Association between Hounsfield Units in Preoperative Wrist Computed Tomography Scans and Outcomes after Wrist Fracture Surgery.

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Article

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Abstract

Purpose

This work aims to evaluate the hypothesis that the value of Hounsfield units (HU), as a marker of bone density, in preoperative wrist computed tomography (CT) scans correlates with the functional outcomes as measured by patient reported outcomes (PROs) after distal radius fracture surgery with volar locking plate fixation.

Methods

Of a database of 92 wrist fractures operated on in our hospital between 2011 and 2020, with a preoperative CT scan performed, we selected the cases with a minimum follow-up period of 12 months. After applying the exclusion criteria, the final cohort comprised 64 patients. Three measurements of HU were performed in correlative coronal sections of the capitate bone. PROs were determined using two functional questionnaires (DASH and PRWE) and one quality of life questionnaire (SF-12). The statistical relationship between PROs and the HU measurements obtained via a CT scan was analyzed.

Results

Patients were classified into two groups, osteoporotic (OST) or non-osteoporotic (non-OST), according to the optimal cut-off value of 323 HU selected using a ROC curve. The median DASH questionnaire score in the OST group was significantly higher (1.7 vs 10.0, $p = .003$) as was the PRWE function subscale score (0 vs 3, $p = .031$).

Conclusion

HU values in preoperative wrist CT scans may help to identify osteoporotic bone in patients prior to wrist fracture surgery and lead to an improved surgical indication and treatment strategy.

Introduction

The incidence of wrist fractures is increasing, particularly among the elderly as a result of longer life expectancy. A recent study predicted a 23% increase in the number of fractures by 2036 and a 33% increase among individuals older than 50 years of age [1]. This trend would entail a considerable increase in cost and morbidity.

Nowadays, the elderly tend to be more active and have greater social and cultural engagement. As a result, they demand better functional outcomes after a wrist fracture. However, wrist fracture surgery in this group is more challenging due to poor bone quality. Osteoporosis affects bone biomechanics, causing greater comminution of the fracture, more instability, and a greater tendency toward malunion [2, 3], all of which may affect functional outcomes after wrist fracture surgery.

For intra-articular fractures with a surgical indication, a preoperative wrist CT scan helps during surgery planning and is increasingly ordered [4]. According to some authors, it is possible to obtain more information about bone quality from the presurgical CT scan by measuring the Hounsfield units (HU) of the trabecular bone. A HU is a dimensionless unit that expresses a linear transformation of the attenuation coefficient of different tissues measured in a CT scan. Distilled water is established as 0 HU and pure air as -1000 HU [5]. As the density or attenuation value of a tissue increases, the HU value increases. The attenuation coefficient—and therefore the HU value—of bone is high (approximately + 2000 for very dense bone). Osteoporosis leads to bone density loss, so the HU values in osteoporotic bone will most likely be lower.

Knowing the bone quality of the wrist before surgery may change surgical action in wrist fractures. In cases of poor bone quality, the surgical results may not be better than non-operative treatment. It could also help in choosing the type and position of the volar plate, the indication of the graft in the focus, and the period of postoperative immobilization, thus improving functional outcomes.

HU measurements may also detect osteoporosis, as some authors have postulated [6–8]. Osteoporosis is the most common metabolic bone disorder and has serious consequences for the individual and public health in general, such as functional disability and increased healthcare expenditure [9]. Fractures of the distal end of the radius are considered "sentinel fractures” of osteoporosis because they help in early diagnosis of the disease. Therefore, improving diagnosis of osteoporosis could lower the incidence of hip fractures, for example, which are a costly entity associated with poor health outcomes, without incurring additional costs [10].

It is unclear whether HU measurements correlate with functional outcomes after surgery. This study will examine the correlation between HU and three patient-reported outcomes (PROs) questionnaires: the 12-Item Short Form Health Survey (SF-12); the Disabilities of the Arm, Shoulder and Hand (DASH) questionnaire; and the Patient-Rated Wrist Evaluation (PRWE) in a follow-up period of at least one year. The primary outcome measure is the DASH questionnaire.

We hypothesize that there is a correlation between HU and functional outcomes after wrist fracture surgery. Our primary aim is to determine the relationship between HU values in the preoperative wrist CT scan and the DASH results obtained after wrist fracture surgery at the end of the follow-up period.

Results

Characteristics of the group

Our study population included 64 cases. The patients had a mean age of 55.4 ± 15.5 years (range 22–84). The majority of patients (69%) were younger than 65 years of age. Only five patients were over 75 years of age and all of them lived independently. 50% of the OST group (13 cases) were < 65 years old (professionally active and independent). On the other way, 55% of the patients > 50 years old (risk of osteoporosis category) were in the OST group.

