Validation of Gray Scale on the C-arm in Correlation with Hounsfield Units on CT

Branko Kovalisko[1,3], Damir Štimac[2], Frane Mihanović[3]

1 "Dr. Juraj Njavro" National Memorial Hospital, Vukovar, Croatia

2 Josip Juraj Strossmayer University of Osijek – Faculty of Medicine, Osijek, Croatia

3 University of Split, Faculty of Health Sciences, Split, Croatia

Corresponding author: Branko Kovalisko, email: b.kovalisko@gmail.com

DOI: 10.55378/rv.49.2.1

Abstract

Introduction: Hounsfield Units (HU) on CT represent a quantitative measure of X-ray attenuation in tissue – 0 HU is defined for water, and −1000 HU for air. On a 3D C-arm (cone-beam flat-panel detector imaging), the degree of attenuation is displayed by shades of Gray Scale Values (GSV) in the device's DICOM image. If a correlation between HU and GSV could be proven, the *in vivo* or *in situ* application of mobile radiological devices could be expanded outside hospital settings (e.g., in field forensic investigations), while enabling quantitative image analysis.

Aim: To investigate the relationship between the GSV on a mobile 3D C-arm and the HU on a standard CT scanner when imaging the same object (a phantom). Correlation between the mean values of GSV and HU was tested, as well as the difference in the measured GSV and HU values in regard to the DICOM viewer used.

Methods: A standard CT calibration quality control phantom was used in this experimental study. The phantom was scanned using a 64-slice medical CT scanner (Siemens Somatom Perspective, 512×512 matrix, 12-bit scale) and a mobile 3D C-arm (Ziehm Vision RFD, 320×320 matrix, 16-bit scale). Scans were performed at 80 kV and 110 kV on the CT and 80 kV and 115 kV on the C-arm. DICOM images were stored and analysed on two independent DICOM software viewers (Onis 2.5 and RadiAnt) to obtain numerical GSV and HU values. Measurements were taken at eight defined ROI areas (P1 – P8) within the phantom (approx. 1 cm2 each), identically located on the CT and C-arm images. For each ROI, the mean GSV (C-arm) and HU (CT) along with the corresponding min, max, and standard deviation were determined. The obtained data were compared and statistically analysed using the Pearson correlation coefficient (with a significance level of $p < 0.05$).

Results: The analysis shows a positive correlation between GSV and HU, but with varying intensity depending on the device voltage. At the same tube voltage on the CT and C-arm (80 kV), a weak positive correlation was found ($r = 0.450$; $p > 0.05$). A similarly weak, but consistent, correlation ($r = 0.434$; $p > 0.05$) was found between the CT at 110 kV and the C-arm at 80 kV. In contrast, at higher voltages (CT 110 kV and C-arm 115 kV), the correlation was very low, non-significant positive ($r = 0.185$; $p > 0.05$). No significant difference was observed in the measurement results between the two different DICOM viewers, suggesting that the choice of software did not affect the obtained values. However, none of the correlations found were statistically significant.

Conclusion: The results suggest that a relationship exists between the shades of gray scale on the 3D C-arm and HU on the CT, but the correlation is of weak intensity. The observed correlation is insufficient for reliable quantitative calibration of the C-arm gray scale to the CT HU scale. Therefore, the hypothesis (of no correlation) cannot be confidently rejected. Further research is needed with different phantoms and improved standardization to determine whether mobile CBCT/C-arm systems with appropriate calibration can provide quantitative information comparable to CT. If a strong correlation or the possibility of converting GSV into pseudo-HU is confirmed, it would open up wider applications for 3D C-arms in clinical practice (e.g., implant planning, bone density determination) and field forensic analysis.

Keywords: C-arm; CT phantom; Hounsfield units; gray scale; quantitative analysis

Introduction

The development of digital X-ray technology has enabled radiological imaging to be used not only in medicine but also in other areas, including forensic science. Forensic radiology encompasses a wide range of applications, from identification and analysis of injuries and causes of death to expert court testimony and investigations of misuse [1].Recently, there is an increasing demand for conducting radiological examinations outside laboratories and healthcare institutions – for instance, in the field during accidents or criminal investigations, which highlights the importance of portable devices that provide high-quality 3D digital images.

Standard CT (Computed Tomography) scanners provide quantitative information on tissue density in the form of Hounsfield Units (HU), but they are large, immobile, and require fixed installation. In contrast, 3D mobile C-arms and CBCT (Cone-Beam CT) devices are compact and portable, making them suitable for field application in forensic and other out-of-hospital conditions. However, the 3D C-arm device does not directly provide calibrated HU values like conventional CT. Instead, the resulting images are displayed in shades of gray scale, whose numerical Gray Scale Values (GSV) depends on the technical characteristics of the detector, scanning parameters, and reconstruction algorithms of the specific device [2].

In CT, the HU scale is defined by a linear transformation of the attenuation coefficient: 0 HU corresponds to the density of water, and −1000 HU to the density of air, while bone yields high positive HU values [3]. CT devices are standardized to provide comparable HU results across different beam energies (kV) with water/air calibration; however, HU values are known to vary depending on tube voltage and other scanning factors, especially across different manufacturers and protocols. In contrast, CBCT technology, due to structural differences (cone beam, flat-panel detector, different algorithms), does not guarantee the comparability of GSV between different devices or even different settings on the same device. Research has shown that CBCT generally cannot directly display true HU values like CT, but a strong correlation may exist between CBCT "gray" values and the corresponding CT HU [4].

