Reliability of Hounsfield Units as a Measure of Bone Density: Applications in the Treatment of Thoracolumbar Fractures

Bernhard Wilhelm Ullrich (✉ b.w.ullrich@me.com)

Department of Trauma and Reconstructive Surgery, BG Hospital Bergmannstrost, Halle (Saale)

Aaron Lawson McLean

Department of Neurosurgery, Jena University Hospital - Friedrich Schiller University, Jena

Thomas Mendel

Department of Trauma and Reconstructive Surgery, BG Hospital Bergmannstrost, Halle (Saale)

Ingamr Kaden

Institution of Radiology, BG Hospital Bergmannstrost, Halle (Saale)

Elizabeth Hein

Institution of Radiology, BG Hospital Bergmannstrost, Halle (Saale)

Anne Lattauschke

Department of Trauma and Reconstructive Surgery, BG Hospital Bergmannstrost, Halle (Saale)

Julia Beyer

Department of Trauma and Reconstructive Surgery, BG Hospital Bergmannstrost, Halle (Saale)

Gunther Olaf Hofmann

Department of Trauma and Reconstructive Surgery, BG Hospital Bergmannstrost, Halle (Saale)

Friederike Klauke

Department of Trauma and Reconstructive Surgery, BG Hospital Bergmannstrost, Halle (Saale)

Philipp Schenk

Department of Research, BG Hospital Bergmannstrost, Halle (Saale)

Research Article

Keywords: Bone Density, Osteoporosis, Spinal Fractures, Spine, Tomography, X-Ray Computed

Posted Date: April 13th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-403496/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Abstract

Purpose

The aim of this study was to evaluate the reliability of Hounsfield units (HU) for bone density measurement in spinal trauma. HU have already been demonstrated to be reliable for this purpose in degenerative spine disease.

Methods

This study is a retrospective cross-sectional analysis considering CT scanner model, slice thickness and HU in native and contrast CT scans. Linear regression, bivariate correlation and ROC analyses were performed to analyze the relationship between qCT values and HU. The inter-rater reliability of HU measurements was assessed using the intra-class correlation coefficient.

Results

344 patient datasets were analyzed. CT scanner model and slice thickness were found to have no significant impact on HU. The inter-rater reliability for HU measurements from native CT scans was $ICC_{(3,1)}=0.932$ (CI_{95} : 0.919 – 0.943, $p<0.001$). The formula $qCT=0.8 \cdot HU_{\text{without CM}}+5$ can be used to predict qCT values from native CT scan HU. ROC analysis revealed maximum sensitivity and specificity of 0.91 and 0.93, respectively, with a cut-off value of 93 HU to predict osteoporosis.

For contrast CT scans we determined an $ICC_{(3,1)}$ of 0.889 (CI_{95} : 0.801 – 0.948, $p<0.001$) and a formula of $qCT=0.6 \cdot HU_{\text{with CM}}-4$. The maximum sensitivity and specificity calculated using HU in the presence of contrast medium were 0.83 and 0.89 with cut-off of values of 122 and 125 HU, respectively, depending on the observer.

Conclusions

HU are reliable for measurement of bone quality in spinal trauma, especially in native CT scans. HU measurements from contrast CT scans should be used more cautiously for bone quality estimation.

Introduction

In 2020, the Federal Statistical Office of Germany [1] reported that 22% of the German population (19.4 million) was older than 64 years, a Fig. 32% higher than that from twenty years earlier. Traumatic spinal injuries occur at a global incidence rate of 10.5 per 100,000 per year and the rate is even higher in the elderly population, with clear implications for morbidity, mortality and healthcare expenditure in this elderly group due to injury and treatment complexity and patient comorbidity [2–4]. Osteoporosis and osteopenia of the spinal column are responsible for the increased rate of pathological vertebral fractures in the elderly; however impaired bone health also affects non-elderly individuals and their fracture rate is also accordingly increased. Indeed, we have previously shown that the mean age of patients with

impaired bone quality who suffer spinal fractures is 56 years (range 19–70) for < 110 HU and 50 years (24–68) for < 180 HU [5]. Bokov et al. [6] found that lower HU values are a key risk factor for screw loosening in degenerative spine surgery and it has also been demonstrated that HU measurements are superior to the DEXA T-Score for the prediction of screw loosening in degenerative spine surgery [7]. Given this, the need to preoperatively assess bone quality in individuals who have suffered spinal fractures seems clear, to inform surgical planning and in doing so to try to avoid future loss of reduction and implant failure.

