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THE BLOOD SUPPLY OF THE SCAPHOID BONE

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Scaphoid vascularisation was investigated using macroscopic and microscopic techniques in 12 uninjured, formalin fixed cadaver hands. A good blood supply of the scaphoid bone from palmar, dorsal and radial vessel groups with a variety of anastomoses was found which should provide sufficient collateral blood flow from adjacent regions in some patients. Since blood supply is available from the palmar circulation, a dorsal approach to the scaphoid bone is possible.

Keywords: scaphoid, bone, anatomy, blood, supply, vessels, vascularisation

INTRODUCTION

The scaphoid bone is the most radial of the carpal bones and contributes to the mechanical integrity of the wrist. Fracture or nonunion of the scaphoid may need reconstruction but a dorsal approach is said to put scaphoid circulation at risk. Preserving a sufficient blood supply aids bone healing. The literature on vascularisation of the scaphoid is conflicting, with its blood supply alternatively described as adequate (Gelberman and Menon, 1980) or deficient (Fasol et al., 1977, 1978). An understanding of scaphoid blood supply will provide an anatomical basis for surgical interventions.

MATERIAL AND METHODS

With approval of the Institutional Review Board, we examined 12 cadaver hands at the Department of Anatomy, the University of Giessen. There were five pairs of hands (four male, one female) and two single hands (one male, one female), of people between 65 and 88 years at the time of death. The causes of death were unrelated to diseases of the upper extremity or peripheral circulation.

Macroscopic preparation

The hands and wrists of formalin-fixed cadavers were severed at the distal third of the forearm. The radial and ulnar arteries were dissected free and flushed with physiological sodium chloride solution. Subsequently, India ink at a 1:3 dilution with physiological sodium chloride solution was injected into the radial artery to identify the vessel. The hands were subsequently stored in 2-phenoxyethanol for 24 hours before dissection. After removing skin and subcutaneous fat, arteries were exposed and veins were removed for clarity. Thin vessels were dissected using a microscope (Carl Zeiss, Oberkochen, Germany). The scaphoid bone was detached from the other carpal bones and its surface area covered by wax tiles which were then transferred on millimetre paper to determine the surface area. Preparation steps were photographed with a Leica camera (Leitz, Wetzlar, Germany) using standardised lighting.

Histological preparation

The scaphoid bones were decalcified for 15 to 23 hours using D-Calcifer (Shandon Life Sciences International GmbH, Frankfurt, Germany). After subsequent dehydration with increasing concentrations of ethanol the specimens were embedded in Paraplast. Seven to 10 μm axial and longitudinal slices were cut with a 1512 Microtom (Leitz, Wetzlar, Germany). Slides were stained with hematoxylin-eosin (HE) and periodic acid Schiff (PAS) and examined with an Orthoplan-Microscope (Leitz, Wetzlar, Germany) and an AH 2 photo-microscope (Olympus, Tokyo, Japan).

RESULTS

The measured surface of the scaphoid averaged 1482 (SD 212) mm^2. Articulating surface with cartilage accounted for 622 (SD 95) mm^2 (42%) and 860 (SD 137) mm^2 (58%) was non articulating.

Macroscopic findings

The blood supply to the scaphoid arose from branches of the radial artery. These main branches had a regular distribution with variations in the arrangement of smaller vessels. The blood supply was similar in the right and left hands.

The palmar surface of the scaphoid was supplied by the palmar carpal artery, the superficial palmar artery, small radial rami arteries, and partly from the first dorsal metacarpal artery (Fig 1).

The palmar carpal artery was always the first branch of the radial artery supplying the scaphoid, originating between 0 and 3 cm proximal to the radial styloid. The palmar carpal artery originated together with the second supplying branch, the superficial palmar artery, three times. In ten specimens, the palmar carpal artery split into a proximal and a distal branch. The distal one ran across the radiocarpal joint heading to the proximal scaphoid bone and the lunate bone, sending several branches to the scaphoid (Fig 2). Two preparations did not include a distal branch of the palmar carpal artery. Instead a well-built branch of the superficial palmar artery was found nourishing the proximal third of the palmar surface of the scaphoid. In these cases, small arteries from the palmar carpal artery ran to the proximal ulnar rim of the scaphoid (Fig 3).

The superficial palmar artery originated from the radial artery at the level of the radial styloid. One centimetre distally, in nine specimens, there was a branch heading towards the carpal tunnel, spreading tiny rami to the proximal palmar rim in five preparations (Fig 4) and to the distal ulnar rim or to the tubercle of the scaphoid in four other hands (Fig 3). The main branch of the superficial palmar artery ran distal and ulnar, crossing the palmar surface of the scaphoid, with several bone vessels branching off. Distal to the tubercle of the scaphoid, the superficial palmar artery split into two branches (in six hands) or three branches (in six hands).