Existing literature presents conflicting conclusions on the possibility of quantitative comparison between CBCT and CT values. Razi et al., in an *in vitro* study of an animal model (sheep's head), found a linear correlation between mean GSV and HU values for all tested CBCT devices [2]. Mah et al., who examined 11 different CBCT devices and 2 CTs on a phantom, showed that conversion of GSV to estimated HU values is possible in principle, proposing a methodology for calculating pseudo-HU [5]. However, two recent systematic reviews offer more cautious conclusions. Selvaraj et al. (2022) reported that most work indicates a positive correlation between CBCT gray values and CT HU [4]. Conversely, Eguren et al. (2022) conclude there is insufficient evidence for an unambiguous mapping of GSV from different CBCT devices to the classic CT HU scale. They emphasize that the lack of standardization across devices prohibits a universal conversion; reliable GSV-to-HU transfer requires correction equations and calibration models for each device. Without additional calibration, GSV from a CBCT (or C-arm) is not directly comparable to HU on a reference CT [6].

Despite these limitations, confirming at least a relative relationship between GSV and HU has practical significance. If a mobile 3D C-arm could provide numerical values proportional to the HU scale, users could employ them for quantitative analysis of materials and tissues *in* ***situ***. In forensic practice, this could aid in estimating the density of an unknown material (e.g., bone, foreign body) through correlation with HU [7]. In clinical dentistry, it would allow for the approximate determination of bone mineral density for implantology based on CBCT images. This research was motivated by these applications, and we examined the relationship between GSV and HU using a 3D C-arm and CT on the same phantom, analysing the impact of different energy settings and software for measurement.

Objectives

The primary aim of the research was to determine whether a quantitative correlation exists between GSV obtained with a 3D C-arm and the corresponding HU obtained with CT, when imaging an identical object under comparable conditions. In other words, the study examined the possibility of validating the grayscale of the C-arm against the reference HU scale of CT. To achieve this aim, two research questions were tested: Is there a significant correlation between the measured mean values of GSV (C-arm) and HU (CT) at the same regions within the phantom; and is there a difference in the measured values of GSV and HU depending on the Digital Imaging and Communications in Medicine (DICOM) viewer (software for image reading and analysis) used.

Materials and Methods

Study Design and Equipment

This was an experimental *in vitro* study conducted on a standard cylindrical CT calibration phantom for quality control. This phantom consists of several test modules of known densities housed within a sturdy casing [8]. Specifically, the phantom contained four sections representing: (1) water (reference density ≈ 0 HU), (2) a section for measuring slice thickness, (3) a module for checking spatial resolution, and (4) a module for device centring/alignment [9]. The phantom is equipped with engraved markers for precise centring using laser lights. The calibration phantom used in the study is shown in Figure 1.

The following radiological devices were used for scanning:

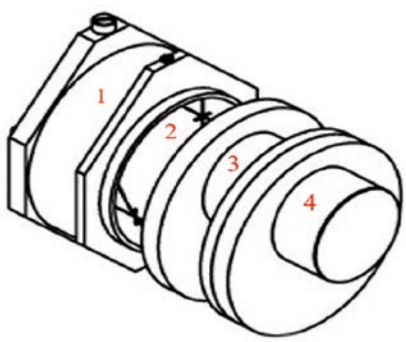


Figure 1. Quality control phantom for CT device
Source: Radiology department user manual of the CT device

Figure 2 (a / b). 3D C-arm Ziehm Vision RFD and the phantom holder used for the research

Medical CT Scanner: A 64-slice Siemens Somatom Perspective (Erlangen, Germany). This served as the reference device, providing HU values in the axial mode.

Mobile 3D C-arm: A Ziehm Vision RFD 3D (Nurnberg, Germany). This device performs 3D image reconstruction by rotating 180∘ around the object and acquiring a series of 2D projections (cone-beam tomography principle) [10]. A stable phantom holder was constructed by the mentor and author to hold the cylindrical phantom upright and centred within the C-arm's rotation path. Figure 2 shows the 3D C-arm used during the experiment and the specially made holder for vertical placement of the phantom.

Image Acquisition Protocols

The phantom was scanned on the CT using two protocols with different tube voltages: 80 kV and 110 kV. On the C-arm, two 3D scans were also performed: at 80 kV and 115 kV (the C-arm's maximum voltage). This selection was motivated by the desire to examine the correlation under low-energy conditions (80 kV vs 80 kV) and high-energy conditions (115 kV C-arm vs 110 kV CT). After scanning, all DICOM images were archived and exported for analysis.

Data Analysis and Measurement

Exported DICOM images were loaded into two different DICOM viewers: Onis 2.5 and RadiAnt DICOM Viewer 2020. On a representative axial image through the center of the phantom for each series, eight Regions of Interest (ROI)—two in each of the four phantom sections—were defined (P1–P8). Each ROI was approximately 1 cm2 and placed to encompass a homogeneous part of the section. An example of the appearance of ROI areas on the CT image and C-arm image is shown in Figure 3a and 3b.

For each ROI in both software packages, the following values were recorded:

- Mean: Mean HU (for CT) or Mean GSV (for C-arm).
- Min and Max: Minimum and maximum value.
- SD: Standard Deviation.
- Mediana**:** Median value (in Onis only).

