Dual-energy contrast-enhanced CT to evaluate Scaphoid Osteonecrosis with surgical correlation

Pianta M (1)*, McCombe D (2), Slavin J (3), Hendry S (3), Perera W (1)

Marcus Pianta (corresponding author, Department of Medical Imaging)

David McCombe (Department of Surgery)

John Slavin (Department of Anatomical Pathology)

Shona Hendry (Department of Anatomical Pathology)

Warren Perera (Department of Medical Imaging)

St Vincent's Hospital

Fitzroy, Victoria, Australia 3065

marcus.pianta@svha.org.au

+613-9288-4310

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DR. MARCUS PIANTA (Orcid ID : 0000-0001-5015-3361)

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Abstract:

Objective, To evaluate the validity of contrast enhanced dual energy CT using a lung perfusion algorithm in assessing for post-traumatic scaphoid proximal pole avascular necrosis.

Materials and Methods, From Aug 2013 to Aug 2016, 18 patients (19 wrists, 16 males, 2 females, mean age 28 years) were assessed as high-risk for proximal pole scaphoid avascular necrosis by a single surgeon following a scaphoid fracture and were referred for contrast-enhanced dual energy CT. 8 wrists had specimens sent for correlative histological analysis and 11 were correlated with operative notes.

Results, 8 surgical specimens were sent to histology and showed a 100% correlation (8/8) with the DECT findings. The remaining 11 wrists that did not have a specimen sent had in-surgery findings that also correlated with DECT. A single case was discrepant (1/11) due to presence of an intra-osseous ganglion, which was reported as osteonecrosis on CT, but considered viable at surgery. No case was called viable on CT that proved to be necrotic at either surgery or histologically.

Conclusion, Contrast-enhanced dual energy CT using a perfusion algorithm is an innovative and promising method in evaluating viability of the post-trauma proximal pole of scaphoid.

Keywords:
computed tomography; dual energy; osteonecrosis; perfusion; scaphoid; vascularity

Introduction:

It is crucial to identify avascular necrosis of the proximal pole fragment in scaphoid fractures given the implications of impaired fragment vascularity for management and prognosis (1).

The predominant scaphoid blood supply enters the scaphoid distally via the dorsal ridge of the scaphoid, and a fracture of the waist or proximal scaphoid leaves the proximal pole susceptible to avascular necrosis (AVN) given this will disrupt the intraosseous vessels. Impaired vascularity of the proximal fragment contributes to a greater risk of nonunion (1,2). The reference standard for assessing vascularity of the proximal scaphoid pole in treating nonunited fractures is direct assessment of the degree of intraoperative bleeding from the cancellous bone of the proximal pole fragment (3).

Whilst MRI is an excellent modality for assessing a scaphoid fracture as well as associated cartilage and ligamentous damage, it can also help evaluate vascularity and integrity of the proximal pole (2). Problems with MRI include access, economic cost, extended time to complete the study, contraindications such as some pacemakers or cochlear implants, patient claustrophobia and allergy to contrast dye (gadolinium). Many of these can be addressed with use of Computed Tomography (CT), but traditionally this has not provided adequate information about proximal pole vascularity.

Computed Tomography can reveal more detail than plain radiographs which are often performed at the time of initial injury (3). CT can identify an occult fracture and better demonstrate fracture anatomy and assist in treatment planning in cases where there is ongoing pain despite good early healing or where there is some complication such as comminution, displacement, intra-articular step and suspected cartilage damage. Determining the anatomy of the fracture, particularly whether of the scaphoid waist compared to a proximal pole is also important given the improved surgical outcomes for the former (4).

Dual Energy CT is a scan technique that utilises differences in material atomic number, assessed with 2 beams of ionizing radiation at different energies (kVp). In musculoskeletal imaging, this has been used to good effect in assessing gout, metal artifact reduction and bone bruising (5). In thoracic imaging, CT perfusion can be performed of the lungs in cases of suspected pulmonary embolus (6), whereby an

iodine map is generated on a post-contrast study using values of air, soft tissue and contrast medium ratio. In this way regions of lung parenchyma can be assessed for decreased iodine uptake ('contrast enhancement'), which can indicate more proximal vascular arterial occlusion. We have adapted this technique to assess scaphoid vascularity.

