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What Exactly is Avascular Necrosis in Nonunion Scaphoid?

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Avascular necrosis or osteonecrosis is said to be higher when the fracture involves proximal one-third of the scaphoid with an incidence of 13 % to 27% [1]. The reason for this is the tenuous [1] blood supply of the scaphoid, primarily from the branch of the radial artery entering mainly from the distal and dorsal surface of the bone. The proximal pole, therefore, is dependent entirely on this intraosseous blood flow. This retrograde, axial and unidirectional pattern of blood supply can result in a protracted healing process after a fracture which eventually leads to osteonecrosis, collapse and arthritis leading to disability. The main aim of this article is to understand the concept of avascular necrosis as laid down by Timothy. J. Herbert [2] as early as 1984 and to use his concepts in choosing an appropriate investigation at the right time to guide towards optimum treatment option. In the present clinical scenario, the term avascular necrosis is used to label a wide spectrum [2] of conditions encompassing vascular compromise beginning with bone ischemia, leading to true avascular necrosis and finally becoming an infarction. As a result, preoperative assessment is important in deciding between vascularized and non-vascularized bone graft, other arrays of salvageable procedures like partial excision and limited fusion and proximal row carpectomy. This point is especially important as the evolutionary process of ischemia may be reversible at any stage, but in the case of true AVN, there is no healing capacity and a salvage procedure should be utilized.

The pathogenesis of this evolutionary process has been well described as initial anoxia leading to necrosis of fat and other elements of bone marrow. Following this, the inflammatory process gets established as a part of the repair process in the form of creeping substitution which develops from adjacent viable tissue leading to revascularization.

Accordingly, this spectrum of injury and repair can be broadly staged [3] into

1) Ischaemic, where the blood supply is insufficient to support the physiological function leading to pathological changes suggestive of ischaemia.

2) Necrosis, where bone death results from loss of blood supply and pathological changes suggesting empty lacunae and marrow fat degeneration is focal.

3) Infarction, where pathological changes suggestive of empty lacunae and granular degeneration of marrow fat is diffuse involving the entire fragment. There is a diffuse absence of vascular fibromyxoid and mucoid changes in the marrow space.

The reason for the above spectrum is with the cessation of the vascular supply, the pathological changes are first noted in the peripheral and distal part of the involved segment which further progress centrally. The only mechanism of correlating these histopathological changes is through imaging and intraoperative findings. Hence preoperative decision making largely rests on the various imaging modalities to select an appropriate procedure among various alternatives. Ideally, the imaging should be able to predict the healing capacity of the fracture.

In patients with preserved vascularity to the proximal pole, a non-vascularized bone graft with screw fixation is often sufficient to achieve osseous union. However, if the proximal pole is avascular, a vascularized bone graft, typically utilizing the 1, 2-intercompartmental supraretinacular artery [11], is considered more likely to achieve an osseous union than a nonvascularized bone graft. Since the

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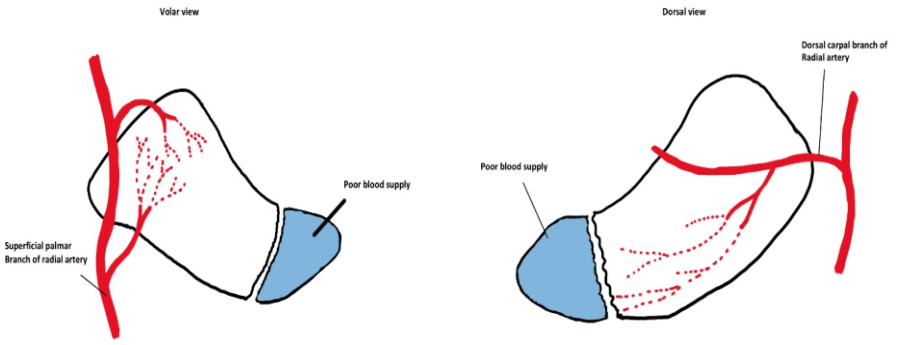

Figure 1: Schematic representation of the blood supply of the scaphoid and its precarious nature when the fracture involves the proximal third

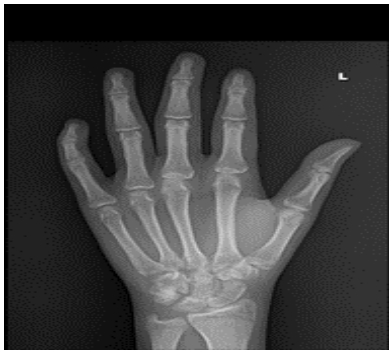

Figure 2: X-ray showing fracture of scaphoid involving proximal one-third of the scaphoid with sclerosis of the proximal pole