Based on national and international guidelines, it is recommended that bone quality be determined using dual-energy X-ray absorptiometry (DEXA) or quantitative computer tomography (qCT) [8], Organization [9]. In relation to the surgical management of traumatic spinal injuries, preoperative determination of bone quality using DEXA or qCT is not recommended by German treatment guidelines for thoracolumbar spine injuries [10] or guidance from the American College of Radiology [11]. Sufficient estimation of bone quality is also possible using CT attenuation values (Hounsfield units, HU), without additional radiation exposure or time-delay, which is important in the context of rapidly managing and definitely treating traumatically injured patients [12, 13]. It has previously been shown that reduced bone quality, as measured with CT-derived HU, correlates with an increased rate of cage subsidence and loss of reduction [5, 14]. Further, CT-based evaluation has a sensitivity comparable to DEXA for the detection of osteoporosis and can be used to predict osteoporotic fractures [15–19].

Gerety et al. reported a high correlation between CT-based HU and qCT-derived bone mineral density for assessing the bone quality of the L1 vertebral body [20].

It is known that the presence of contrast medium (CM) affects CT attenuation [21]. Thus, it is important to precisely delineate how HU values are affected by the administration CM.

Materials And Methods

This study sought to investigate the inter-rater reliability of CT-derived HU measurements and ascertain the correlation between HU with qCT-derived BMD in cases of traumatic thoracolumbar fracture, based on native and contrast-enhanced CT scans.

Ethical approval:

This study was approved by the research ethics committee of Jena University Hospital – Friedrich Schiller University, Jena, Germany (reference: 2020-2000-Daten) and was performed in accordance with the principles laid down in the current revision of the Declaration of Helsinki. It was determined that informed consent from each patient was not necessary due to the retrospective, anonymized nature of the research.

Epidemiology:

This study is a retrospective cross-sectional analysis of data from a single level 1 trauma center. We reviewed all thoracolumbar spinal trauma cases admitted to our institution that received CT and qCT scans of the same vertebral body.

CT scanner model:

CT scans were performed using either the Toshiba Aquilion One (Toshiba Medical Systems, Otawara, Japan) or Toshiba Aquilion Prime devices. To assess the comparability of scans obtained using these two devices, the impact of CT scanner model and slice thickness on the HU values was analyzed by stratifying a subgroup of patients who had native CT imaging of L2 or L3 with a peak kilovoltage of 135 kVp and a slice thickness of 3 mm to minimize heterogeneity.

Slice thickness:

Native CT scans were performed with slice thicknesses of 2-3mm. Contrast CT scans were performed with 5mm thickness. The impact of slice thickness on HU values was assessed for each observer, stratified by the presence or absence of CM.

HU determination:

Bone quality was measured using qCT in a non-fractured vertebral body between L4 and T11. For the same vertebral body, CT attenuation was independently measured in HU by four observers according to the method described by Schreiber et al. and Mi et al. [12, 22]. The observers were blinded to the clinical and qCT data and the assessments were performed independently. In brief, the mean HU of three separate elliptical regions of interest (immediately inferior to the superior end plate, in the middle of the vertebral body, and superior to the inferior end plate) were determined for the vertebral body being investigated. The HU value of each region of interest is calculated automatically using the IMPAX PACS client (Agfa-Gevaert, Mortsels, Belgium). A region of interest was defined as the largest possible region without any sclerotic or cortical structures within a vertebral body. Patients with qCT values below 80 were determined to have osteoporosis according to the American College of Radiology guidelines [10]. Two observers were experienced attending radiologists (E.H., I.K.), with 10 and 15 years of radiology experience, respectively. The other two observers were medically-trained trauma fellows (J.B., A.L.) without formal radiology accreditation. The measurements were performed with identical hardware and software set-ups.

Effect of CM:

21 patients received contrast CTs during their admission (Accupaque 350 (GE Healthcare), 100ml 3,8 ml/second). Five of the 21 patients with contrast CTs also received native CT scans. Matched pairs were determined to investigate the effect of CM on HU for 16 patients. For the 16 patients with contrast CT scans, appropriate comparison scans were selected based on qCT values and the fractured level.

Statistical analysis:

The impact of CT scanner model on measured HU for each observer was assessed using an ANOVA with repeated measures (rmANOVA (observer (4) × device (2))). The effect of the CT device on qCT values was determined using univariate ANOVA.

The effects of slice thicknesses on HU values were checked using an rmANCOVA (observer (4) × slice thickness (3)) with the information if CM was given as additional covariate. The effect of the slice thicknesses on qCT values was checked using univariate ANCOVA, using the CM information as a covariate.

The inter-rater reliability of HU measurements across the four observers was determined using the intra-class correlation coefficient ($ICC_{(3,1)}$: two-way mixed, single measure), presented with the 95% confidence interval ($CI_{95\%}$). The inter-rater reliability was calculated for the dataset without CM, as well for the data set with CM.