The primary data set consisted of paired values: mean HU (CT) and mean GSV (C-arm) for the eight ROIs. As expected, the two software programs yielded very similar or identical mean values, confirming the repeatability of the measurement.

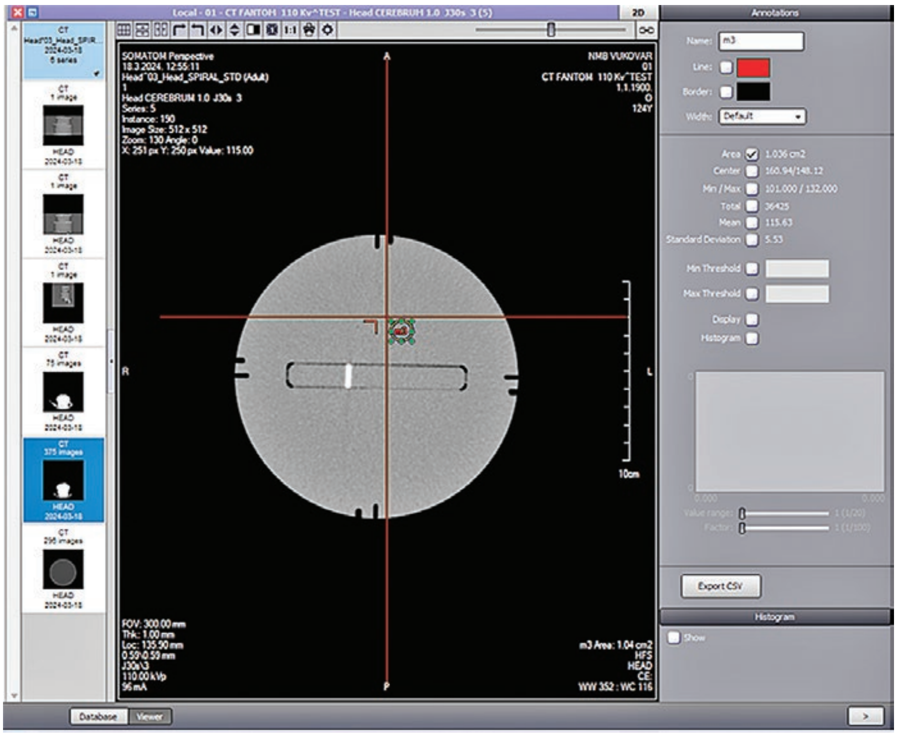


Figure 3a. Example of HU measurement in the ONIS software.

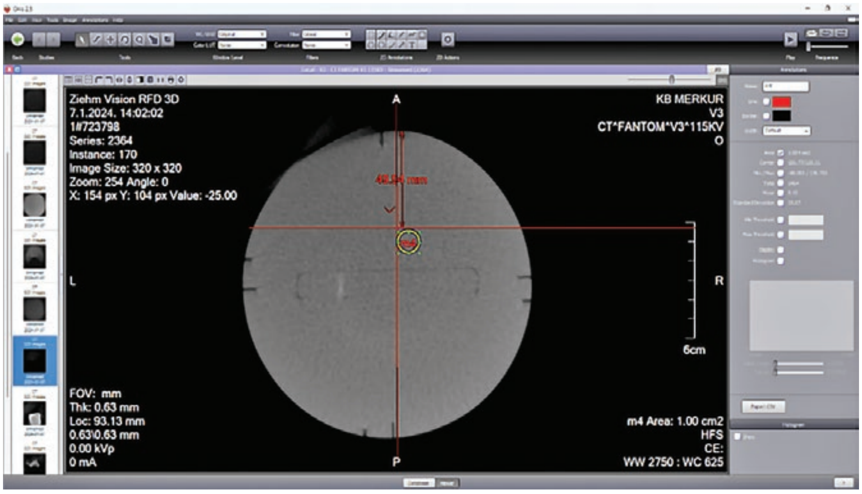
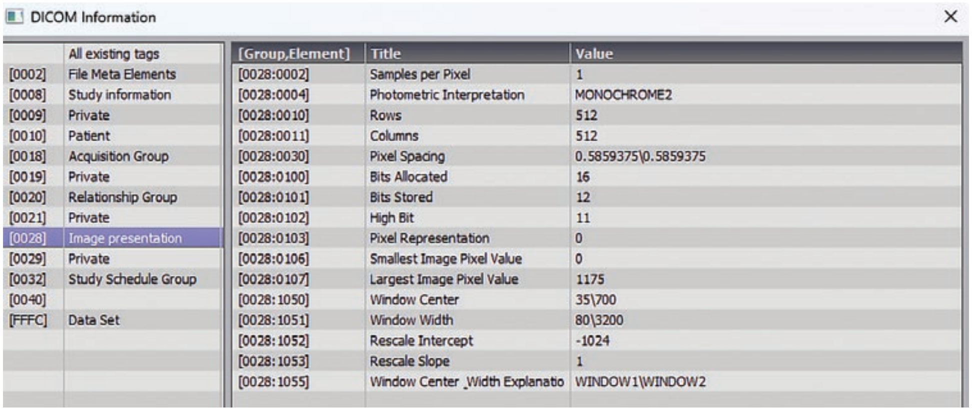