The objective of our pilot study is to correlate post-contrast Dual energy CT using a lung perfusion-algorithm in suspected post traumatic scaphoid proximal pole AVN with surgery and histology.

Materials and Methods:

Institutional Review Board ethics approval was obtained for this retrospective review study. All patients with a scaphoid fracture and clinical concern for proximal pole avascular necrosis (AVN) from August 2013 to August 2016 who were referred to a hand surgeon and had undergone DECT were considered for the study (54 patients, 55 wrists). 36 patients were excluded due to being considered at a 'lower-risk' by the surgeon. A total of 18 patients (19 wrists, 2 females and 16 males, age range 15 – 61 years, mean 28, median 24) were included and of these, 8 wrists underwent surgery with surgical specimens sent for histopathological correlation (approximately 0.2-0.4 cc^3 fragments of bone). 11 wrists underwent DECT and correlation with operative notes without histology specimen sent. Those with multiple DECT scans had all included in the analysis (single patient, one CT scan each wrist).

Patients were scanned following intravenous contrast administration (75 cc Omnipaque-370 (GE Healthcare, Princeton, New Jersey) 90 second delay) at dual energy on a Siemens Somatom Force CT scanner (Siemens AG, Erlangen, Germany). One wrist was scanned per field of view. Post processing was performed on the Syngo.Via workstation, version 2.0 VA30A, (Siemens Healthcare, Erlangen, Germany) and images sent to PACS. All scans were read by 2 fellowship trained musculoskeletal radiologists independently who had some limited experience with interpretation of cases including surgical correlation, performed prior to this study.

The patient's dual energy CT scan data was loaded into Syngo via. The chest – pooled blood volume algorithm was selected with the default settings and then the maximum Hounsfield unit (HU) was changed from -600 to +500 in order to increase the threshold of displayed densities such as contrast-enhancing material in dense bone, including the scaphoid which has a Hounsfield unit of approximately 500.(7, 8) This also enabled generation of visible and assessable colour maps which were stored for reference on PACS. These images were then correlated with a) intra-operative assessment of AVN (relating to proximal pole bleeding with probing during surgery) and/or b) a histological specimen of the cancellous bone that was curetted from the proximal pole fragment as part of preparation of the surface of the fragment for bone grafting and fixation of the fracture.

Criteria for radiologic AVN was strictly defined by the colour map distribution output from Syngo.Via. Results were recorded as either viable or necrotic. If the proximal pole demonstrated similar colour as the more distal scaphoid, it was considered viable. If it predominantly (Reader impression of >50% whilst scrolling through coronal colour map images) had no colour, it was recorded as necrotic. Changes in proximal pole density or bone mineralisation were not considered for this study. Excluded patients included those with significant wrist or hand metalware that resulted in distortion of the colour map due to artifact.

Results:

Of the 19 wrists with a scaphoid fracture which were reviewed by a specialist hand surgeon and underwent DECT, 8 were clinically assessed as being at a higher suspicion for AVN and underwent surgery with specimens sent to pathology (Table 1). The other 11 of the 19 surgical wrists had DECT performed without a histological specimen sent, and correlation was made with operative notes as to scaphoid fracture site bleeding status.

Table 1.

All 8 surgical specimens correlated with the DECT findings. 6 no AVN (Figure 1) and 2 AVN (Figure 2 & 4). All cases were treated surgically with open reduction and

internal fixation (ORIF) with either vascularised or non-vascularised bone graft obtained from the distal radius or in one case a non-vascularised graft from the iliac crest.

Of the 11 DECT scans performed of wrists which did not have a surgical specimen evaluated but were correlated with the operative report, only a single case of DECT suggested AVN but at surgery the scaphoid was considered viable with a large intra-osseous ganglion within the proximal pole accounting for the erroneous CT findings (Figure 3). There was no instance where the DECT suggested viability (no AVN) and at surgery found to be osteonecrosis (Table 2).