To investigate the ability of HU to predict the qCT value, linear regression was used, both for the presence and absence of CM. To analyze the accuracy of prediction of qCT values based on HU, bivariate correlation of measured and predicted qCT values was carried out. ICCs and correlation coefficients greater 0.8 were considered to represent very good or strong agreement.

To predict osteoporosis, based on the classification on qCT below 80 HU, cut-off values for HU were analyzed using ROC analysis. Sensitivity and specificity were calculated using the Youden index, which is calculated as the furthest orthogonal point on the ROC curve from the diagonal [23]. In addition the positive and negative predictive values (PPV and NPV) were calculated.

SPSS (SPSS Statistics for Windows, version 26.0, IBM Corp., Armonk, NY, USA) was utilized for all statistical analyses. Alpha was set at 0.05.

Results

Epidemiology:

In total, datasets from 344 patients with thoracolumbar spinal fractures were analyzed (mean age 68 years (range 23 – 92), 130 male, 214 female). 323 patients had native CT scans and qCT. Five patients had all modalities available (native CT, qCT and contrast CT) and 16 had only qCT and contrast CT. Twenty-one patients (12 male, 9 female) received a contrast CT scan.

CT scanner model:

A subgroup of 164 patients (CT One: 106, CT Prime: 58) was analyzed to assess the impact of the scanner device on HU values. No significant differences were found in the analyses to determine the comparability of HU determinations between CT scanner models ($F_{(1,162)}=0.972$, $p=0.326$) and observers ($F_{(3,486)}=1.467$, $p=0.223$).

In the subgroup of stratified 164 patients the qCT values were similarly unaffected by the CT scanner model. The univariate ANOVA showed no significance ($p=0.761$). Imaging obtained with either scanner (CT One: $n=211$, CT Prime: $n=133$) was therefore deemed suitable for inclusion in the further analyses.

Slice thickness:

In total data from 344 patients were analyzed to determine the effect of slice thickness on HU and qCT values. The analyzed dataset contained 14 CT scans with a slice thickness of 2mm (without CM), 317 with a slice thickness of 3mm (without CM=311, with CM=8) and 13 with a slice thickness of 5mm (all with CM). The presence or absence of CM was used as the covariate.

For the HU values, the rmANOVA showed no significance for slice thickness ($F_{(2, 340)}=0.004$, $p=0.996$). The second main effect (observer) showed non-significance ($F_{(3, 1020)}=1.225$, $p=0.299$). The covariate also showed no significant effect ($F_{(1, 340)}=3.336$, $p=0.069$). For the qCT values, no significance was found, neither for slice thickness ($F_{(2, 340)}=0.058$, $p=0.943$) nor for the covariate ($F_{(1, 340)}=$, $p=0.361$).

In conclusion, no significant effects of slice thicknesses on HU values or qCT values could be determined. As a result, datasets of varying slice thicknesses were included in the further analyses.

HU values from native CT scans:

Results based on native and contrast CT scans will be presented separately. Firstly, determinations from native scans will be considered.

The lowest and highest absolute measured HU values without CM of the four observers were very close to one other. The smallest measured HU values differed by 10 units between the four observers, between -14 and -24 HU. The highest measured values were also very close to each other and varied between 250 and 267 HU. A detailed overview is given in Table 1.

Inter-rater reliability of HU measurements from native CT scans:

The inter-rater reliability for HU measurements from native CT scans was very high ($ICC_{(3, 1)}=0.932$, CI_{95} : 0.919 – 0.943, $p<0.001$). The inter-item correlation matrix is shown in Table 2.

Linear regression (native CT scans):

To predict qCT values from HU (native Scans) a linear regression for each observer was performed. A detailed overview is given in Table 3. Very high correlation between qCT and HU values was found for each observer. By averaging the constants and factors of the observers, a general equation for the prediction of qCT values from HU in the absence of CM was generated:

$$qCT=0.8 \cdot HU_{\text{native}}+5.$$

The measured density attenuation in HU for native CT scans across the four observers with linear regressions and their CI_{95} are shown in Figure 1(a).

Predicting qCT from HU derived from native CT scans:

Based on the linear regression model and the predicted qCT values obtained using the general equation above, the bivariate correlation showed significant correlation ($p < 0.001$) between the measured and predicted qCT values for each observer (Table 4). High correlation between measured and predicted qCT values was found. The mean r was 0.91 ± 0.03 . The mean predicted qCT values were between 81 ± 30 and 84 ± 33 , depending on the observer.