Palmar surface	1. Palmar carpal artery
	2. Superficial palmar artery
	3. Small radial rami arteries
	4. First dorsal metacarpal artery (variable)
Dorsal surface	1. Styloid artery
	2. Dorsal scaphoid artery
	3. Dorsal carpal artery
	4. Small radial rami arteries (variable)

Fig 1 Blood supply of the scaphoid bone. Arteries branching from the radial artery from proximal to distal for each surface.

In the hands with two branches, one vessel ran ulnar, the other one headed towards the thumb and supplied the distal rim of the scaphoid. In the hands with three branches, an additional vessel followed the direction of the main branch to the palm of the hand (Fig 5).

In one preparation, a second artery branched 15 mm after the junction of the radial artery and the superficial palmar artery, macroscopically resembling the superficial palmar artery and forming an anastomosis with the first one. The resulting artery ran to the tubercle of the scaphoid entering the bone there (Fig 6).

The arteries originating 0.5 to 2.5 cm after the superficial palmar artery from the radial artery were small radial rami arteries and varied considerably in number (two to five) and course. They ran to the proximal radial side of the scaphoid and entered the bone at the palmar or dorsal surface (three palmar only, three dorsal only, six palmar and dorsal). Just before entering the bone they split into two or three branches. In six specimens, branches ran to the tubercle, divided into two or three smaller branches, and encircled the bone before entering it (Fig 7).

In five specimens, the distal radial area of the scaphoid was supplied by small branches of a proximally running

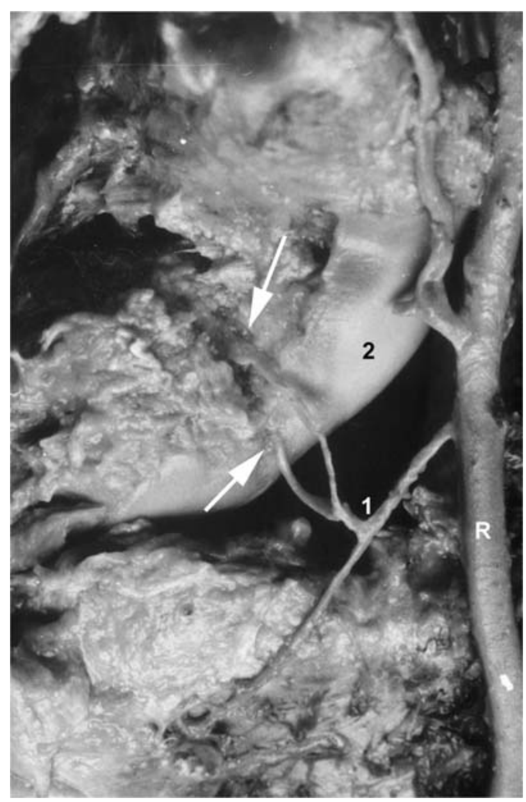

Fig 2 Palmar view of the scaphoid of the right hand. Palmar carpal artery (1) with two branches running to the proximal palmar area of the scaphoid (arrows), 2 = articular surface of the scaphoid bone with the radius, R = radial artery. Enlargement: 2×.

first dorsal metacarpal artery (Fig 7). This occurred when the first dorsal metacarpal artery originated from the radial artery at the same level as the dorsal carpal artery (four) or proximal (one) to it, not more than 20 to 30 mm distal to the origin of the superficial palmar artery. If the first dorsal metacarpal artery originated distal to the dorsal carpal artery (seven) it did not contribute to the scaphoid blood supply.

The dorsal area of the scaphoid was supplied by the styloid artery, the dorsal scaphoid artery, the dorsal carpal artery, and partly by the small radial rami arteries (Fig 1).

The styloid artery was the most proximal branch, supplying the dorsal surface of the scaphoid and originating from the radial artery at the level of the palmar carpal artery or the superficial palmar artery. In all preparations, it split into two branches. The first one ran proximal to the radial styloid, the second one headed directly to (nine cases) or split into three to four smaller vessels (three cases) which ran to the proximal radial rim of the dorsal surface of the scaphoid. From these smaller vessels, only one branch reached the scaphoid. Size of the styloid artery was inversely related to the size of the dorsal scaphoid artery, with the styloid artery being even larger than the dorsal scaphoid artery in two preparations. The styloid artery was similar between hand pairs for form and route.