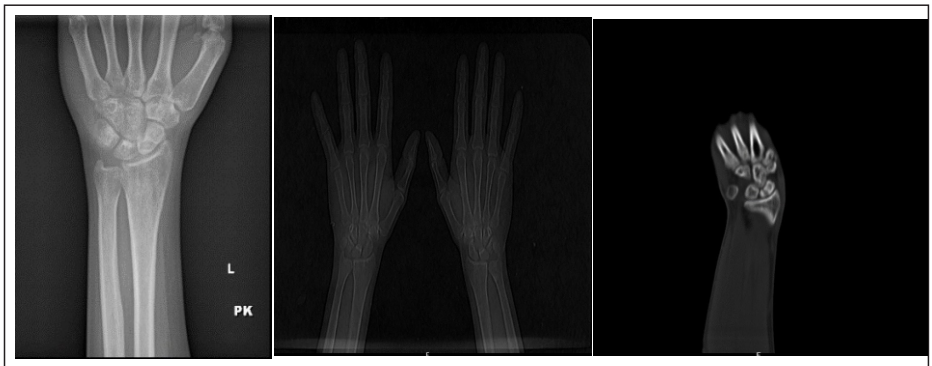

Figure 3: X-ray showing fracture of the scaphoid involving the waist with sclerosis of the proximal pole which is complimented by CT image

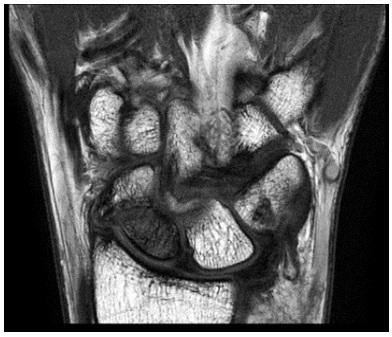

Figure 4: Homogenous hypointensity on a T-1 weighted unenhanced MRI

placement of a vascularized bone graft for a scaphoid non-union is more challenging technically and requires a longer operative time than does the use of a nonvascularized graft, knowledge of the vascular status of the proximal pole will allow more appropriate surgical planning, as well as more accurate preoperative counselling.

Vascularity of the scaphoid may be assessed by

a) Changes in radiographic density (plain radiograph)

b) Sclerosis on a CT scan

c) T1 and T2 weighted magnetic resonance imaging(MRI) signal intensity

d) Contrast-enhanced(gadolinium) Magnetic resonance imaging

e) Non-quantitative and quantitative perfusion MRI

f) Intraoperative punctate bleeding

g) Histopathology

Sakuma et al [4] (1995) compared x-rays (figure 2) with proximal pole sclerosis to T1 and T 2 weighted MRI and the surgical outcomes. He concluded that there was no relationship between sclerotic changes on plain radiography and the degree of avascularity of the proximal fragment as assessed by MRI. This was mainly because sclerosis on X-ray was found to be nonspecific as it could also reflect new bone formation as a reaction of living tissue to ischemia, dystrophic calcification, bone impaction or relative osteopenia of other bones due to immobilization Similarly scintigraphy is not also specific for avascular necrosis as synovitis may lead to false-positive results.

Smith et al [5] (2009) explained how CT scan (figure 3) could negate the inconsistent sclerotic feature on X-ray and can be used as a diagnostic tool where MRI facilities are not available to detect AVN of the scaphoid. CT scan had the added advantage of removing soft tissue and bony orientation as confounders. Increased radio density, absence of bridging trabeculae, comminuted fracture, low dorsal cortical percentile trended towards correlation with avascular necrosis but did not reach a statistical significance when correlated with histological diagnosis.