The median time of follow-up was 39 months (IQR: 16–52 months). Although only six patients (9%) included in the study had a previous diagnosis of osteoporosis, 11 (17%) had a previous osteoporotic fracture.

The mean HU value obtained from the three different coronal slices for each patient was 352.7 ± 84.7. The mean values of the capitate slices were HU1 of 323.3 ± 84, HU2 of 403.1 ± 92, and HU3 of 331.5 ± 93. The central coronal slice had a significantly higher HU value than the more volar and dorsal slices.

Based on the relationship between the data on the 26 patients who had a DEXA scan and the HU value on the ROC curve, our cohort was divided in two groups according to the threshold of 323 HU: the osteoporotic (OST) group, with HU ≤ 323, and non-osteoporotic (Non-OST) group, with HU > 323. For those patients with a DEXA confirmed diagnosis of OP (T-score ≤ -2.5) the mean HU was 322 ± 48. The area under the curve was 0.714, with a sensitivity of 63% and specificity of 86% for the detection of osteoporosis (Fig. 1).

A comparison of the patient characteristics between the groups showed no differences in regard to the independent variables except for age and sex (Table 1).

Patient-reported outcomes (Table 2):

A statistically significant difference was found between responses to the DASH questionnaire ($p = .008$) between the groups. There were no significant differences among the other outcomes (PRWE-total, PRWE-function and PRWE-pain; and SF-12), though the median value of PRWE-total was higher in the OST group (7.5, range 0.8–31.5) than in the non-OST group (2.3, range 0-11.2).

Radiological characteristics

The median time between fracture and preoperative MDCT was six days in both groups (IQR: 1–10) ($p = .983$). This corresponded to the period of immobilization before surgery which could affect bone quality —and consequently the HU measurement—due to disuse. In regard to the radiological factors, there was a slight yet statistically significant difference between the groups in the kilovoltage (kVp) used ($p = .049$) (Table 3). The Table 4 shows that at different kV, the DASH questionnaire is higher in the cases with HU < 323, so although the kV influences it does not significantly change the relationship between HU measure and DASH results.

Surgical and postoperative characteristics

All patients who met the inclusion criteria were operated on with volar locking plate fixation in the same conditions. There were no statistical differences between either group in the surgical variables nor in postoperative treatment (Table 5).

Complications

Major complications included loss of reduction or articular collapse in three cases (all in the OST group). There were no cases of deep tissue infection, permanent neuropathy, or tendon rupture.

Minor complications included tendon irritation requiring hardware removal in two cases; transient neuropathy requiring carpal tunnel release in two cases; and reflex sympathetic dystrophy with articular and finger stiffness in four cases (6.3%), three of which required arthroscopic arthrolysis. There were no superficial infections.

Discussion

The OST and non-OST groups in our study had similar characteristics in regard to patient and surgical variables, even the casting duration and length of rehabilitation. They only differed in age and sex, perhaps as a result of the fact that these variables are both intimately linked to osteoporosis.

In this study, the OST group had a worse result on the DASH questionnaire than the non-OST group ($p = .003$). This is in line with the results of the work by Fitzpatrick et al. [14]. Their work studied the effect of osteoporosis on functional outcomes after wrist fracture surgery. Like our study, they found a relationship between osteoporosis and outcomes, though unlike in our work, they diagnosed osteoporosis using DEXA and we did so by evaluating HU values in CT scans.

Fitzpatrick et al. also found that osteoporosis negatively affected PROs regardless of age. However, their group comprised 64 women over 50 years of age. In contrast, our study group consisted of patients with an identical diagnosis (intra-articular distal radius fractures (DRF)) and though age differed between our groups, 89% of patients in the OST group were over 50 years of age ($p = .001$). Bone mineral density has been shown to decline after age 50 and therefore, age is a key factor in patients with fragility fractures [14].

There is controversy on the use of CT scans to detect osteoporosis by measuring the HU values of trabecular bone. The International Society for Clinical Densitometry states it is possible only if validated machines are used and scanner stability has been established. In current clinical practice, these are difficult conditions to meet. Some authors have proposed a correlation between wrist CT scan HU values and DEXA scan values [7], but some of these works include non-enhanced and enhanced scans, which could affect the HU values measured [15]. All of our patients underwent non-enhanced scans and therefore possible differences as a result of enhancement or non-enhancement were not present in our results.