ROC analysis (native CT scans):

In our cohort of 328 patients, 171 (52%) were assigned a diagnosis of osteoporosis (i.e., $qCT < 80$). For each observer, statistical significance could be shown regarding prediction of osteoporosis ($p < 0.001$). The area under the curve (AUC) ranged from 0.94 to 0.98 among raters. The ROC curves for each rater are shown in Figure 2(a). All four ROC curves, based on HU measurements from native scans to predict qCT-confirmed osteoporosis, lay close together. The best positive predictive value (PPV) was obtained using 93 HU as the cut-off value. The maximum sensitivity and specificity of 0.91 and 0.93, respectively, were found with a cut-off value of 93 HU. The sensitivity and specificity for each observer are provided in Table 5. One observer reached a PPV of 93%, representing very high concordance. The PPV of the other observers reached agreement levels between 65 and 69%. The NPVs were quite similar between the observers and were between 90 and 100%.

HU values from contrast CT scans:

For the assessment of HU derived from contrast CT scans, integer matched pairs could be found for the 16 cases for which native CT scans were not available. The qCT values matched identically except for two patients. In one matched pair the qCT value was 1 value less and in the other the qCT value was 2 higher. The minima ($qCT = 17$), maxima ($qCT = 121$), mean ($qCT = 72$) and standard deviation ($qCT = 26$) were identical in both groups (contrast enhanced and native scans).

The smallest measured HU values were even closer between the four observers than seen for native scans and differed just by 6 units (from 55 to 61 HU), as shown in Table 1. In contrast, the maxima differed between the observers by 48 units, from 179 to 227. Nevertheless, the mean values were again very close.

Inter-rater reliability of HU measurements from contrast CT scans:

For HU measurements from CT scans with CM, the $ICC_{(3,1)}$ was 0.889 (CI_{95} : 0.801 – 0.948, $p < 0.001$), demonstrating very good inter-rater reliability. The inter-item correlation matrix for the HU values from scans with CM is shown in Table 2.

Linear regression (contrast CT scans):

In patients with contrast CT scans, qCT values between 17 and 121 with a mean of 72 ± 26 were measured. Twelve of 21 patients (57%) had qCT values below 80, consistent with osteoporosis. The measured density attenuation in HU for contrast CT scans across the four observers with linear regression is shown in Figure 1(b). The correlation between qCT and HU for contrast scans showed, as for the native scans, very good predictability. Averaging the constants and factors of the observers (Table 3) allowed the formulation of a general equation for the prediction of qCT values based on HU in the presence of CM:

$$qCT = 0.6 \cdot HU_{\text{contrast enhanced}}^{-4}.$$

Predicting qCT with HU from contrast CT scans:

For the predicted qCT values using the generalized equation for HU values in the presence of CM, the bivariate correlation showed significant correlation ($p < 0.001$) between the measured and predicted qCT values for each observer (Table 4). High correlation between measured and predicted qCT values was shown. The mean r was 0.86 ± 0.04 . The mean predicted qCT values were between 68 ± 22 and 71 ± 24 , depending on the observer.

ROC analysis (contrast CT scans):

Classification showed that in this cohort of 21 patients, there were 12 (57%) with osteoporosis ($qCT < 80$). The ROC-analysis showed significance for each observer ($p < 0.001$). The AUCs were slightly smaller, compared to the AUCs for the cut-off values without CM. Nevertheless, the AUCs were high, ranging from 0.84 to 0.91 (Figure 2(b)). All ROC curves lay quite close together. The maximum sensitivity and specificity calculated using HU in the presence of CM were 0.83 and 0.89 with cut-off of values of 122 or 125 HU, respectively, depending on the observer. The sensitivity and specificity results for each observer are provided in Table 5. The PPV and NPV were quite similar between observers. The highest PPV (91%) was seen for two observers and this PPV was obtained with cut-off values of 122 and 125 HU. The NPVs were slightly lower (80%), again using 122 and 125 HU as the cut-offs.

Discussion

Our results suggest that HU bone density determinations derived from native and contrast CT scans are highly concordant with directly measured qCT values. There was a strong relationship between CT-derived HU estimations and predicted qCT values. In addition, the very high ICCs despite variable observer expertise showed that this measuring technique has excellent inter-rater reliability.

Lee and colleagues in 2017 suggested that L1 attenuation should not be used in place of DEXA or qCT for bone density estimations owing to presently existing technical variations in spinal attenuation measurements. Rather, patients with markedly low L1 attenuation (such as ≤ 90 HU) should be selected

for further BMD assessment to address and potentially reduce fracture risk [24]. In our cohort we found qCT values lower than 80 in over 50% of the cases. This substantial proportion with osteoporotic qCT values highlights the importance of preoperative BMD assessment.

