of correlation between the results of distance measurements in mm and pixels in DICOM format, and pixels in different image formats with zoom showed strong and significant association (*P* value in all correlations was $P < 0.001$). For example, in F.1.0 DICOM format measured in mm in correlation with measurements in F1.0 DICOM format measured in pixels the r values was 1.00 and 95% CI for r was 1:00 - 1:00, while correlated with measurements F1.0_JPEG_mm, F1.0_JPEG_pix, F1.2_JPEG_pix, F1.4_JPEG_pix, F1.6_JPEG_pix, F1.8_JPEG_pix, the value of r was from 0.9982 to 0.9996 and 95% CI for r from 0.9975 - 0.9987 to 0.9995 - 0.9997.

Results for all correlations of measurements are listed in Table 3. Dot plot presenting correlation between pixel number in DICOM and JPEG with F1.0 zoom and marked line of equality (y = x) is shown in Fig. 4.

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Table 3

Correlation coefficients of distance measurements on DICOM and JPEG images

Variable x	**Variable y**	**N**	**r**	***P***	**95% CI for r**
F1.0_DICOM_mm	F1.0_DICOM_ pix	126	1.00	<0.001	1.00 – 1.00
	F1.0_JPEG_mm	126	0.9996	<0.001	0.9995 - 0.9997
	F1.0_JPEG_pix	126	0.9996	<0.001	0.9995 - 0.9997
	F1.2_JPEG_pix	126	0.9987	<0.001	0.9981 - 0.9991
	F1.4_JPEG_pix	126	0.9988	<0.001	0.9983 - 0.9991
	F1.6_JPEG_pix	126	0.9987	<0.001	0.9981 - 0.9991
	F1.8_JPEG_pix	126	0.9982	<0.001	0.9975 - 0.9987
F1.0_DICOM_pix	F1.0_JPEG_mm	126	0.9996	<0.001	0.9995 - 0.9997
	F1.0_JPEG_pix	126	0.9996	<0.001	0.9995 - 0.9997
	F1.2_JPEG_pix	126	0.9987	<0.001	0.9981 - 0.9991
	F1.4_JPEG_pix	126	0.9988	<0.001	0.9983 - 0.9991
	F1.6_JPEG_pix	126	0.9987	<0.001	0.9981 - 0.9991
	F1.8_JPEG_pix	126	0.9982	<0.001	0.9975 - 0.9987