The optimal MRI technique to diagnose AVN in the proximal pole of the scaphoid has varied over the past two decades. Initial reports utilizing unenhanced MRI to evaluate the proximal pole of the scaphoid were very favourable in terms of diagnosing AVN when correlated with histopathology. Trumble and Irving [6, 7] reported that decreased T1-weighted (figure 4) and T2-weighted signal (figure 5) involving more than 50% of the proximal pole of the scaphoid correctly indicated AVN in the majority of their cases. Perlik et al [8] has reported that decreased T1-weighted (figure 4) signal alone was accurate in diagnosing AVN in the proximal pole of the scaphoid as decreased T2-weighted signal was present in only 50% of their patients

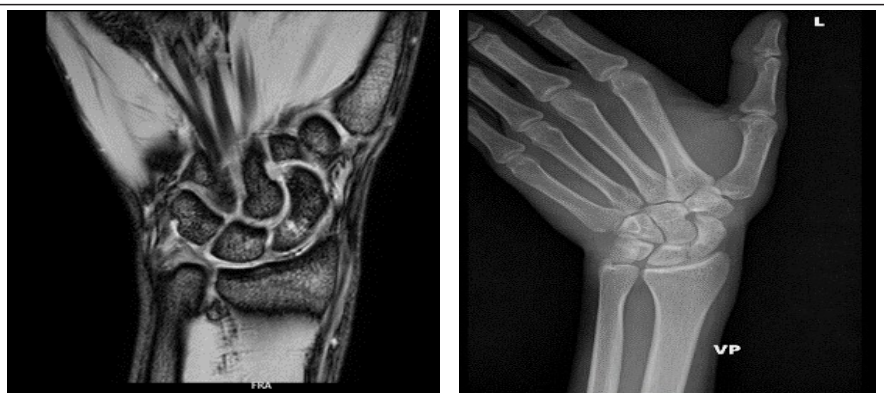

Figure 5: An unenhanced MRI (T2 weighted) with heterogeneous hypointensity involving proximal pole of the scaphoid with no evidence of sclerosis on X-ray

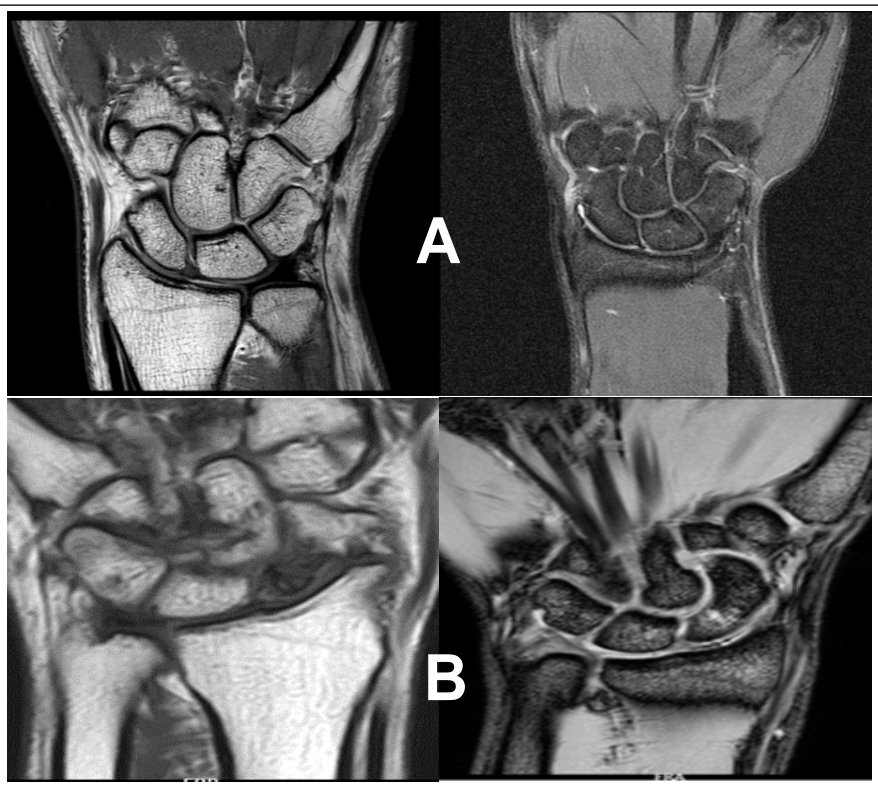

Figure 6: A) Normal MRI of wrist followed by B) decreased T1 weighted and T2 weighted MRI signals (diffuse) more in favour of late necrotic phase

Based on such literature support of changes in T1-weighted and T2-weighted signal, an MRI classification system was devised [12, 25] to determine bone viability.