The dorsal scaphoid artery originated from the anatomic snuffbox, approximately 1 cm distal from the branching point of the styloid artery and 1 cm proximal to the branch of the dorsal carpal artery; artery size and route varied considerably. In six cases a well-formed vessel coursed across the dorsal tuberosity or dorsal surface of the scaphoid heading ulnarwards to the distal end of the radius. Four to eight small arteries originated from this main branch and converged to nourish the bone's proximal and radial regions. After its origin, the dorsal scaphoid artery split into a proximal and distal branch in four hands (Fig 8). The distal branch ran to the dorsal tuberosity of the scaphoid. After splitting in two or three small branches, it supplied the dorsal radial part of the scaphoid. The proximal branch ran to the radius and sent one to two small vessels to the dorsal area of the scaphoid or to the articulation of the scaphoid and radius. In one case the proximal branch continued ulnarwards, forming an anastomosis with the dorsal carpal artery (Fig 8). If the styloid artery and a big dorsal carpal artery supplied the dorsal surface (two hands) the dorsal scaphoid artery had only small and short

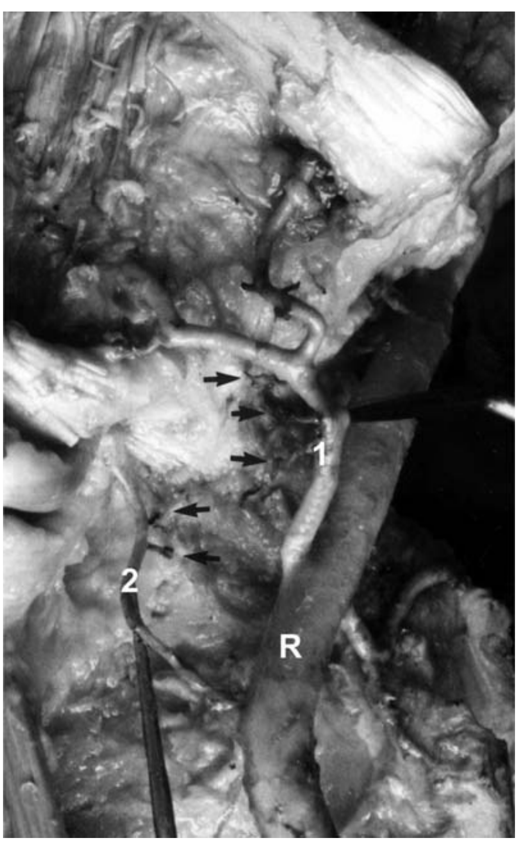

Fig 3 Palmar view of the scaphoid of the right hand. Three thin arteries originate from the superficial palmar artery (1) and run towards the tubercle of the scaphoid. Two small arteries from the palmar carpal artery (2) run to the proximal palmar rim of the scaphoid (arrows), R = radial artery. Enlargement: 3×.

Fig 4 Palmar view of the scaphoid of the right hand. Superficial palmar artery (1) with an artery to the carpal tunnel, heading in the direction of the proximal rim of the scaphoid (arrow), 2 = scaphoid, R = radial artery. Enlargement: 2×.

Fig 5 Palmar view of the scaphoid of the right hand. Superficial palmar artery (1) dividing distal to the scaphoid. The artery running to the thumb supplies the scaphoid with small vessels from distal (arrow), R = radial artery. Enlargement: 3×.

Fig 6 Palmar view of the scaphoid of the left hand. Superficial palmar artery (1) running across the palmar surface of the scaphoid. Approximately 15 mm distal to the superficial palmar artery a small artery (2) originates from the radial artery (R), building anastomosis with the superficial palmar artery (1). This anastomosis sends an artery (black arrow) to the tubercle of the scaphoid. Enlargement: 3×.

branching vessels at the radial dorsal area (Fig 9). The dorsal scaphoid artery demonstrated asymmetry between hand pairs for number of vessels and their routes.

The dorsal carpal artery originated at the level of the trapezium from the radial artery and crossed the dorsal surface of the distal carpal bones in an ulnar direction (Figs 8 and 9). The main branch sent one or two small vessels to the distal rim (nine hands), running up to the middle of the dorsal surface of the scaphoid in three preparations (Fig 9). In six specimens, this main branch split into a distal and proximal branch at the ulnar rim of the dorsal surface of the scaphoid.

If the dorsal carpal artery sent branches to the scaphoid, a vessel from the main branch (four) or the proximal branch (five) ran to the ulnar rim. This artery supplied the scaphoid directly with bone branches. Further on, it formed an anastomosis with branches of the ulnar artery and terminal branches of the dorsal scaphoid artery (Fig 8). If no branch ran from the dorsal carpal artery to the scaphoid (three), the size of the dorsal scaphoid artery was larger than the dorsal carpal artery and branches from the styloid artery were always present.