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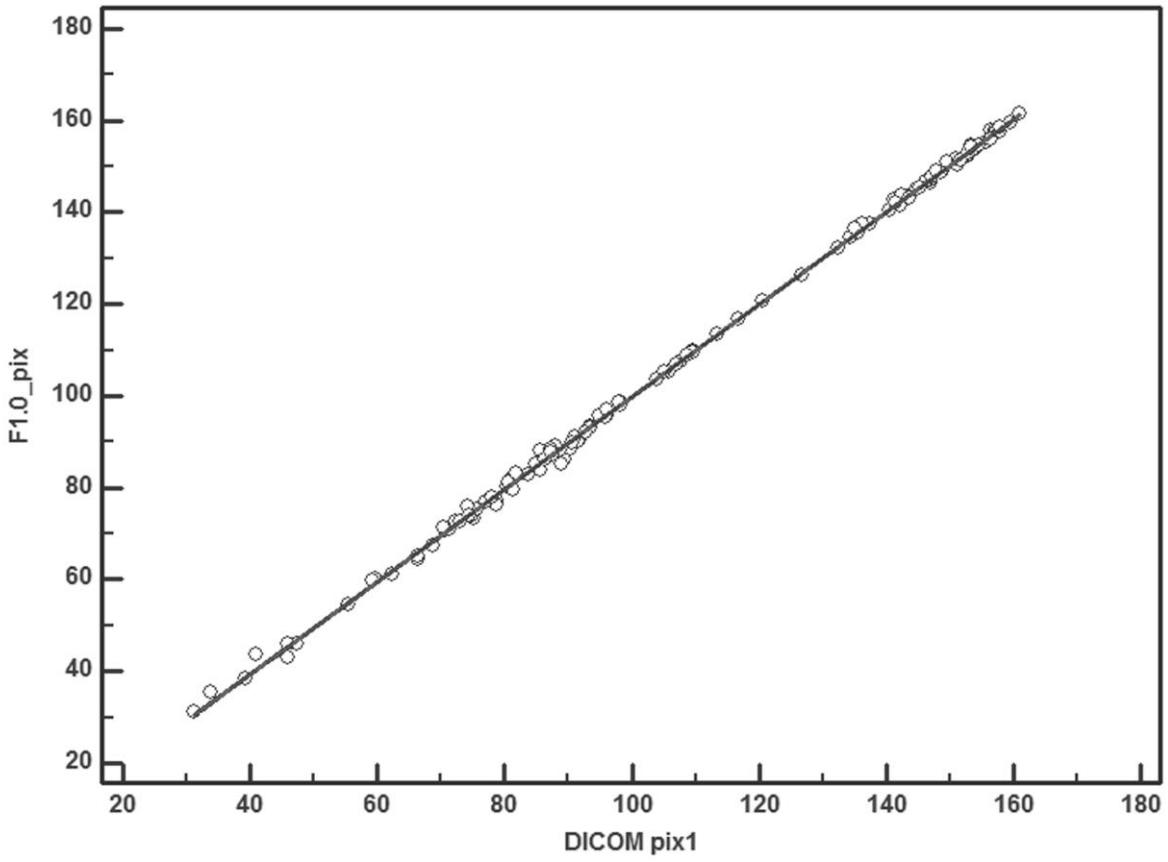

Fig. 4. The association between number of pixels in DICOM and JPEG with F1.0 zoom with marked line of equality (y=x).

Comparison of differences in measured distances in DICOM and JPEG image formats with F1.0 zoom with respect to the average value of that distance was interpreted by Bland Altman plot. Distance in DICOM format is on average longer for 0.1 mm, and the error ranges from -1.7 mm (JPEG) to 1.8 mm (DICOM). The error is larger when measuring small distances to e.g. up to 80 mm. Comparison of the measured distances are shown in Fig. 5.