In light of our findings, we feel that is clear practical benefit in using HU to preoperatively estimate bone quality, in particular to ameliorate the risk of complications (such as loss of reduction, cage subsidence and screw loosening) by adjusting operative strategies and technique. Gerety et al. in 2017 showed good inter- and intra-rater reliability for HU measurements compared with to qCT across three observers and 30 cases [20]. In addition, across three observers, there was excellent intra- and inter-observer agreement in CT-based L1 density measurements using HU (inter-observer intra-class correlation coefficient: 0.97, intra-observer intra-class correlation coefficient: 0.94-0.99), based on measures from 30 healthy individuals from the Anglo-Cardiff Collaborative Trial cohort (individuals selected at random from general practices and open-access cardiovascular clinics across East Anglia and Wales in the United Kingdom), who each underwent native helical CT imaging of the spine [20]. Overall, the average L1 density measurement for each patient ranged from 89 to 230 HU. Our cohort is ten-times larger than that reviewed in this study and worked with one more investigator and we demonstrate similar, supportive findings.

The same authors noted that it is not possible to define a single L1 HU threshold for osteoporosis screening owing to variations in scanning protocols with differing kVp, CM phase and dose parameters. Slice thickness was found to have no impact on attenuation measurements [25]. Similarly, our findings demonstrate that slice thickness does not pertinently influence HU values. This finding must nevertheless be interpreted cautiously owing to the varying sample sizes of different slice thicknesses in this study, which was not intended to explore this aspect in depth.

The linear regressions produced coefficients of 0.8 and 0.6 for native CT and CM CT scans, respectively. The presence of CM leads to higher HU overall. In the subgroup of 21 patients with CT scans with and without CM, HU measurements from native scans were a means of 28 to 30% lower, depending on the observer, than those from contrast enhanced scans. This is in line with the findings from Gerety et al. [25].

Pompe et al. reported an adjustment factor of 14 HU for arterial phase and 18 HU for portal phase CM scans [21]. Applying such a correction factor across the CM CT cases in the present study, we come to the conclusion that such scans can reliably be used for preoperative bone quality determinations, albeit with a lower degree of reliability than native CT scans. We think that the broader variation (minimal lower correlations coefficients) for HU in the cases with CM in the current study might be secondary to slightly different CM phases being utilized, to individual differences in circulation parameters and to the smaller sample size, with a wide range of 55 HU to 227 HU observed. Given that trauma scan are frequently performed with contrast-enhancement, the effect of CM on HU and bone quality determinations will be of interests to the spinal trauma community. Here, further investigations are required to gain more broadly representative results.

In the investigated range of -24 to 267 HU, the mean conversion factor to qCT values through the linear regression was 0.8 (0.744 – 0.869). Using the generalized equations, the variation leads to a mean

overestimation of 4 to 7% of qCT value using HU measured in the absence of CM and 1 to 7% using HU measured in the presence of CM, depending on the observer.

Kim et al found out a value of 146 HU in a ROC with sensitivity 94.3% and specificity 87.5% [26]. Our results were in general agreement, with a sensitivity of 0.91 and a slightly better specificity of 0.93 for HU in CT scans without CM. However, our cut-off value of 93 HU was clearly lower in comparison with that reported by Kim et al. For contrast CT scans we found, despite a much smaller sample size, also comparably high sensitivity of 0.83 and specificity of 0.89 for cut-off values of 122 and 125 HU.

Our findings support the view that HU estimations from CT scans can be reliably applied to detect patients with reduced bone quality in cases of spinal trauma. In cases where HU values consistent with reduced BMD are seen, operative strategies to optimize the surgical result, for example by enhancing the implant-bone interface with PMMA, may be implemented [27, 28]. To confirm the suspicion of osteoporosis or osteopenia and obtain a specific treatable diagnosis, additional qCT or DEXA scans should be performed. In cases of spinal fracture or where spinal implants are already present, we recommend that qCT scanning be performed. Nevertheless, for preoperative planning and surgical technique adaptation, we have shown that HU measurements are sufficient to estimate BMD.

In terms of study limitations, the analyzed data set of patients with CM is small and our findings regarding the estimation of BMD using HU obtained from contrast CT scans and the cut-off values derived from ROC analysis should be viewed cautiously. Further, the retrospective character of the study may have resulted in selection bias

Conclusion

HU measurement using the technique described in this study has a very high inter-rater reliability. The HU values correlate closely with qCT BMD values. CM application increases absolute HU values in vertebral bodies. When CM CT scans are used for HU measurements, the results are not as reliable as those from native CT scans, but may still be sufficient for surgical planning purposes.

In summary, it seems that HU measurement is a suitable tool to readily and accurately assess bone quality without further scans or effort in cases of thoracolumbar spinal trauma. A surgeon using this technique can detect bone quality deterioration and modify the surgical technique appropriately and potential complications resulting from reduced bone quality can thus be avoided.