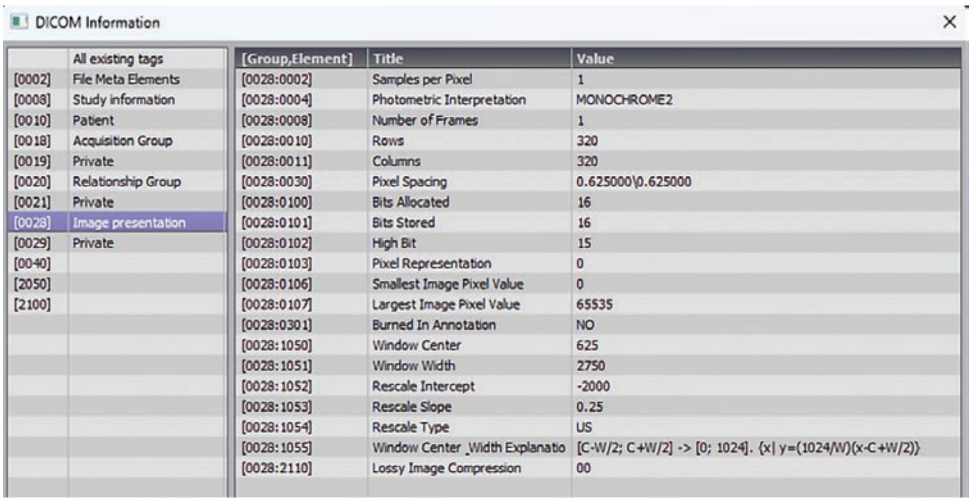
Figure 3b. Example of GSV measurement in the ONIS software


DICOM Information

	All existing tags
[0002]	File Meta Elements
[0008]	Study information
[0009]	Private
[0010]	Patient
[0018]	Acquisition Group
[0019]	Private
[0020]	Relationship Group
[0021]	Private
[0028]	Image presentation
[0029]	Private
[0032]	Study Schedule Group
[0040]	
[FFFC]	Data Set

[Group,Element]	Title	Value
[0028:0002]	Samples per Pixel	1
[0028:0004]	Photometric Interpretation	MONOCHROME2
[0028:0010]	Rows	512
[0028:0011]	Columns	512
[0028:0030]	Pixel Spacing	0.5859375\0.5859375
[0028:0100]	Bits Allocated	16
[0028:0101]	Bits Stored	12
[0028:0102]	High Bit	11
[0028:0103]	Pixel Representation	0
[0028:0106]	Smallest Image Pixel Value	0
[0028:0107]	Largest Image Pixel Value	1175
[0028:1050]	Window Center	35\700
[0028:1051]	Window Width	80\3200
[0028:1052]	Rescale Intercept	-1024
[0028:1053]	Rescale Slope	1
[0028:1055]	Window Center Width Explanatio	WINDOW1\WINDOW2

Figure 3c and 3d show dialog boxes with the measured values (metadata) in the DICOM viewer.


DICOM Information

	All existing tags
[0002]	File Meta Elements
[0008]	Study information
[0010]	Patient
[0018]	Acquisition Group
[0019]	Private
[0020]	Relationship Group
[0021]	Private
[0028]	Image presentation
[0029]	Private
[0040]	
[2050]	
[2100]	

[Group,Element]	Title	Value
[0028:0002]	Samples per Pixel	1
[0028:0004]	Photometric Interpretation	MONOCHROME2
[0028:0008]	Number of Frames	1
[0028:0010]	Rows	320
[0028:0011]	Columns	320
[0028:0030]	Pixel Spacing	0.625000\0.625000
[0028:0100]	Bits Allocated	16
[0028:0101]	Bits Stored	16
[0028:0102]	High Bit	15
[0028:0103]	Pixel Representation	0
[0028:0106]	Smallest Image Pixel Value	0
[0028:0107]	Largest Image Pixel Value	65535
[0028:0301]	Burned In Annotation	NO
[0028:1050]	Window Center	625
[0028:1051]	Window Width	2750
[0028:1052]	Rescale Intercept	-2000
[0028:1053]	Rescale Slope	0.25
[0028:1054]	Rescale Type	US
[0028:1055]	Window Center Width Explanatio	[C-W/2; C+W/2] -> [0; 1024]. {x| y=(1024/W)(x-C+W/2)}
[0028:2110]	Lossy Image Compression	00

Figure 3d. Example of DICOM image information of the measured GSV area in the ONIS software.

Statistical Analysis

Statistical analysis was performed in MedCalc v14.8.1. The Pearson correlation coefficient **(r)** was calculated for three correlation pairs: (1) CT 80 kV vs C-arm 80 kV, (2) CT 110 kV vs C-arm 80 kV, and (3) CT 110 kV vs C-arm 115 kV (N = 8 in all cases). The correlation was interpreted using the established classification [11]. All significance tests were two-tailed with a threshold of $p < 0.05$.

Results

All obtained measurement results (mean HU and GSV for ROI P1–P8) are presented in Table 1.

Mean HU values on the CT were within the expected range for the phantom materials (near 0 HU for water, negative for plastic/acrylic). Mean GSV on the C-arm followed a similar trend across the ROIs. However, the absolute GSV were highly dependent on the voltage: the higher voltage (115 kV) on the C-arm produced lower GSV (darker images) than the 80 kV setting, illustrating the C-arm's different contrast behaviour.

The key results are the calculated correlation coefficients (Table 2), which assess the linear relationship between the HU and GSV for each voltage combination.