Table 2.

Considering the total 19 wrists that underwent surgery, DECT demonstrates a sensitivity of 100% (95% CI: 16-100%) and specificity of 94% (71.3-99.9%) for detecting proximal pole necrosis in cases of scaphoid fracture.

Viable proximal scaphoid

Figure 1a, b & c.

Non-perfusion of the proximal pole compatible with osteonecrosis

Figure 2a, b & c

Large intraosseous cyst of the proximal pole with heterogeneous perfusion.

Figure 3a, b & c

Patchy uptake of a proximal pole <50% with sclerosis compatible with AVN.

Figure 4a, b & c

Discussion:

Whilst musculoskeletal imaging has benefited from the use of dual energy CT scans in assessing for gout, metal artifact reduction and bone mineral density amongst others, assessing perfusion in bone has traditionally been the domain of MRI using a gadolinium contrast agent to assess for uptake in bone, often observed over a time period or delay (9), or a nuclear medicine Technetium-99m bone scan. There has been no data on assessing bone viability with contrast enhanced dual energy CT, although measuring Hounsfield units in the proximal pole has been studied (10) without showing a reliable correlation.

Following acquisition of a contrast-enhanced Dual-Energy CT scan, the Syngo.via software uses a decomposition algorithm to create an iodine distribution map which analyses the presence of soft tissue, air and iodinated contrast in tissue including bone, to generate a colour map essentially of contrast enhancement (perfusion), overlaid on the scanned anatomy. This process is predominantly automated by the proprietary Syngo.Via software which evaluates the ratio of air and soft tissue in a voxel with Hounsfield unit thresholds for each of these at both 80kVp and 140kVp, whilst deriving the iodine component from the CT numbers at both energy levels. A Relative Contrast Material parameter of 2.0 indicates iodine attenuation at the 80kVp setting is twice that of 140kVp, enabling it to be discerned and demonstrated on the perfusion / colour map, as opposed to completely removing the iodine in so called "virtual non-contrast" (VNC) images.(11) Whilst useful in cases of suspected pulmonary embolism where there is a proximal arterial thrombus and reduced iodine perfusion through the more distal lung parenchyma, the same algorithm has been used to evaluate perfusion of iodinated contrast-enhancing metastasis in bone(12) and could theoretically help assess proximal scaphoid pole vascularity that may appear at risk for AVN. The idea for this study was generated following a vendor demonstration of an iodine perfusion map in a case of pulmonary embolism, whereby the technique seemed transferable to the common and difficult problem of post traumatic osteonecrosis of the scaphoid proximal pole.

The Dual Energy nature of the CT scan assesses atomic number of the materials in the field of view i.e. tissue and air. Iodinated material can therefore be analyzed and when absent, or relatively less in the proximal pole compared to the remainder of the scaphoid, suggests AVN. The scan can take less than 5 minutes to perform, the actual image acquisition close to 10 seconds so that temporal resolution is excellent and far exceeds that of MRI. When MRI is requested, intravenous gadolinium contrast may be administered in order to improve accuracy (13, 14) however more recently there remains debate about if and how best to perform a post-contrast study (9, 15, 16), and whilst bone marrow edema signal can be useful in defining a target region of abnormality, it is of no help in assessing for the presence of AVN (17, 18). A crucial benefit of MRI however is in assessing the surrounding soft tissues, including ligaments, tendons and neurovascular structures in the setting of traumatic injury. MRI gadolinium-based contrast agents also exhibit a lower reaction / hypersensitivity rate than CT iodinated contrast(19).