The bone shall be considered

Viable: T1- weighted and T2-weighted signals were normal (figure 6 A)

Ischaemic: decreased T1-weighted and increased T2-weighted signals

Necrotic: decreased T1-weighted and T2-weighted signals (figure 6 B)

Later Schmitt et al [9, 24] described the use of gadolinium-based contrast agent to categorize the vascular status of the proximal pole of the scaphoid where homogeneous enhancement represented viable bone, inhomogeneous enhancement represented coexisting AVN and viable (ischaemic) bone, and the absence of enhancement represented necrosis. Gadolinium has seven unpaired electrons, strongly paramagnetic and known to shorten the spin-lattice relaxation time resulting in a brighter signal in T1 weighted image. Also, it shortens the T2 relaxation time at large doses leading to a hypointense signal in T2 weighted image. Gadolinium alters the image contrast leading to differential enhancement due to its intrinsic property. This enables visualization of abnormal tissue with more clear detail clarifies differential vascularity in a given tissue.

Cerezal et al [10] directly compared the accuracy of unenhanced and contrast-enhanced MRI to intraoperative findings for evaluating the proximal pole AVN. He found that using gadolinium-enhanced T1-weighted fat-suppressed imaging, the ischaemic group had 20 to 80 per cent enhancement whereas the necrotic group had less than 20 per cent enhancement. However, this was only 10 to 15 per cent increased sensitivity and specificity compared to the unenhanced MRI group. With these observations, he concluded that although inferior to gadolinium-enhanced MR imaging, unenhanced MR imaging enabled us to distinguish between potentially viable bone and nonviable bone.

Concerning gadolinium-enhanced MRI, Anderson [11] commented that the exact cause for this increased uptake in gadolinium contrast leading to false-positive result remains unknown. Several theories were postulated such as the in-growth of viable fibrous mesenchymal tissue into necrotic bone, diffusion of contrast agent throughout the soft tissues and bone which may provide less information about the vascular status He concluded that diffusely decreased T1-weighted signal, equal to or less than that of skeletal muscle is more accurate in diagnosing the AVN.

Fox et al [12, 13] also confirmed that neither STIR nor T2-weighted fat-suppressed sequences help determine the vascular status of the proximal pole.

Donati et al [14] came up with the study involving the role of dynamic gadolinium-enhanced MRI in diagnosing proximal pole AVN. He concluded that the diagnostic performance of dynamic gadolinium-enhanced MR imaging was inferior to that of a standard MR imaging protocol in the evaluation of scaphoid viability and the findings from dynamic gadolinium-

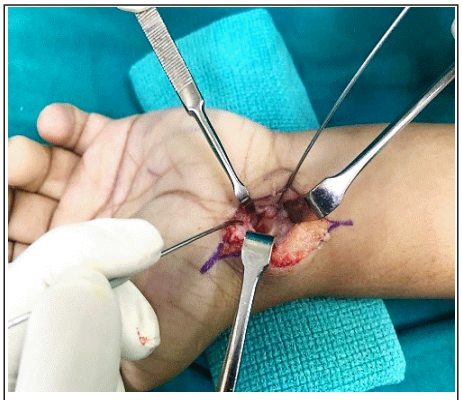

Figure 7: Intraoperative image with punctate bleeding suggestive of viable proximal pole.

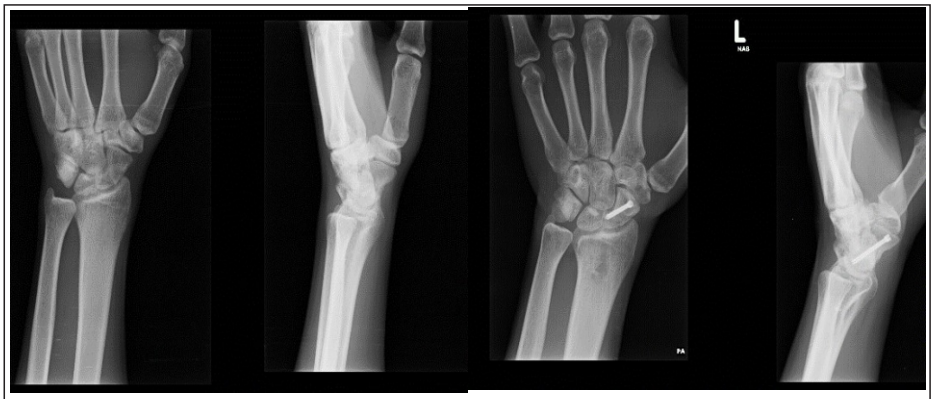

Figure 8: X-ray with non-union of the scaphoid with sclerosis of proximal pole. Eight months follow up following internal fixation with avascular bone graft showing signs of union

enhanced MR imaging did not correlate with those from the histologic examination. HPE may not correlate with MR imaging based on the observation made by Urban and Green[15] who assessed trabecular viability on the histopathological specimen(ischaemic proximal pole) by the percentage of osteocytic lacunae and necrotic trabeculae. They explained that the presence of vascularized bone, necrotic bone, and callous material was in a patchy distribution in the histologic specimen and may not truly reflect the vascularity and tissue composition throughout the whole of the proximal scaphoid fragment. Depending on the condition of the bone structure, a distinct delineation of the proximal scaphoid fragment may be difficult and other parts of the scaphoid may be mixed into the curettage of the specimen.