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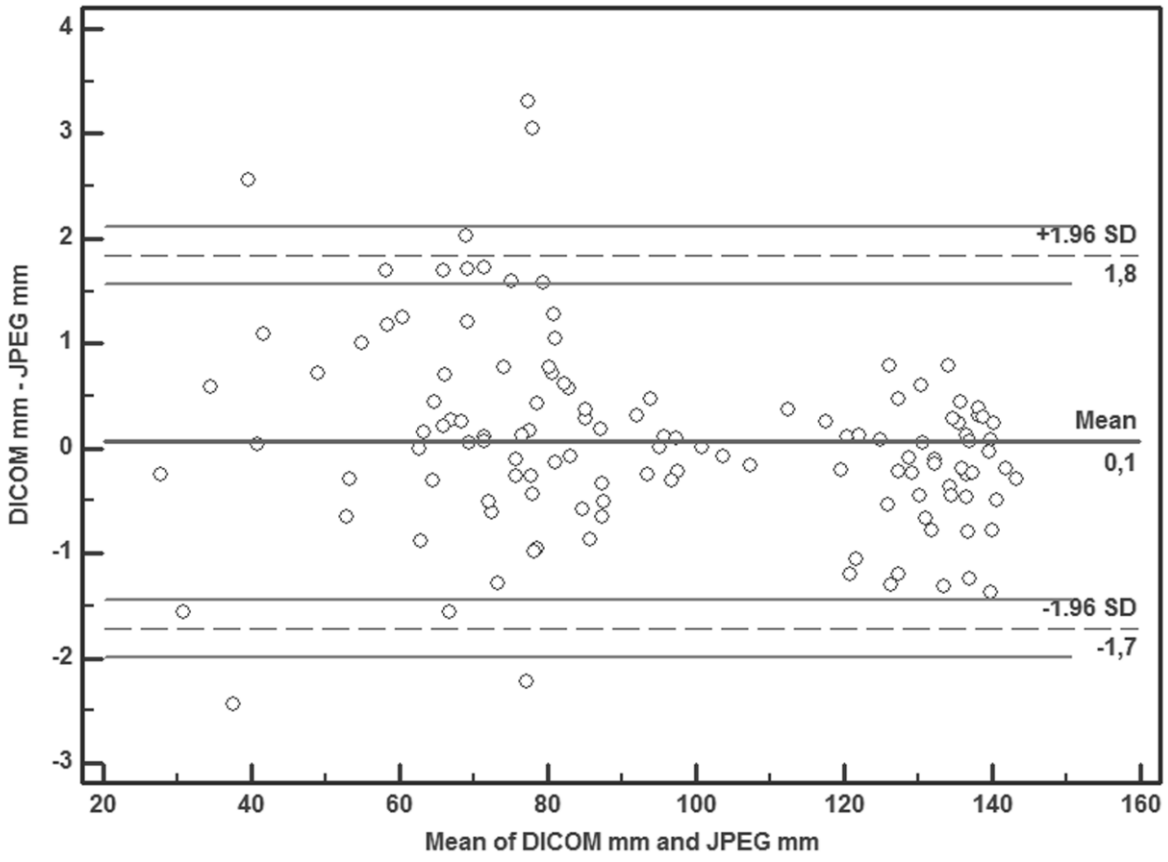

Fig. 5. Comparison of differences in measured distances in DICOM and JPEG image formats with F1.0 zoom considering their mean.

The effects of zooming (F1.0 to F1.8) on change in the pixel number in JPEG format was described by Bland Altman plot as well. The results of distance measurements F1.8 JPEG pix were divided by zoom factor of 1.8 and thus an idealized reproduction of the measured values of image pixel F1.8 JPEG pix with a zoom factor of F1.0 was obtained. Bland Altman plot was used to compare the differences between results of actual distance measurements F1.0 JPEG pix with idealized values (F1.8 JPEG_pix/1.8).

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Image zooming from F1.0 JPEG_pix to F1.8 JPEG pix compared to the idealized value of zoomed image F1.8 JPEG_pix with that zoom factor on average increases the number of pixels for 1, wherein the change can range from the increase of 5 pixels to the loss of 4 pixels (Fig. 6.).