As shown, the highest correlation was found when the voltages were matched (CT 80 kV vs C-arm 80 kV) with r = 0.450. A very similar scatter pattern and correlation strength was found for the mismatched 110 kV CT vs 80 kV C-arm (r = 0.434). In contrast, the 110 kV CT vs 115 kV C-arm comparison showed a negligible correlation (r = 0.185).

Critically, in none of the cases did the correlation achieve statistical significance (p > 0.05).

For easier visualization, Figure 4 shows scatter diagrams illustrating the GSV vs HU relationship for each of the three analysed voltage combinations. The graphs also include a trend-line (linear regression line) whose slope indicates the direction of the correlation. Figure 4. Examples of scatter diagrams for (a) CT 80 kV & C-arm 80 kV, (b) CT 110 kV & C-arm 80 kV, (c) CT 110 kV & C-arm 115 kV.

Table 1. Descriptive statistics of mean gray scale and HU unit values at different measurement areas (P1 – P8) with different kV values on the C-arm and CT and different DICOM viewers.

	Mean	95% CI	SD	Median	95% CI	Min.	Max.
Onis C-luk GSV 115kV Mean	233,892	8,337 – 459,448	269,7969	196,715	-16,813 – 565,300	-26,250	569,540
RadiAnt C-luk GSV 115kV Mean	227,914	-1,308 – 457,137	274,1825	193,628	-25,830 – 559,994	-45,150	566,610
Onis CT HU 110kV Mean	57,819	10,678 – 104,959	56,3868	59,185	-2,548 – 115,762	-2,970	116,330
RadiAnt CT HU 110kV Mean	58,223	11,520 – 104,926	55,8637	59,445	-1,716 – 115,804	-1,812	116,290
Onis C-luk GSV 80kV Mean	183,121	-56,747 – 422,989	286,9162	31,360	-8,367 – 635,348	-10,240	650,890
RadiAnt C-luk GSV 80kV Mean	185,768	-55,739 – 427,276	288,8771	35,570	-12,827 – 638,358	-14,140	658,480
Onis CT HU 80kV Mean	46,360	5,243 – 87,477	49,1817	45,835	-2,019 – 95,928	-3,770	96,050
RadiAnt CT HU 80kV Mean	46,311	5,107 – 87,515	49,2859	46,054	-2,899 – 95,995	-3,682	96,190

Table 2. Correlation (Pearson) of mean values of measurement areas (P1 – P8) with different kV values on the C-arm and CT and different DICOM viewers

		Onis C-luk GSV 115kV Mean	RadiAnt C-luk GSV 115kV Mean	Onis CT HU 110kV Mean	RadiAnt CT HU 110kV Mean	Onis C-luk GSV 80kV Mean	RadiAnt C-luk GSV 80kV Mean	Onis CT HU 80kV Mean	RadiAnt CT HU 80kV Mean
Onis C-luk GSV 115kV Mean	Correlation Coefficient		1,000	0,185	0,184	0,838	0,844	0,169	0,171
	Significance Level P		<0,0001	0,6608	0,6635	0,0093	0,0085	0,6897	0,6855
	N		8	8	8	8	8	8	8
RadiAnt C-luk GSV 115kV Mean	Correlation Coefficient	1,000		0,191	0,190	0,831	0,836	0,174	0,176
	Significance Level P	<0,0001		0,6499	0,6525	0,0106	0,0098	0,6810	0,6766
	N	8		8	8	8	8	8	8
Onis CT HU 110kV Mean	Correlation Coefficient	0,185	0,191		1,000	0,434	0,422	0,998	0,998
	Significance Level P	0,6608	0,6499		<0,0001	0,2827	0,2978	<0,0001	<0,0001
	N	8	8		8	8	8	8	8
RadiAnt CT HU 110kV Mean	Correlation Coefficient	0,184	0,190	1,000		0,432	0,420	0,998	0,998
	Significance Level P	0,6635	0,6525	<0,0001		0,2847	0,2999	<0,0001	<0,0001
	N	8	8	8		8	8	8	8
Onis C-luk GSV 80kV Mean	Correlation Coefficient	0,838	0,831	0,434	0,432		1,000	0,450	0,450
	Significance Level P	0,0093	0,0106	0,2827	0,2847		<0,0001	0,2630	0,2632
	N	8	8	8	8		8	8	8

		Onis C-luk GSV 115kV Mean	**RadiAnt C-luk GSV 115kV Mean**	**Onis CT HU 110kV Mean**	**RadiAnt CT HU 110kV Mean**	**Onis C-luk GSV 80kV Mean**	**RadiAnt C-luk GSV 80kV Mean**	**Onis CT HU 80kV Mean**	**RadiAnt CT HU 80kV Mean**
RadiAnt C-luk GSV 80kV Mean	Correlation Coefficient Significance Level P N	0,844 0,0085 8	0,836 0,0098 8	0,422 0,2978 8	0,420 0,2999 8	1,000 <0,0001 8		0,438 0,2778 8	0,438 0,2779 8
Onis CT HU 80kV Mean	Correlation Coefficient Significance Level P N	0,169 0,6897 8	0,174 0,6810 8	0,998 <0,0001 8	0,998 <0,0001 8	0,450 0,2630 8	0,438 0,2778 8		1,000 <0,0001 8
RadiAnt CT HU 80kV Mean	Correlation Coefficient Significance Level P N	0,171 0,6855 8	0,176 0,6766 8	0,998 <0,0001 8	0,998 <0,0001 8	0,450 0,2632 8	0,438 0,2779 8	1,000 <0,0001 8	