There is a high correlation between what is found on dual energy CT and the underlying bone pathology. Donati et al (15) describe the difficulties with obtaining a representative histology specimen due to the heterogeneity of viable and non-viable bone within a proximal pole sample, which may be expected in a more acute to subacute setting. This was not a noted problem for our reading Pathologist and whilst unsubstantiated, could be due to a longer duration between the trauma and surgery in our patients, allowing for either viability or necrosis to appear as the dominant feature. The bone sample sent (and its analysis) is also in a way representative of the method of observing intra-operative scaphoid bleeding from a particular puncture site, and whilst not perfect, does seem a reasonable surrogate technique. Whilst the pathology report was dichotomous (the bone was either necrotic or viable), some CT scans of viable proximal scaphoid poles did demonstrate small regions of absent iodine uptake. This was not observed in the pathology specimens possibly due to sampling error (small sample size or temporal heterogeneity of the avascular necrosis process), or may alternatively reflect small regions of necrosis that subsequently healed, or of reversible ischemia, and appear of little consequence to the overall viability of the proximal pole. 100% of cases (8/8) demonstrated the same findings on DECT as at surgery when specimens were sent for evaluation. DECT was 91% accurate (10/11) when compared to surgery where the surgeon made an on-table

evaluation (and specimens were not sent for histology analysis). The single case that was incorrectly called AVN on CT showed an intra-osseous ganglion with surrounding viable bone at surgery. The strict criteria for the study included a binary response of perfusion or not of the proximal pole, illustrating the need in everyday practice to review the anatomical imaging simultaneously to avoid such an error.

Given such small numbers in this pilot study, if larger patient numbers were to be used there may be issues with reproducibility due to variant timing between contrast administration and the scan, differential use of the Syngo.Via workstation, variant thresholding of values such as maximum Hounsfield unit and contrast medium ratio and use of different dual energy / dual source scanners and other proprietary software. Our small patient numbers are a significant limitation given that although 2/8 (25%) surgical specimens correlated with DECT for AVN, this represents only 2/19 (10.5%) of a patient population considered “high-risk” . Possible bias exists due to the exposure of the 2 readers to the same limited experience of reading and discussing only several scans prior to this study, potentially promoting case analysis in a similar way and thus contributing to comparable results. Results could be more comprehensive by evaluating whether there had been a single or multiple traumatic events, duration from injury to imaging, or duration from imaging to surgery. Quantitative techniques in measuring amount of viable or non viable bone (eg. Area on a central slice or 3D volume) would be advantageous over our methodology of observing the coronal colour map images and forming an impression of 3D region involved by osteonecrosis or not. Ideally all patients undergoing surgery would have specimens sent for histologic review, although unless the entire proximal pole is sent to histology, some sampling error would be expected given the temporal heterogeneity of the avascular necrosis process. This may also result in more even numbers of AVN and viable samples, the discrepancy of 2 AVN to 6 viable cases in this series possibly due to samples being sent in cases where there was relatively poor intra-operative bleeding and therefore a higher suspicion for AVN.

Conclusion:

This preliminary retrospective study shows dual energy, contrast-enhanced CT to be a promising technology to aid the evaluation of post-fracture, proximal-pole scaphoid viability which may help reduce premature osteoarthritis and pain by prompting

appropriate management and early intervention if required. CT evaluation for anatomy can be assessed simultaneously. Further studies with larger patient numbers and histologic correlation, defining appropriateness criteria for patients to undergo a DECT scan and refining post-processing techniques may yield improved diagnostic accuracy.

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Disclosures:

None of the Authors have any conflict of interest to disclose.

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Figures:

Figure 1a. Coronal CT Bone algorithm demonstrates a sclerotic-rimmed transverse scaphoid waist fracture in a 47 year old female. 1b. 3d perfusion render demonstrates clear iodine uptake of both the proximal and distal scaphoid i.e. Viability and no osteonecrosis. 1c. H&E stain shows a viable trabecula with osteocytes present in lacunae (white arrow) and viable adipose tissue in the marrow space.

Figure 2a. Multiplanar CT perfusion imaging shows absence of iodine uptake of the proximal scaphoid pole with a transverse waist fracture, in keeping with osteonecrosis in an 18 year old male. 2b. 3d render with distal scaphoid appearing similar to the remainder of the carpus and minimal iodine uptake within the proximal pole. 2c. H&E stain shows a fragment of necrotic bone demonstrating empty lacunae (black closed arrow) and undergoing resorption by osteoclasts (black open arrow).