We chose the trabecular bone of the capitate for HU measurements, as did Johnson et al. [7], because the capitate is located away from the DRF site and there are few direct contusions in this type of trauma. This is important because it reduces the risk of presence of edema, which is not visible on the CT scan and which could alter HU values by increasing the mean value of bone marrow. In addition, fatty marrow conversion in the capitate is evident from an early age and is probably very similar in both sexes. This is in contrast to the lumbar spine—an area where HU are frequently measured—as it is part of the axial skeleton, which shows greater variability of composition as individuals age.

Some authors have measured HU values in the trabecular bone of the distal radius and ulna after DRF [6, 8, 16]. However, it is likely that fatty marrow embedded between the trabeculae is infiltrated by blood and edema, which could cause the HU value to rise. As the capitate has fewer degenerative changes than the spine, its use also avoids the distortion of true values by sclerosis, which produces degenerative changes.

Our measurements of the capitate showed that the central coronal slice had a significantly greater HU value than the more volar and dorsal slices. There is most likely denser trabecular bone in this part of the capitate, however no other authors have described similar findings. In fact, Schreiber et al. found very similar HU values in each slice and even proposed that just one measurement could be enough [6].

To obtain the threshold HU value, we used the 26 patients (41%) in our cohort who had DEXA scan results. The work by Johnson et al. found a correlation between the HU values and DEXA; we reproduced their technique for measuring the capitate HU value [7]. Our cut-off value of 323 HU differs from that of Johnson et al., which was 307, but the differences could be explained by the fact that the study populations were different: our group included both men and women, instead of just women, and all our patients had wrist fractures instead of other wrist pathologies.

Different voltages are related to different HU values in the same patient when assessing vertebral bodies or when using phantoms [17]. It has been demonstrated that the mean HU decreases as tube voltage increases [18], though to our knowledge, this has not been confirmed in the appendicular skeleton. Our study's findings were in line with this observation and found that there was a slight but statistically significant difference between tube voltages used and HU values obtained ($p = .049$). This is one of the limitations of the study and indeed further research should stratify patients by the kVp used in light of the differences in HU measurements obtained. Furthermore, the results reported in this work must be considered with caution, given that patients whose measurements were taken with different tube voltages were analyzed jointly. To our knowledge, most studies include patients with CT scans performed with a tube voltage of 120 kVp. Some authors do not specify the tube current used, which can be considered a limitation in their works.

Another limitation of this study is its retrospective nature. However, the two groups were similar in terms of almost all the independent variables assessed in this study, including all surgical and postoperative variables.

In regard to the secondary outcomes, no significant difference among the PRWE-total and SF-12 questionnaires were found, but the results of the PRWE-function subgroup were significantly different. This could indicate a possible limitation of sample size.

One of the strengths of our study was the long follow-up period. A systematic review of DRF outcomes by Diaz-Garcia et al., which used the Structured Effectiveness Quality Evaluation Scale (SEQES) to evaluate the quality of the articles, indicated that a minimum follow-up period of approximately 12 months should be used [19]. Our work only included patients with a follow-up period of at least one year, in accordance with Díaz-García et al.'s recommendations.

We did not include range of motion, strength, or radiographic outcomes as part of this work due to the extensive amount of literature describing how measured impairments are not directly linked to self-reported functional outcomes, which cover a different aspect of health. Indeed, Goldhahn et al. recommend a core set of domains for reporting outcomes in DRFs that include function and pain outcomes rather than radiological or wrist motion parameters, which are considered optional outcomes for analysis [20].

All major complications observed in this work (articular collapse that required additional surgery) occurred in the OST group. However, to date, the link between osteoporosis and postoperative complication remains controversial [14, 21].

As a minority of the wrist fractures cases in our study had a CT scan performed for surgical management (26%), it is unknown whether our cohort is truly representative of the larger DRF cohort. Our work analyzed preoperative wrist CT scans that were carried out mainly in complex fractures with comminution. Therefore, we cannot extrapolate our results to other types of wrist fracture and as such, broader prospective studies are necessary to definitively establish the relationship between HU values and wrist fracture surgery outcomes.

In conclusion, we assert that measuring HU in a preoperative wrist CT scan offers valuable information for the diagnosis of distal radius bone quality prior to surgery. It is especially useful in patients over 50 years of age and may modify the treatment strategy or even the relevance of surgery in these cases.

Materials And Methods

Study Design

This work is a retrospective, single-center cohort study of patients selected from a database of wrist fracture surgeries with volar locking plate fixation performed with a preoperative non-enhanced CT scan of the wrist in 92 patients, between 2011 and 2019.