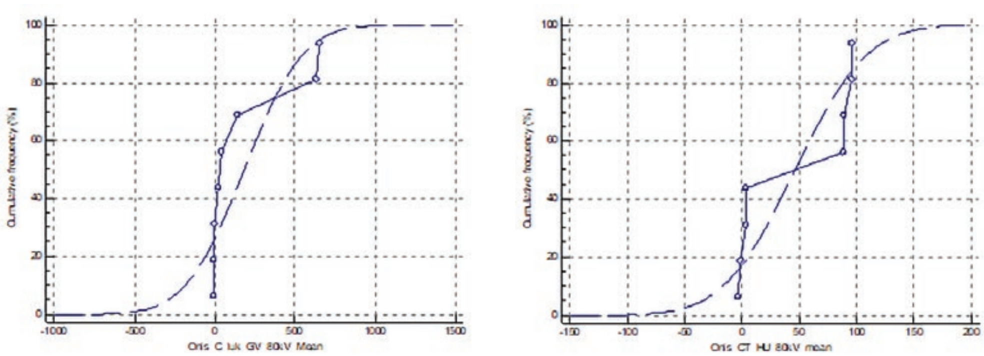


Figure 4a. Graphical representation of frequency distribution of mean values C-arm GSV 80 kV and CT HU 80 kV Onis DICOM viewer.

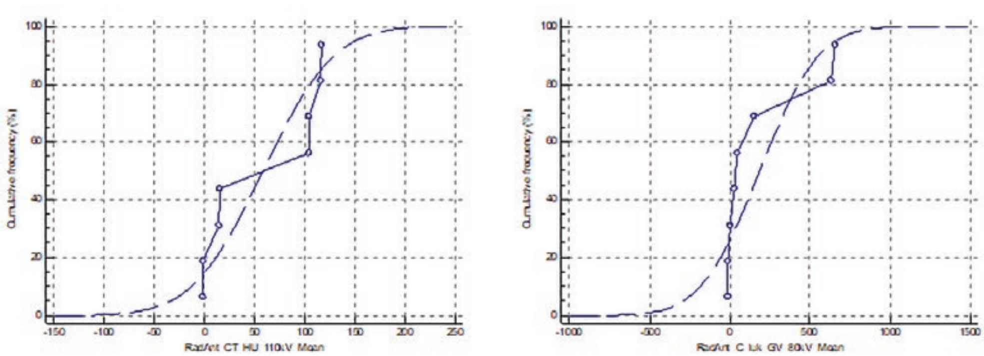


Figure 4b. Graphical representation of frequency distribution of mean values HU CT 110 kV and GSV C-arm 80 kV RadiAnt DICOM viewer.

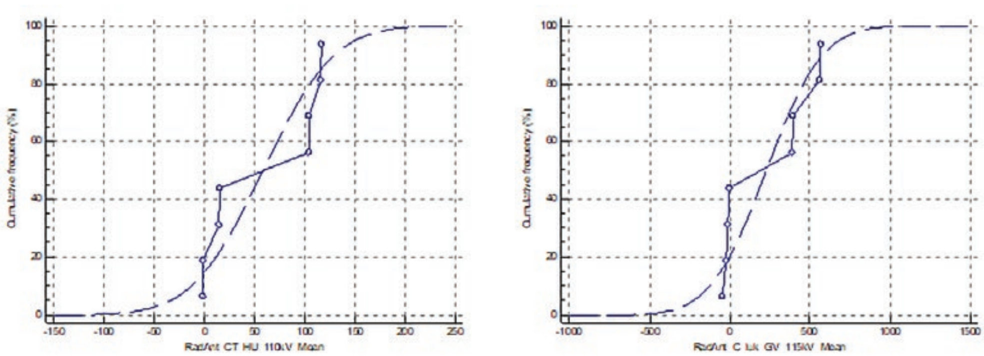


Figure 4c. Graphical representation of frequency distribution of mean values HU CT 110 kV and GSV C-arm 115 kV RadiAnt DICOM viewer.

It is important to note that no significant difference was observed between the results obtained using the two different DICOM viewers (Onis and RadiAnt). This confirms that measurement was replicated independently, and the choice of software did not influence the final correlation results.

Discussion

This study investigated the correlation between the numerical GSV on a 3D C-arm and the reference HU on a CT. The results show a positive relationship between GSV and HU, but the correlation is weak and statistically non-significant (r ≈ 0.4 – 0.45 for comparable voltages). This implies that while a lower GSV on the C-arm generally corresponds to a lower HU on the CT, the data scatter is too large, and the relationship is unreliable for precise quantitative prediction.

The comparison was limited to one specific phantom and predetermined voltages. Razi et al. (2014) found a significantly stronger correlation using a heterogeneous biological sample (sheep's head) that included a wide range of densities, from soft tissue to bone [2]. In our study, the phantom contained mostly similar-density materials (water and plastic), leading to a narrower HU range (≈ -100 to +120 HU). This restricted dynamic range may partially explain why the correlation was not stronger. Razi et al. also noted that results with homogeneous phantoms are not necessarily applicable to heterogeneous tissues, which is confirmed here—the correlation, while present, is inadequate for predicting HU in real clinical situations.