Figure 3a. Coronal CT bone algorithm anatomically demonstrates a large intraosseous cyst of the proximal scaphoid in a 22 year old male. 3b. Coronal fused and 3c. 3D rendered perfusion imaging demonstrates no iodine uptake in this region – erroneously reported as osteonecrosis, but viable at surgery.

Figure 4a. Coronal CT iodine colour distribution map in a 30yo male patient shows heterogeneous, patchy uptake in the proximal pole but this is less than 50% the overall volume on the 3D perfusion colour map 4b. which confirms very limited uptake in the proximal scaphoid and 4c. Coronal bone algorithm CT with transverse fracture at the junction of proximal and middle thirds with sclerotic proximal pole typical for osteonecrosis.

Tables:

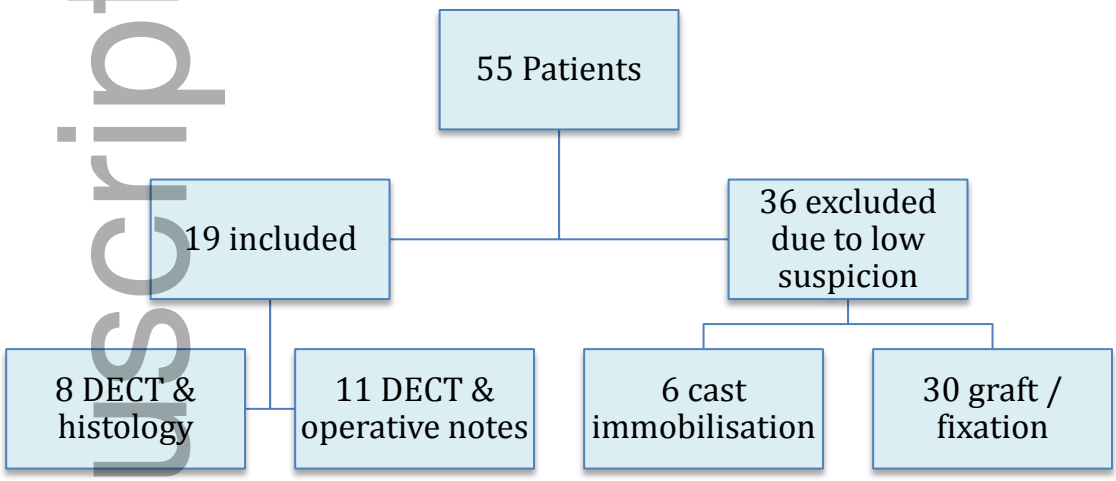

Table 1. Patient group population flowchart.

	Total Surgery	Total DECT
Total Number	19	19
Viable / Intra-op bleed	9	8
Necrosis / No bleed	10	11

Table 2. Total numbers for Surgery and Dual Energy CT viable and necrotic proximal scaphoid pole.

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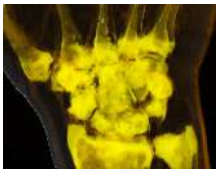