Abbreviations

BMD: bone mineral density

CM: contrast medium

CT: computed tomography

DEXA: dual-energy X-ray absorptiometry

HU: Hounsfield units

NPV: negative predictive value

PACS: picture archiving and communication system

PPV: positive predictive value

qCT: quantitative computed tomography

ROC: receiver operating characteristic

Declarations

Ethics approval and consent to participate: This study was approved by the research ethics committee of Jena University Hospital – Friedrich Schiller University, Jena, Germany (reference: 2020-2000-Daten) and was performed in accordance with the principles laid down in the current revision of the Declaration of Helsinki. It was determined that informed consent from each patient was not necessary due to the retrospective, anonymized nature of the research by the above mentioned ethics committee.

Consent for publication: The authors give the consent for publication of all contents of this manuscript.

Availability of data and material: The datasets used and analyzed with this study are available on reasonable request from the corresponding author.

Competing interests: The authors declare that they have no conflict of interest or competing interests.

Funding: This research received no specific grant from any funding agency, commercial entity or not-for-profit organization.

Authors' contributions: All authors met the authorship criteria forth by the International Committee for Medical Journal Editors and have approved the content of the manuscript. B.U and P.S. wrote the main manuscript text. A.L. performed english editing as native speaker and reviewed the manuscript. I.K., E.H., A.L., J.B. performed HU evaluation as rater and reviewed the manuscript. G.H., T.M. and F.K. reviewed the manuscript. P.S. additionally performed statistics and prepared all figures.

Acknowledgements: Not applicable

References

1. <https://service.destatis.de/bevoelkerungspyramide/> (2020) 14. koordinierte Bevölkerungsvorausberechnung des Statistischen Bundesamtes. (2019). Statistisches Bundesamt

(Destatis) Accessed 22. November 2020

2. Kumar R, Lim J, Mekary RA, Rattani A, Dewan MC, Sharif SY, Osorio-Fonseca E, Park KB (2018) Traumatic Spinal Injury: Global Epidemiology and Worldwide Volume. *World Neurosurg* 113:e345-e363. doi: 10.1016/j.wneu.2018.02.033
3. Oliver M, Inaba K, Tang A, Branco B, Barmparas G, Schnüriger B, Lustenberger T, Demetriades D (2012) The changing epidemiology of spinal trauma: a 13-year review from a Level I trauma centre. *Injury* 43:1296-1300
4. Chapman J, Bransford R (2007) Geriatric spine fractures: an emerging healthcare crisis. *Journal of Trauma and Acute Care Surgery* 62:S61-S62
5. Ullrich BW, Schenk P, Spiegl UJ, Mendel T, Hofmann GO (2018) Hounsfield units as predictor for cage subsidence and loss of reduction: following posterior-anterior stabilization in thoracolumbar spine fractures. *European spine journal : official publication of the European Spine Society, the European Spinal Deformity Society, and the European Section of the Cervical Spine Research Society*. doi: 10.1007/s00586-018-5792-9
6. Bokov A, Bulkin A, Aleynik A, Kutlaeva M, Mlyavykh S (2019) Pedicle screws loosening in patients with degenerative diseases of the lumbar spine: potential risk factors and relative contribution. *Global spine journal* 9:55-61
7. Zou D, Sun Z, Zhou S, Zhong W, Li W (2020) Hounsfield units value is a better predictor of pedicle screw loosening than the T-score of DXA in patients with lumbar degenerative diseases. *European Spine Journal*:1-7
8. Thomasius F, Baum E, Bernecker P, Böcker W, Brabant T, Clarenz P, Demary W, Dimai H, Engelbrecht M, Engelke K (2018) DVO Leitlinie 2017 zur Prophylaxe, Diagnostik und Therapie der Osteoporose bei postmenopausalen Frauen und Männern. *Osteologie* 27:154-160
9. World Health Organization (2003) Prevention and management of osteoporosis: report of a WHO scientific group. Diamond Pocket Books (P) Ltd.
10. https://www.awmf.org/uploads/tx_szleitlinien/012-028l_S1_Verletzungen-der-thorakolumbalen-Wirbels%C3%A4ule_2019-02_.pdf (2019) Accessed 22. November 2020
11. Radiology ACo (2018) ACR–SPR–SSR practice parameter for the performance of musculoskeletal quantitative computed tomography (QCT). American College of Radiology, Reston Available via <https://www.acr.org/-/media/ACR/Files/Practice-Parameters/QCT.pdf> Accessed 22. November 2020
12. Schreiber JJ, Anderson PA, Rosas HG, Buchholz AL, Au AG (2011) Hounsfield units for assessing bone mineral density and strength: a tool for osteoporosis management. *The Journal of bone and joint surgery American volume* 93:1057-1063. doi: 10.2106/JBJS.J.00160
13. Pickhardt PJ, Pooler BD, Lauder T, del Rio AM, Bruce RJ, Binkley N (2013) Opportunistic screening for osteoporosis using abdominal computed tomography scans obtained for other indications. *Ann Intern Med* 158:588-595. doi: 10.7326/0003-4819-158-8-201304160-00003
14. Jaramillo JD, Wilson C, Stinson DJ, Lynch DA, Bowler RP, Lutz S, Bon JM, Arnold B, McDonald M-LN, Washko GR, Wan ES, DeMeo DL, Foreman MG, Soler X, Lindsay SE, Lane NE, Genant HK, Silverman