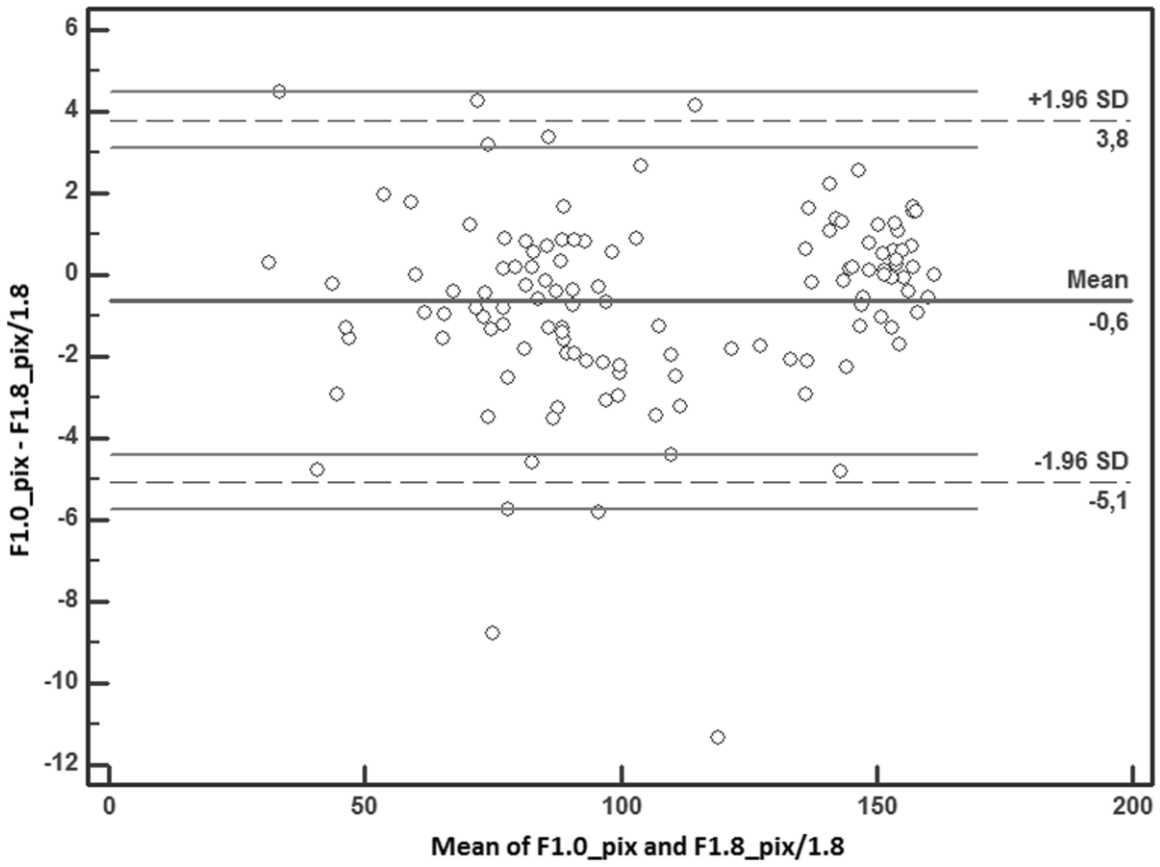

Fig. 6. Comparison of difference between the measured number of pixels with zoom factor of F1.0 and idealized number of pixels with zoom factor of F1.8 with respect to the mean value of number of pixels with F1.0 zoom and idealized number of pixels with F1.8 zoom.

Linear regression shows the results of measuring the pixel number in JPEG format with different zoom factors in relation to: a) the original pixel number F1.0 in DICOM format (Table 4, column

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A), and B) the number of mm in DICOM format (Table 4, column B). In the resulting equation y is the number of pixels in JPEG format.

Table 4

Results of linear regression of relationship between measuring the number of pixels in JPEG format with different zoom factors and the original pixel number.

	A	**B**
Zoom	**DICOM_pix (F1.0), x – broj pix**	**DICOM_mm (F1.0), x-broj mm**
F1.0	y = -0.7719 + 1.0064 x	y = -0.7728 + 1.1325 x
F1.2	y = -0.8238 + 1.2118 x	y = -0.8250 + 1.3637 x
F1.4	y = 1.0742 + 1.3972 x	y = 1.0729 + 1.5722 x
F1.6	y = 2.7938 + 1.5831 x	y = 2.7924 + 1.7815 x
F1.8	y = 1.6806 + 1.7940 x	y = 1.6789 + 2.0188 x

4. Discussion and conclusions

Results of previous studies suggest the need for selective implementation of the converted images from DICOM image format to other image formats, such as JPEG, for the purpose of visual interpretation and in particular from the point of precise distance measurement on the images. Enlarged images in other image formats question the validity of the measurements on these images for both diagnostic and research purposes.