Based on the above concept of patchy distribution on histopathology, Gunal et al [16] concluded that the viability of scaphoid fragments should be assessed by combining MRI findings with the intraoperative observation of bleeding, and the diagnosis of AVN can only be made when both of the parameters indicate avascularity and the importance of observing intraoperative punctate bleeding under tourniquet was established.

However, the concept of intraoperative punctate bleeding (figure 7) was explained by Green [17] as early as 1985 where he reported that scaphoid nonunion without punctate bleeding from the proximal pole always failed to unite with nonvascularized bone grafting. Vascularity was assessed by the quantity and quality of punctate bleeding found in the cancellous portion of the bone. Vascularity was considered good if the bleeding point were numerous and imparted pinkish hue to the bone.

The vascularized bone graft does not always guarantee a good surgical outcome as Boyer et al [18] (1998) suggested that the union incidence of a vascularized bone graft from the dorsum of the distal radius was 60%. Straw et al [19] (2002) reported a union incidence of only 27% after the use of vascularized grafts based on the 1,2 ICSRA and Tambe et al [20] (2006) reported only 55% union incidence of vascularized bone grafts taken from the dorsum of the distal radius.

Further, in the article by Rancy and Morgan [21], it was concluded that the success of non-union scaphoid surgery is independent of proximal pole vascularity and Pinder [22] et al in their systematic review of 1600 patients concluded there was no statistical benefit of vascular over non-vascular grafts (figure 8) for scaphoid non-union.

Baek et al [23] concluded that nonvascularized iliac bone grafting can be used for the surgical management of scaphoid nonunion with avascular necrosis. They used pre-operative MRI (unenhanced) to diagnose AVN and non-vascularised iliac crest bone grafting was performed in all patients irrespective of intraoperative punctate bleeding status thereby not giving importance to

Investigation	Ischaemic	Avascular necrosis
X-ray	Patchy sclerosis	Homogenous sclerosis
CT scan	Patchy sclerosis	Homogenous sclerosis
Unenhanced MRI	Hypo intense T1 and hyperintense T2 weighted	Hypo intense T1 andT2 weighted
Contrast MRI	20 to 80 percent enhancement	<20 percent enhancement
Punctate bleeding (intraop)	Sparse	Absent
Histopathology	Presence of vascular fibromyxoid and mucoid changes in the marrow space and focal changes of AVN.	Empty lacunae and granular degeneration of marrow fat is diffuse

Table 1: Table summarizes the important observation laid down from the evidence available and its clinical application

it. Although revascularization of the proximal fragment after surgery was not evaluated in their study, the bony union was confirmed in nearly all patients by postoperative CT scan.

The main reason behind these results is the inability to accurately define AVN in scaphoid as it has got a wide range of spectrum [25]. There is no appropriate investigation modality that determines AVN in scaphoid as the drawbacks of each of them has been explained in detail in the above discussion

Table 1 summarizes the important observation laid down from the evidence available and its clinical application.

We believe that by using a combination of investigation and intra op findings, the fallacies can be considerably reduced. Since the earlier studies have not convincingly propagated the use of contrast-enhanced MRI in determining the vascularity, decreased T1 weighted (along with T2 weighted) signals on unenhanced MRI along with an absence of punctate bleeding in the proximal pole intraoperatively would lead more towards the diagnosis of avascular necrosis of scaphoid. AVN is used to label a wide spectrum of conditions of assumed circulatory compromise which ranges from ischaemia in the early phase to an infarction in the late phase. Serial MRI evaluation may be considered as a useful guiding tool and is an area of further research. The use of serial T1 weighted MRI can be useful in detecting the natural course of the disease and help in early intervention mainly in high-risk cases like proximal pole short segment fracture, comminuted/displaced fracture and delayed union, thereby gaining the advantage of managing the disease at an early stage of evolution.

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