This study was approved by the local Research Ethics Committee (COMITÉ ÉTICO DE INVESTIGACIÓN DEL HOSPITAL CLÍNICO SAN CARLOS DE MADRID (CEIm Hospital Clínico San Carlos). For this type of study, formal consent is not required, and was waived by the local Research Ethics Committee (COMITÉ ÉTICO DE INVESTIGACIÓN DEL HOSPITAL CLÍNICO SAN CARLOS DE MADRID (CEIm Hospital Clínico San Carlos)). All methods were performed in accordance with the relevant guidelines and regulations, in accordance with the Declaration of Helsinki.

Inclusion factors were a valid preoperative multidetector computed tomography (MDCT) scan as well as complete answers to the three patient-reported outcomes (PROs) questionnaires—DASH, PRWE, and SF-12—at least 1 year after surgery. Criteria for surgery were no acceptable anatomical reduction obtained after traction and casting as measured by radial and sagittal angulation; ulnar variance; and/or the presence of joint steps measured on the post-reduction x-ray. Secondary fracture displacement during follow-up was also a criterion for intervention.

The exclusion criteria in regard to HU measurements in the preoperative wrist CT scan were poor CT scan quality; CT scans performed by other institutions; inadequate patient position or movement during the CT scan with poor image quality; and the presence of associated carpal bone fractures, given that they entail a higher probability of capitate contusion with consequent edema, which could alter the HU value. Fifteen patients were excluded from the study for these reasons.

Three PROs questionnaires were administered: DASH, PRWE, and SF-12. The DASH questionnaire was the primary outcome measure because it is the most frequently used in the literature and is well-validated [11]. The DASH questionnaire (30 items measuring disability and symptoms related to the upper extremity) is scored from 0 to 100, with a higher score indicating higher disability. The PRWE is a wrist outcome measurement tool based on an assessment of pain and ability to do activities related to daily living and work [12]. The SF-12 questionnaire examines quality of life. It has 12 items and is divided into a physical component score (PCS) and a mental component score (MCS), each normalized to a mean of 50 and a standard deviation of 10 compared to the general population, with higher scores indicating better quality of life [13]. We excluded 14 patients who did not properly answer the questionnaires (one patient died, one had a mental disability, 12 had inadequate follow-up). The final cohort comprised 64 patients (Fig. 2).

Dual-energy X-ray absorptiometry (DEXA) was performed in 26 (41% of the final cohort of the patients in the study population) within one year of the CT scan. The lowest T-score was used to determine presence of osteoporosis, as recommended in the Clinician's Guide to Prevention and Treatment of Osteoporosis. In this subgroup of patients, 19 (73%) had osteoporosis, established as a T-score ≤ -2.5.

The independent variables collected were patient characteristics (demographic, medical history related to osteoporosis, mechanism of injury and obesity (as a factor related to the mechanism of injury), AO classification of the fracture, and dominance), surgical and postoperative data that we considered could affect outcomes, and radiological factors that could alter the HU value (the main dependent variable).

Hounsfield Unit Methodology

All non-enhanced MDCT scans were performed with the patient in the prone position with the palm of the hand facing downwards, placed above the head, and resting flat on the table. In this position, x-ray beams did not interact with other organs or structures. All scans were performed with an immobilization cast after closed reduction. All casts were of similar thicknesses and characteristics. The studies were carried out on two different OPTIMA CT660 (GE) 64-MDCT scanners. Automatic tube current modulation was disabled. The standard CT image acquisition protocol for wrist examination in clinical practice was followed (section thickness 0.625, pitch 0.531), though different kV were used for the acquisitions (100,120 and 140 kv). All CT images were stored using a picture archiving and communication system (PACS).

The post-processing tool used was a Philips IntelliSpace Portal v.7.0.3.20090. A standard bone reconstruction algorithm was applied for multiplanar reconstruction. Three coronal consecutive reconstructions of the capitate along its major axis were obtained, each measuring 2 mm thick (media reconstruction), according to a previously published protocol for other anatomical structures. Irregular Regions Of Interest (ROI) were manually traced in each consecutive coronal image of the capitate: one on the middle zone (HU2), one on the volar zone (HU1), and one on the dorsal zone (HU3), including as much trabecular bone as possible and avoiding the cortical bone, a narrow peripheral rim between cortex and trabeculae, cysts, and bone islands (Figs. 3 and 4). The mean HU values of trabecular bone for each image were obtained from the three values measured in each patient; this mean value was obtained for statistical analysis. The measurement was performed by a radiologist who was not informed about the patients' clinical data, background, surgery, postsurgical progress, or outcomes.

Statistical Analysis

Qualitative variables are shown along with the distribution of absolute and relative frequencies. Quantitative variables are shown as means and standard deviation (SD). Variables that did not follow a normal distribution are shown as medians and interquartile ranges (IQR). The normality study was performed by means of a visual inspection of the histogram and quantitative graphs (normal Q-Q plots).