- EK, Hokanson JE, Make BJ, Crapo JD, Regan EA (2015) Reduced Bone Density and Vertebral Fractures in Smokers. Men and COPD Patients at Increased Risk. *Annals of the American Thoracic Society* 12:648-656. doi: 10.1513/AnnalsATS.201412-591OC
15. Lenchik L, Weaver AA, Ward RJ, Boone JM, Boutin RD (2018) Opportunistic Screening for Osteoporosis Using Computed Tomography: State of the Art and Argument for Paradigm Shift. *Current rheumatology reports* 20:74
 16. Zou D, Ye K, Tian Y, Li W, Zhou F, Zhang Z, Lu Z, Xu Z (2020) Characteristics of vertebral CT Hounsfield units in elderly patients with acute vertebral fragility fractures. *European Spine Journal*:1-6
 17. van Dort M, Driessen J, Geusens P, Romme E, Smeenk F, Wouters E, van den Bergh J (2019) Vertebral bone attenuation in Hounsfield Units and prevalent vertebral fractures are associated with the short-term risk of vertebral fractures in current and ex-smokers with and without COPD: a 3-year chest CT follow-up study. *Osteoporosis International* 30:1561-1571
 18. Berger-Groch J, Thiesen DM, Grossterlinden LG, Schaewel J, Fensky F, Hartel MJ (2019) The intra-and interobserver reliability of the Tile AO, the Young and Burgess, and FFP classifications in pelvic trauma. *Archives of orthopaedic and trauma surgery* 139:645-650
 19. Zaidi Q, Danisa OA, Cheng W (2019) Measurement techniques and utility of Hounsfield unit values for assessment of bone quality prior to spinal instrumentation: a review of current literature. *Spine* 44:E239-E244
 20. Gerety E-L, Hopper M, Bearcroft P (2017) The reliability of measuring the density of the L1 vertebral body on CT imaging as a predictor of bone mineral density. *Clinical radiology* 72:177. e179-177. e115
 21. Pompe E, Willemink MJ, Dijkhuis GR, Verhaar HJJ, Hoesein FAAM, de Jong PA (2015) Intravenous contrast injection significantly affects bone mineral density measured on CT. *European Radiology* 25:283-289. doi: 10.1007/s00330-014-3408-2
 22. Mi J, Li K, Zhao X, Zhao CQ, Li H, Zhao J (2016) Vertebral Body Hounsfield Units are Associated With Cage Subsidence After Transforaminal Lumbar Interbody Fusion With Unilateral Pedicle Screw Fixation. *Clin Spine Surg.* doi: 10.1097/BSD.0000000000000490
 23. Youden WJ (1950) Index for rating diagnostic tests. *Cancer* 3:32-35
 24. Lee SJ, Pickhardt PJ (2017) Opportunistic screening for osteoporosis using body CT scans obtained for other indications: the UW experience. *Clinical Reviews in Bone and Mineral Metabolism* 15:128-137
 25. Gerety E-L, Bearcroft PW (2018) L1 vertebral density on CT is too variable with different scanning protocols to be a useful screening tool for osteoporosis in everyday practice. *The British journal of radiology* 91:20170395
 26. Kim KJ, Kim DH, Lee JI, Choi BK, Han IH, Nam KH (2019) Hounsfield units on lumbar computed tomography for predicting regional bone mineral density. *Open Medicine* 14:545-551

27. Geiger F, Kafchitsas K, Rauschmann M (2011) Anterior vertebroplasty of adjacent levels after vertebral body replacement. European spine journal : official publication of the European Spine Society, the European Spinal Deformity Society, and the European Section of the Cervical Spine Research Society 20:1385-1392. doi: 10.1007/s00586-011-1766-x
28. Elder BD, Lo S-FL, Holmes C, Goodwin CR, Kosztowski TA, Lina IA, Locke JE, Witham TF (2015) The biomechanics of pedicle screw augmentation with cement. The Spine Journal 15:1432-1445

Tables

Table 1
Measured Hounsfield Units (HU) by the four observers for native and contrast CT scans.

		n	minimum	maximum	mean $\pm$ sd
native scans	HU (J.B.)	328	-18	267	95 $\pm$ 37
	HU (A.L.)	328	-24	250	98 $\pm$ 39
	HU (E.H.)	328	-24	255	98 $\pm$ 41
	HU (I.K.)	328	-14	250	96 $\pm$ 39
contrast scans	HU (J.B.)	21	55	195	123 $\pm$ 33
	HU (A.L.)	21	57	226	123 $\pm$ 37
	HU (E.H.)	21	57	227	124 $\pm$ 40
	HU (I.K.)	21	61	179	120 $\pm$ 37

Table 2
Inter-item correlation matrix for Hounsfield units (HU) determined from scans with and without contrast medium (CM), determined independently by four observers.