The results of this study indicate:

a) there were no major deviations in measurements when measuring the distances in mm in DICOM and JPEG formats with a zoom factor of F1.0 and the same results are obtained when measuring the distance in pixels with a zoom factor of F1.0 for both image formats;

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b) the obtained minimum differences may be the result of observer's measurement error. Results of descriptive statistics for measuring the distance in JPEG image format in pixels with different zoom factors (F1.2, F1.4, F1.6 and F1.8) expectedly increase depending on the zoom factor. Analysis of correlation between results of measuring distances in mm and pixels of all JPEG and DICOM image formats indicate a strong and significant association between all measurement results.

The results comparing the difference of the measured distances in DICOM and JPEG image formats in mm with a zoom factor of F1.0 regarding the average value of the distance shown by Bland Altman plot indicate that there is no significant difference in obtained values, which may be the result of observer's measurement error.

The effects of zooming (F1.0 to F1.8) on change in the number of pixels in JPEG format and differences between the results of actual distance measurement in pixels F1.0 JPEG_pix and idealized values (F1.8 JPEG_pix/1.8) shown by Bland Altman plot indicate that obtained differences have impact on validity of distance measurements on zoomed images.

The obtained values of the linear regression equation for all zoom factors (F1.0 - F1.8) in which the independent variable is the result of the measurement F1.0 DICOM mm indicate that distance measurement on zoomed images is not suitable for obtaining accurate results of distance measurement in JPEG format i.e. it is necessary to have data on value of the linear regression equation for certain zoom factors to obtain accurate results.

Possible observer's errors of are the limitations of this study. In future studies the effect of image zooming during conversion from DICOM to JPEG image format can be applied to other sizes of image matrix for example 3000 x 2000 pixels (in this study the image matrix is 512 x 512 pixels) as well as on images generated from other radiological devices (DR, CT, ultrasound, Angio, CT Dental, Othopantomograph etc.) The other studies show a high reproducibility of measurements

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in JPEG image formats without image zooming and with possible observer's error, which is the result of this study as well (Duarte et al. 2014; Yasar et al. 2012). As indicated in the general recommendations of the European Society of Radiology (ESR), the parameters of image compression should be listed in the DICOM header (Dujic et al. 2013; Radiology 2011).

Besides images in DICOM format, a radiologist routinely encounters images in several other image formats such as JPEG, JPEG 2000, TIFF, GIF, and PNG etc. Each format has its own distinctive advantages and disadvantages that must be taken into account when the images are archived, used in teaching, stored in files, and used in research or for publication. Knowledge of these formats and their properties, such as resolution, image compression, and images with a header, helps the radiologist in optimizing files, organizing and displaying images, as well as their evaluation. For these reasons, the radiologist can use a digital potential of these image formats to maximize work in the practice of radiology (Varma 2012).

Because of the frequent use of conversion from DICOM to JPEG image format for measurements in JPEG images the implementation of some of the data from the DICOM header should be considered such as the physical size of pixel spacing in JPEG or other image format which can contribute to the precise distance measurement in JPEG format and in zoomed images. In subtraction and fusion of JPEG images generated by dynamic recordings (recording in the same spatial points/planes with different recording time) allow measurements of new anatomical relationships (e.g., differences in the diaphragmatic movements) in the image, so as to compare thus obtained results to the other results of control or comparative measurement methods (Batinic 2012.; Kolar et al. 2009; Kolar et al. 2010).

There is a need for distance measurements on images in JPEG format in radiology, both for teaching and research, as well as in other medical fields (e.g. dental radiography) which use radiological imaging methods. Conversion of images from DICOM to JPEG image file format for

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distance measuring can be selectively used depending on clinical case, physiological and pathological changes, the purpose of measurement and user's assessment of the usefulness of measurements, for example in research. Measurements of distance in JPEG images without zoom are fully consistent with distance measurements in images in DICOM format. In zoomed images in JPEG format the distance measurement results differ from the results in DICOM format. Therefore, the data on zoom factor, the physical acquisition pixel size and values of linear regression equation are necessary in order to use the results of distance measurements in JPEG format.

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