A receiver operating characteristic (ROC) curve was used to establish the HU cut-off point that best discriminates between patients with and without osteoporosis. A cut-off point was selected with the best Youden index.

A comparison of the means of multiple variables between the groups according to the selected HU cut-off point was carried out using Student's t-test when the variables followed a normal distribution or using the non-parametric Mann-Whitney U test when they did not. The association between qualitative variables was analyzed using the chi-square test or Fisher's exact test, when necessary.

Significance was established as $p < .05$. Data processing and analysis were performed using the SPSS v. 21.0 statistical package.

Declarations

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CONFLICT OF INTEREST STATEMENT:

Neither the authors, their immediate family members, or any research foundation with which they are affiliated have received any remuneration or other benefits from any commercial entity related to the subject of this article.

Ethical approval: This study was approved by the local Research Ethics Committee. Consent to Participate: For this type of study, formal consent is not required.

Consent for publication: All authors meet the authorship criteria and agree to the publication of their contributions. This manuscript has been read and approved by all authors.

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

REPORTING GUIDELINES:

The authors have adhered to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines.

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Tables

Table 1 Comparison of patient characteristics between the groups.

Patient characteristics	Total	Non-OST group (n= 38) n (percentage)	OST group (n=26) n (percentage)	*p* value
Age (years)*		50.8 ± 14.9	62.1 ± 14.0	.004
Female **	70%	20 (53%)	25 (96%)	< .001
Previous Osteoporosis	9.4%	2 (5.3%)	4 (15%)	.213
Previous Fracture	17%	6 (16%)	5 (19%)	.746
Posterior Fracture	11%	3 (7.9%)	4 (15%)	.428
Tobacco Use **	23%	7 (18%)	8 (31%)	.252
Anticoagulant Use	6.3%	3 (7.9%)	1 (3.8%)	.640
Corticoid Use	6.3%	3 (7.9%)	1 (3.8%)	.640
Psychotropic Use	16%	3 (7.9%)	7 (27%)	.076
Obesity **	28%	13 (36%)	4 (16%)	.085
Mechanism of injury:				.254
Low energy	59%	22 (58%)	16 (62%)	
Medium energy	20%	6 (16%)	7 (27%)	
High energy	20%	10 (26%)	3 (12%)	
Dominant Hand **	30%	13 (34%)	6 (23%)	.338
AO Classification:				.193
A	1.6%	0 (0%)	1 (3.8%)	
B	11%	6 (16%)	1 (3.8%)	
C	87%	32 (84%)	24 (92%)	
C3		20 (53%)	13(50%)	

*Shown as mean ± SD, compared using two independent Student's t-tests. **Compared using the chi-square test.

Table 2 Patient-reported outcomes (PROs).

Patient-reported outcomes (PROs).	Non-OST group (n=38)	OST group (n=26)	*p* value
DASH *	1.8 (0.0-10.4)	9.6 (2.5-25.5)	.008
PRWE (total)*	2.2 (0-12)	7.5 (0.8-35.4)	.111
PRWE (Pain subscale) *	2 (0-8)	6.5 (0-17.8)	.163
PRWE (Function subscale) *	0 (0-4.5)	3 (0-11)	.062
SF-12 (Physical)**	50 ± 9.7	49 ± 9.0	.476
SF-12 (Mental)**	49 ± 9.6	44.3 ± 12.3	.077

*Shown as medians and interquartile range, compared using the nonparametric Mann- Whitney U-test.
***Shown as mean ± SD, compared using two independent Student's t-tests.

Table 3 Radiological characteristics.

Radiological Characteristics	Total	Non-OST group (n= 38) n (percentage)	OST group (n=26) n (percentage)	*p* value
Type of Scanner **:				.545
1	47%	19 (50%)	11 (42%)	
2	53%	19 (50%)	15 (58%)	
kVp of the CT scan**:				.049
100	59%	27 (71%)	11 (42%)	
120	22%	7 (18%)	7 (27%)	
140	19%	4 (11%)	8 (31%)	
Time to CT scan (days)*		7 ± 5.8	7 ± 7.6	.983

*Shown as mean ± SD, compared using two independent Student's t-tests. **Compared using the chi-square test.

Table 4 is available in the Supplementary Files section.