Another significant factor is the difference in technology between CT and the C-arm. CT uses high-resolution images with a 12-bit depth, while the 3D C-arm uses a lower matrix but a 16-bit depth. Crucially, the GSV on the C-arm is not physically calibrated in the same way that 0 HU is defined for water on a CT. The fact that changing the voltage on the C-arm from 80 kV to 115 kV dramatically changes the GSV (reducing them) without an analogous change in the reference HU illustrates that GSV are not directly comparable even between different settings on the same device. Furthermore, noise and artifacts are typically more pronounced in CBCT/C-arm systems, reducing the accuracy of GSV measurement for fine quantification, a challenge emphasized by Eguren et al. [6].

Despite the weak correlation, our results align with the general trend in the literature of a positive relationship between gray scales and HU. Selvaraj et al.'s systematic review reported a positive correlation in most included studies [4]. Mah et al. (2010) demonstrated that mathematical prediction of HU from CBCT is possible using the linear attenuation coefficient as an intermediary [5]. In practical terms, this suggests that device-specific calibration using phantoms of known densities could allow for GSV-to-pseudo-HU conversion, useful in fields like dental implantology.

Eguren et al., however, caution that due to the lack of clinically validated studies, CBCT gray values cannot yet be reliably converted to HU. They recommend developing standardized models and conducting additional research on non-homogeneous tissues before clinical approval [6]. Our results support this cautious approach: although a trend is shown, it is far from the level needed for clinical prediction.

Study Limitations and Implications

The main limitation is the small number of measured points (N = 8 ROI) and the use of one phantom type, which limited the statistical power. The phantom lacked inserts of diverse densities (like bone or fatty tissue), which would have provided a wider HU range and potentially a stronger correlation. Furthermore, the maximum voltage of the C-arm (115 kV) was slightly different from the CT's 110 kV, which affected contrast. Interestingly, the correlation was better when the voltages were matched (80 kV vs 80 kV) than when they deviated, suggesting that correlation is better achieved under similar spectral conditions.

Clinical and Forensic Implication: While this study did not prove a strong correlation, the mere presence of a relationship suggests that future improvements could lead to viable quantitative methods on mobile devices. In forensics, CBCT is already useful for detecting small bone damage around projectiles due to reduced metal artifacts compared to classical CT [12]. If density assessment could be obtained via GSV, investigators could distinguish materials *in situ* (e.g., wood vs. plastic vs. bone) based on their relative attenuation. For clinical applications like implant planning, quantitative CBCT would open up the possibility of bone mineral density assessment without a full CT. Reaching this stage requires solving the problem of standardization, with modern CBCT devices needing to include self-calibration to standard references (air, water).

Conclusion

The study demonstrated that a weak, statistically non-significant relationship exists between the shades of gray scale on the 3D C-arm and HU on the CT when scanning the same phantom. Although positive correlations were obtained in the three voltage combinations tested (r = 0.18 – 0.45), none were strong enough for reliable prediction of HU based on GSV. The results are therefore insufficient for validating the C-arm gray scale as a quantitative substitute for CT values.

Despite this, the research confirmed the consistency of the measurements and observed a correlation trend consistent with the literature. This indicates that further method improvement (using more diverse phantoms, larger samples, and sophisticated correction algorithms) has the potential to achieve better correlation.

Future research is recommended to focus on: (1) using phantoms with multiple reference materials (including trabecular bone, compact bone, and fat tissue) to increase the range of correlation points; (2) examining the impact of different C-arm factors (e.g., filtration, voxel size, reconstruction algorithm) on GSV; and (3) developing a calibration procedure for the C-arm/CBCT to convert GSV to pseudo-HU (e.g., implementing two-point calibration on air and water).

In conclusion, although the current 3D C-arm cannot replace CT for absolute density measurements, evidence of even a weak GSV–HU relationship motivates continued research. Achieving reliable quantitative concordance would allow mobile radiographic devices to become a powerful tool for quantitative radiology outside the radiology department, with applications ranging from clinical diagnostics to forensic investigations.

All data in this paper are part of the results of the master's thesis "Validation of Gray Scale on the C-arm in Correlation with Hounsfield Units on CT" written at the University Department of Health Studies, University of Split [13]. ■

References

1. Brogdon BG. The scope of forensic radiology. Clin Lab Med. 1998;18(2):203-240.
2. Razi T, Niknami M, Alavi Ghazani F. Relationship between Hounsfield Unit in CT Scan and Gray Scale in CBCT. J Dent Res Dent Clin Dent Prospects. 2014;8(2):107-110.
3. DenOtter TD, Schubert J. Hounsfield Unit. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; updated Mar 6, 2023.
4. Selvaraj A, Jain RK, Nagi R, Balasubramaniam A. Correlation between gray values of cone-beam computed tomograms and Hounsfield units of computed tomograms: A systematic review and meta-analysis. Imaging Sci Dent. 2022;52(2):133-140.
5. Mah P, Reeves TE, McDavid WD. Deriving Hounsfield units using grey levels in cone beam computed tomography. Dentomaxillofac Radiol. 2010;39(6):323-335.
6. Eguren M, Holguin A, Diaz K, et al. Can gray values be converted to Hounsfield units? A systematic review. Dentomaxillofac Radiol. 2022;51(1):20210140.
7. Emadi N, Safi Y, Akbarzadeh Bagheban A, Asgary S. Comparison of CT-Number and Gray Scale Value of Different Dental Materials and Hard Tissues in CT and CBCT. *Iran Endod J*. 2014;9(4):283-286.
8. Hacking C, Baba Y, Bell D, et al. Phantom. Radiopaedia.org.
9. Siemens Somatom Perspective; User Manual. NMB Vukovar.
10. Ziehm Imaging Product Portfolio (2021). Available at: https://www.ziehm.com/en/downloads/en-ziehm-imaging-product-portfolio.pdf/
11. Croatian Encyclopedia, Miroslav Krleža Institute. Correlation coefficient. Available at: https://www.enciklopedija.hr/clanak/koeficijent-korelacije
12. Issrani R, Prabhu N, Sghaireen MG, et al. Cone-Beam Computed Tomography: A New Tool on the Horizon for Forensic Dentistry. Int J Environ Res Public Health.
13. Kovalisko B. Validacija sive skale na C-Luku u korelaciji s HU na CT-u [Master thesis]. Split: Sveučilište u Splitu; 2024 Available at: https://urn.nsk.hr/urn:nbn:hr:176:250840