		HU (J.B.)	HU (A.L.)	HU (E.H.)	HU (I.K.)
native scans	HU (J.B.)		0.925	0.919	0.918
	HU (A.L.)	0.925		0.961	0.940
	HU (E.H.)	0.919	0.961		0.939
	HU (I.K.)	0.918	0.940	0.939	
contrast scans	HU (J.B.)		0.924	0.867	0.826
	HU (A.L.)	0.924		0.927	0.883
	HU (E.H.)	0.867	0.927		0.911
	HU (I.K.)	0.826	0.883	0.911	

Table 3
Results of the linear regressions model for each observer, to predict qCT values using Hounsfield units (HU) from CT scans with and without contrast medium (CM).

		n	r	p value	constant	factor
native scans	HU (J.B.)	328	0.95	< 0.001	-1.00	0.869
	HU (A.L.)	328	0.91	< 0.001	4.27	0.792
	HU (E.H.)	328	0.89	< 0.001	8.74	0.744
	HU (I.K.)	328	0.89	< 0.001	7.43	0.777
	mean $\pm$ sd				5 $\pm$ 4	0.8 $\pm$ 0.05
contrast scans	HU (J.B.)	21	0.81	< 0.001	-6.75	0.641
	HU (A.L.)	21	0.89	< 0.001	-5.02	0.624
	HU (E.H.)	21	0.83	< 0.001	3.15	0.552
	HU (I.K.)	21	0.90	< 0.001	-5.50	0.644
	mean $\pm$ sd				-4 $\pm$ 5	0.6 $\pm$ 0.04

Table 4

Results of the bivariate correlation analysis ($p < 0.001$) of the measured and predicted qCT values for the four observers. The correlation coefficient (r) is given for qCT from scans with and without contrast medium (CM). The mean $\pm$ sd values and the mean deviation of the measured qCT values are shown.

		qCT _{predicted} (J.B.)	qCT _{predicted} (A.L.)	qCT _{predicted} (E.H.)	qCT _{predicted} (I.K.)
native scans	r	0.949	0.912	0.889	0.888
	qCT _{predicted}	81 $\pm$ 30	83 $\pm$ 31	84 $\pm$ 33	82 $\pm$ 31
	mean difference	4%	7%	7%	5%
contrast scans	r	0.815	0.891	0.831	0.898
	qCT _{predicted}	70 $\pm$ 20	70 $\pm$ 23	71 $\pm$ 24	68 $\pm$ 22
	mean difference	7%	4%	5%	1%

Table 5

Results of the ROC analysis using the Youden index to calculate the cut-off value and its sensitivity and specificity for osteoporosis (qCT < 80). The area under the curve (AUC), the positive (PPV) and negative predictive values (NPV) in percentages and the classification results are provided.

	observer	AUC	HU cut-off	Sensitivity	Specificity	PPV	NPV
native scans	HU (J.B.)	0.98	93	0.906	0.930	93% (155/166)	90% (146/162)
	HU (A.L.)	0.96	96	0.889	0.892	69% (171/248)	100% (80/80)
	HU (E.H.)	0.94	97	0.854	0.866	68% (170/249)	99% (78/79)
	HU (I.K.)	0.94	94	0.865	0.860	65% (171/264)	100% (64/64)
contrast scans	HU (J.B.)	0.84	125	0.750	0.889	90% (9/10)	73% (8/11)
	HU (A.L.)	0.91	122	0.833	0.889	91% (10/11)	80% (8/10)
	HU (E.H.)	0.89	125	0.833	0.889	91% (10/11)	80% (8/10)
	HU (I.K.)	0.88	129	0.833	0.778	83% (10/12)	78% (7/9)

Figures

A) without CM

B) with CM

Figure 1

Multiple scatter plot of Hounsfield Units (HU) measured by four observers for HU (a) without contrast media (CM), and (b) with CM. Linear regression between the observers and its CI95 is shown in orange.

A) without CM

B) with CM

Figure 2

ROC-curves for each observer and their measured HU (a) of 328 patients in native CT scans to predict osteoporosis (qCT<80) and (b) 21 patients with contrast CT scans to predict osteoporosis classified by the qCT values.