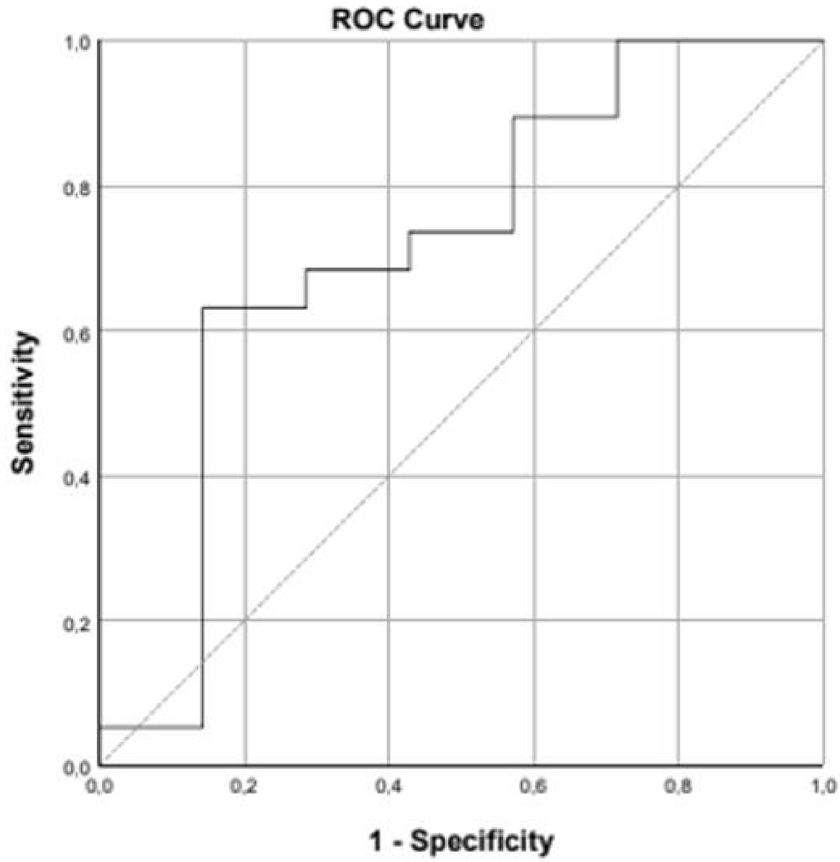
Table 5 Surgical characteristics and postoperative complications.

Surgical Characteristics and postoperative complications	Total n (percentage)	Non-OST group (n= 38) n (percentage)	OST group (n=26) n (percentage)	*p* value
Time to surgery (days)*		13.6 ± 5.4	13.9 ± 8.0	.899
Bone graft **	28 (44%)	15 (40%)	13 (50%)	.404
Tourniquet time (minutes)*		99.8 ± 33.7	94.1 ± 24.8	.471
Reflex sympathetic dystrophy	4 (6.3%)	3 (7.9%)	1 (3.8%)	.640
Additional surgery	14 (22%)	6 (16%)	8 (31%)	.155

* Shown as mean ± SD, calculated using two independent Student’s t-tests. **Compared using the chi-square test. FCT: Fibrocartilage triangle.

Figures

ROC Curve



Area Under the Curve

Test Result Variable(s): HU MEDIA

Area	Std. Error[a]	Asymptotic Sig.[b]	Asymptotic 95% Confidence Interval	
			Lower Bound	Upper Bound
,714	,127	,099	,465	,964

a. Under the nonparametric assumption

b. Null hypothesis: true area = 0.5

Figure 1

A receiver operating characteristic (ROC) curve was used to establish the HU cut-off point that best discriminates between patients with and without osteoporosis. (Área=Area; Media=Mean; DE= SD; Perim=Circum)