Validacija sive skale na C-luku u korelaciji s HU na CT-u

Sažetak

Uvod: Hounsfieldove jedinice (HU) na CT-u predstavljaju kvantitativnu mjeru oslabljivanja rendgenskih zraka u tkivu – 0 HU definiran je za vodu, a -1000 HU za zrak. Na 3D C-luku (konusno snimanje s ravnim detektorom) stupanj atenuacije prikazan je nijansama sive skale (GSV) u DICOM slici uređaja. Ako bi se dokazala korelacija između HU i GSV, in vivo ili in situ primjena pokretnih radioloških uređaja mogla bi se proširiti izvan bolničkih uvjeta (npr. u forenzičkim istragama na terenu), uz omogućavanje kvantitativne analize slike.

Cilj: Istražiti odnos između vrijednosti sive skale (GSV) na pokretnom 3D C-luku i (HU) na standardnom CT uređaju pri snimanju istog objekta (fantoma). Istraženo je postoji li statistički značajna korelacija srednjih vrijednosti GSV-a i HU-a i ima li razlike u izmjerenim vrijednostima GSV i HU bez obzira na korišteni DICOM preglednik.

Metode: U okviru eksperimentalnog istraživanja korišten je standardni kalibracijski CT fantom za kontrolu kvalitete. Fantom je snimljen 64-slojnim medicinskim CT uređajem (Siemens Somatom Perspective, 512 × 512 matrica, 12-bitna skala) i 3D mobilnim C-lukom (Ziehm Vision RFD, 320×320 matrica, 16-bitna skala). Snimanja su provedena pri 80 kV i 110 kV na CT-u te 80 kV i 115 kV na C-luku. DICOM slike su pohranjene i analizirane na dva neovisna softverska DICOM preglednika (Onis 2.5 i RadiAnt) radi dobivanja numeričkih vrijednosti GSV i HU. Mjerenja su vršena na osam definiranih ROI područja (P1–P8) unutar fantoma (cca 1 cm^2 svako), identično lociranih na CT i C-luk slikama. Za svako ROI određena je srednja vrijednost GSV-a (C-luk) i HU-a (CT) zajedno s pripadajućim min, max i standardnom devijacijom. Dobiveni podatci uspoređeni su i statistički analizirani uz pomoć Pearsonovog koeficijenta korelacije (uz razinu značajnosti $p < 0,05$).

Rezultati: Analiza pokazuje pozitivnu korelaciju između GSV-a i HU-a, ali različitog intenziteta ovisno o naponu uređaja. Pri istim naponima cijevi na CT-u i C-luku (80 kV) utvrđena je slaba pozitivna korelacija ($r = 0,450$; $p>0,05$). Također slaba, ali dosljedna korelacija ($r = 0,434$; $p > 0,05$) nađena je i između CT-a na 110 kV i C-luka na 80 kV. Nasuprot tome, pri višim naponima (CT 110 kV i C-luk 115 kV) korelacija je bila vrlo niska, neznačajna pozitivna ($r = 0,185$; $p > 0,05$). Nije uočena bitna razlika u rezultatima mjerenja između dva različita DICOM preglednika, što upućuje da odabir softvera (Onis vs. RadiAnt) nije utjecao na dobivene vrijednosti. Međutim, sve utvrđene korelacije statistički nisu značajne.

Zaključak: Rezultati upućuju na postojanje određenog odnosa između nijansi sive skale na 3D C-luku i HU na CT-u, no korelacija je slabog intenziteta. Uočena povezanost nedovoljna je za pouzdanu kvantitativnu kalibraciju sive skale C-luka u HU skalu CT-a. Stoga se pretpostavka o nepostojanju korelacije ne može sa sigurnošću odbaciti. Potrebna su daljnja istraživanja s različitim fantomima i poboljšanom standardizacijom kako bi se utvrdilo mogu li pokretni CBCT/C-luk sustavi uz odgovarajuću kalibraciju davati kvantitativne informacije usporedive s CT-om. Potvrdi li se čvrsta korelacija ili mogućnost pretvorbe GSV-a u pseudo-HU, otvorila bi se šira primjena 3D C-lukova u kliničkoj praksi (npr. planiranje implantata, određivanje gustoće kosti) i forenzičkim analizama na terenu.

Ključne riječi: C-luk; CT fantom; Hounsfieldove jedinice; siva skala; kvantitativna analiza