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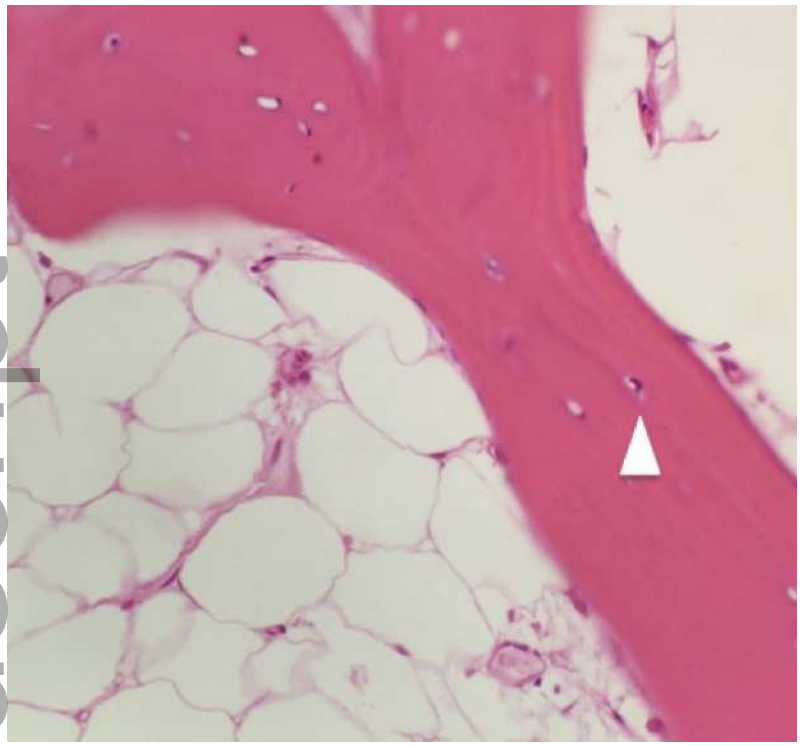

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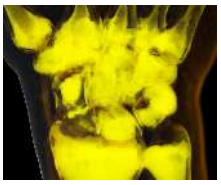

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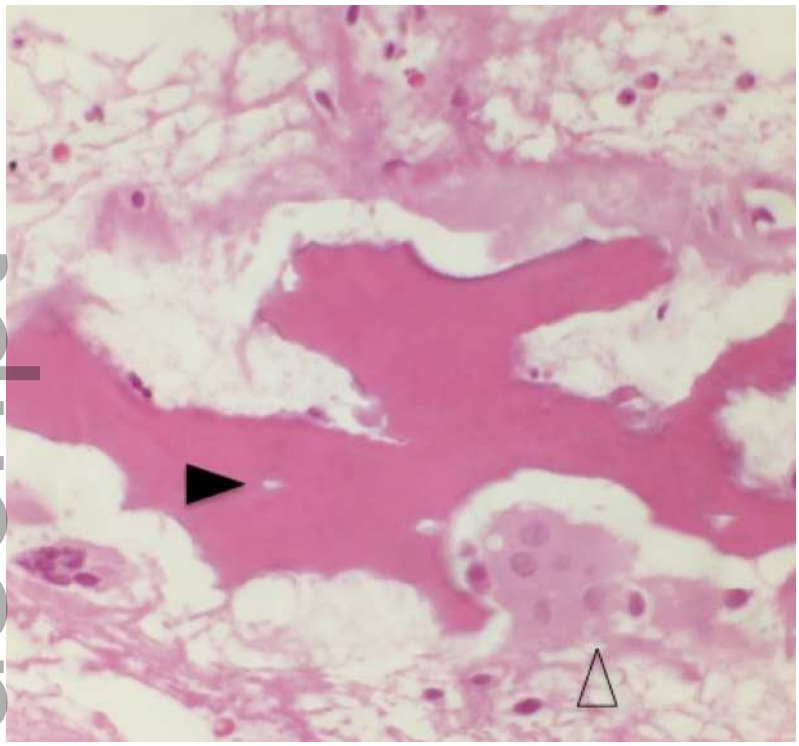

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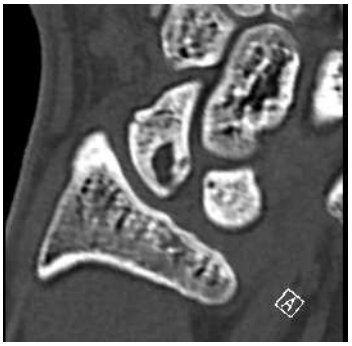

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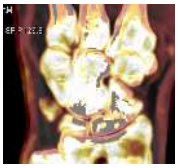

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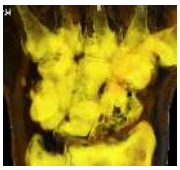

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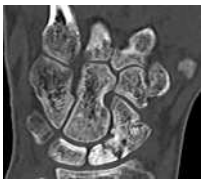

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