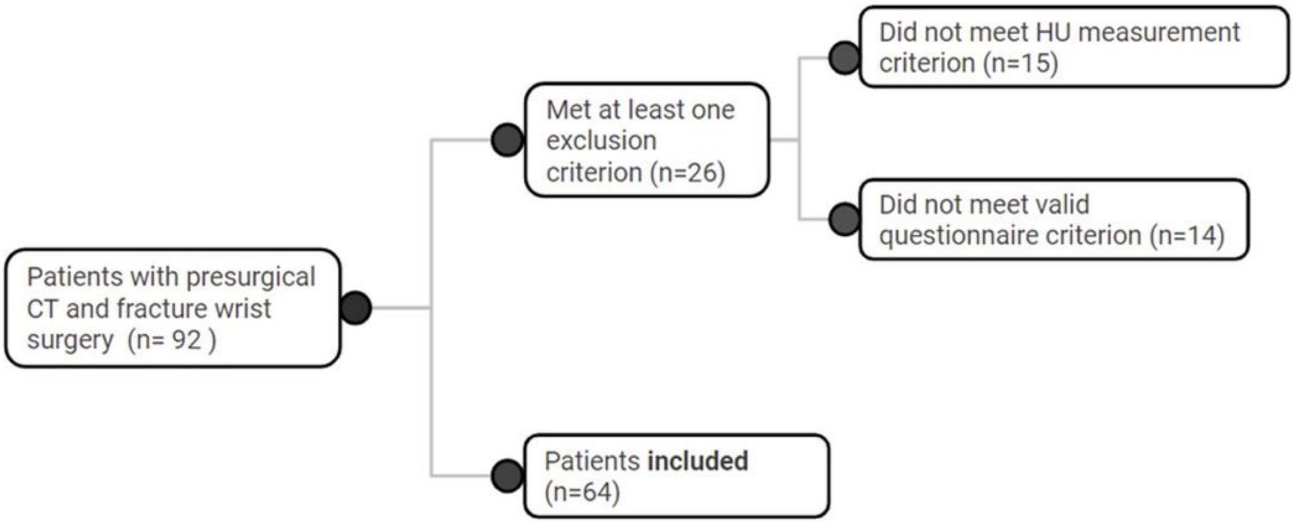


Figure 2

Patient inclusion flowchart.

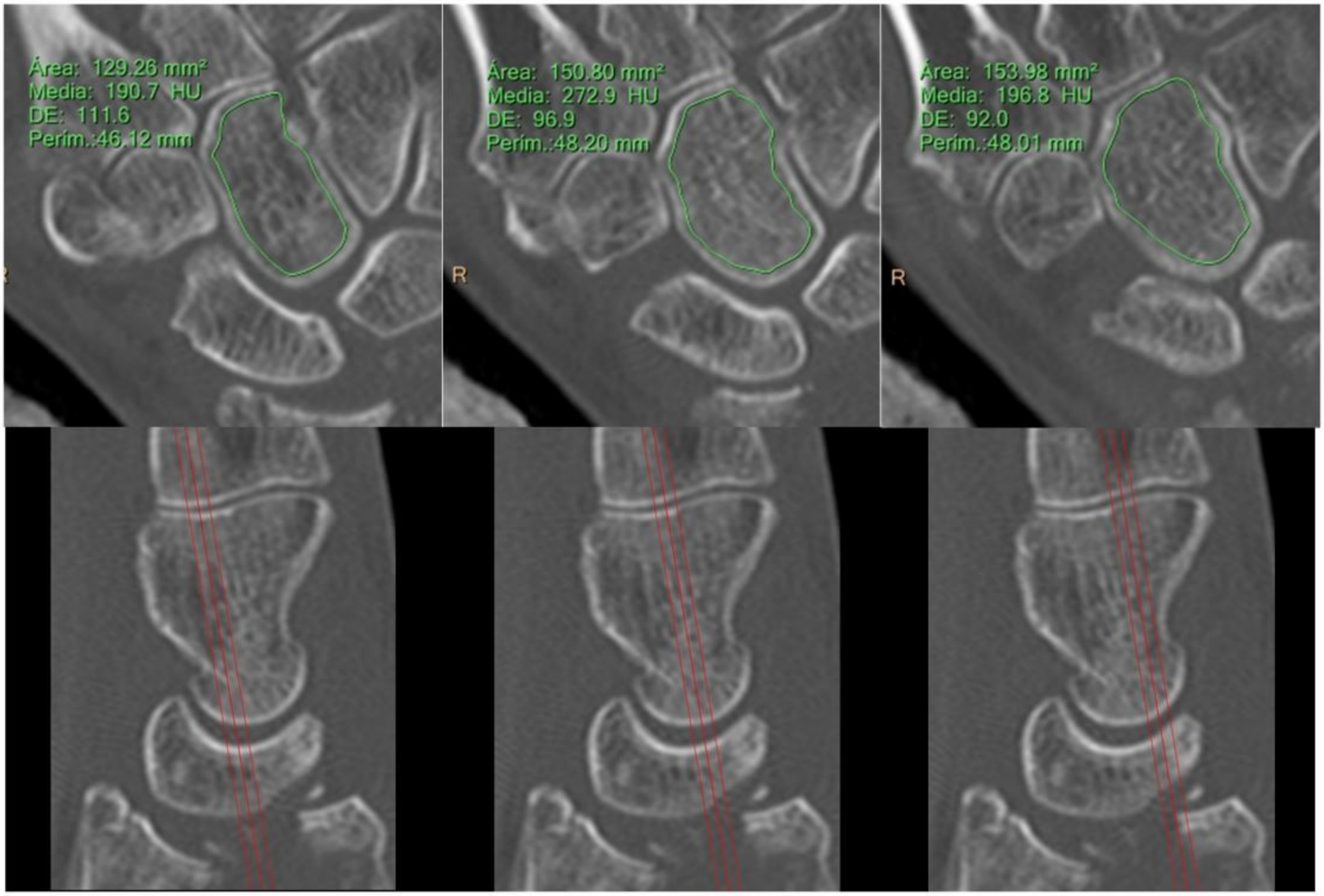


Figure 3

The images above show the three coronal slices along the long axis of the capitate in which a ROI (green) has been manually plotted to obtain mean HU values. The images below show the sagittal reconstruction of each of the 2-mm thick cuts (red), with AIP reconstruction, from volar to dorsal and from left to right.

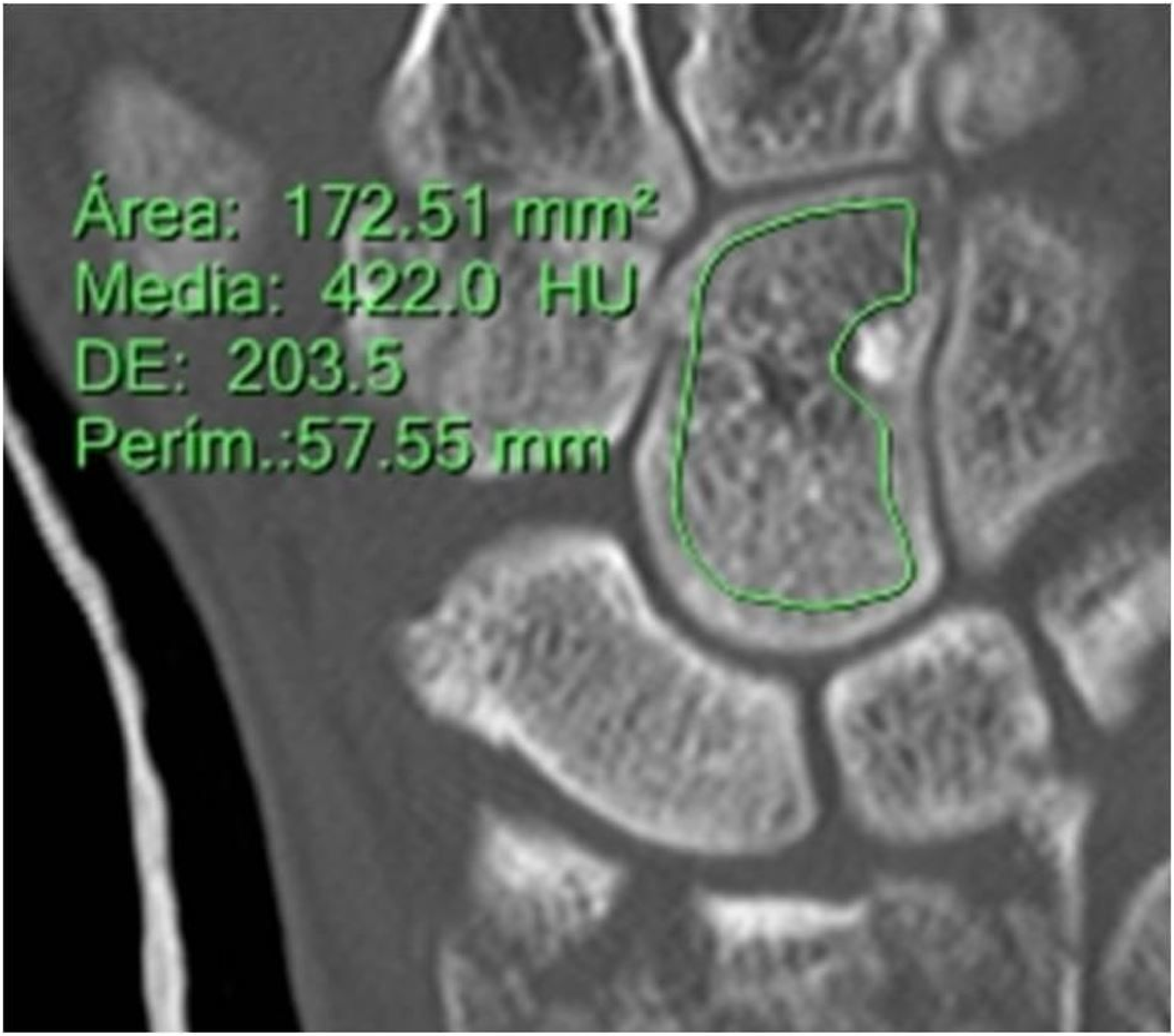


Figure 4

This example shows how elements such as bone islands or cysts are excluded so that they do not alter mean HU values. In this case, we excluded a manually plotted juxtacortical bone island from the ROI.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Table4.jpg