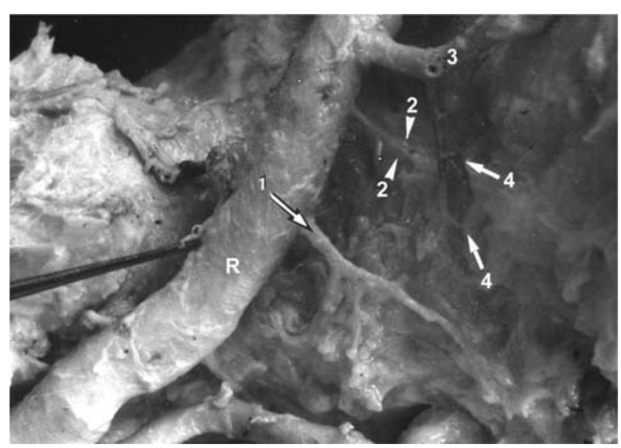

Fig 7 Palmar view of the scaphoid of the left hand. One of the small radial rami arteries (1) sends three branches to the tubercle of the scaphoid. Other arteries of this group (2) supply the radial surface of the scaphoid. Branches of the first dorsal metacarpal artery (3) run to the distal radial rim of the scaphoid (4). R = radial artery. Enlargement: 6×.

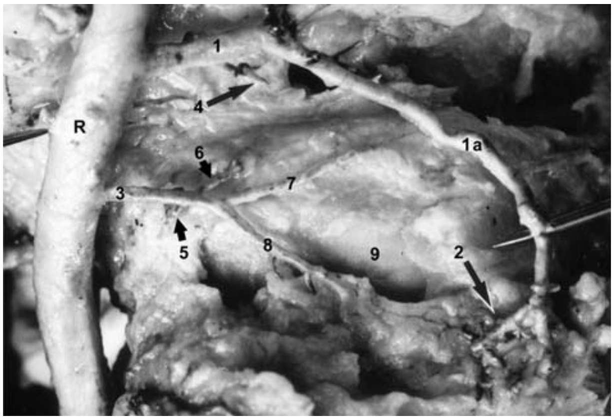

Fig 8 Dorsal view of the scaphoid of the right hand. Branch (1a) of the dorsal carpal artery (1) running to the ulnar surface of the scaphoid, forming an anastomosis (arrow 2) with the proximal branch of the dorsal scaphoid artery (3). The dorsal carpal artery (1) sends a small artery (4) to the articulation between the scaphoid and the trapezium. The dorsal scaphoid artery (3) divides into a distal and a proximal branch. The main branch sends two smaller vessels to the dorsal surface of the scaphoid before dividing (5, 6). The distal branch runs to the dorsal tuberosity of the scaphoid (7). The proximal branch sends a few branches to connective tissue of scaphoid's articulation with the radius (8), 9 = scaphoid. Enlargement: 5×.

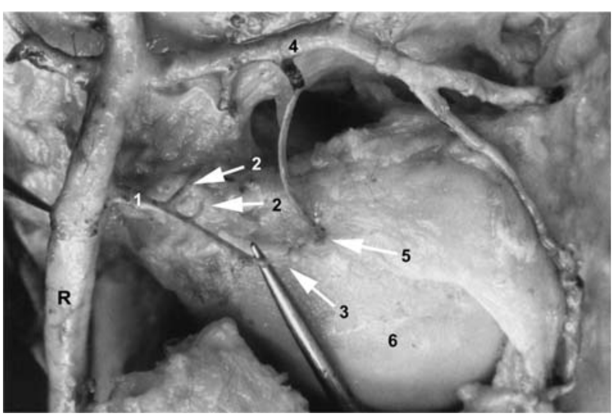

Fig 9 Dorsal view of the scaphoid of the right hand. The dorsal scaphoid artery (1) originates from the radial artery (R) and sends two short branches to the dorsal radial surface of the scaphoid (2). The final branch reaches the dorsal tuberosity of the scaphoid directly (3). One branch of the dorsal carpal artery (4) runs across the articulation between scaphoid and trapezium reaching the dorsal tuberosity of the scaphoid (5), 6 = radial articular surface of the scaphoid. Enlargement: 6×.

Regions of the scaphoid supplied by macroscopically visible arteries displayed a dense vascularisation with numerous arteries seen microscopically. Some of these vessels approached the scaphoid cortex, but had no direct branches that entered the bone. However the cortex in this region showed many canaliculi containing small vessels, especially within the cancellous part of the bone.

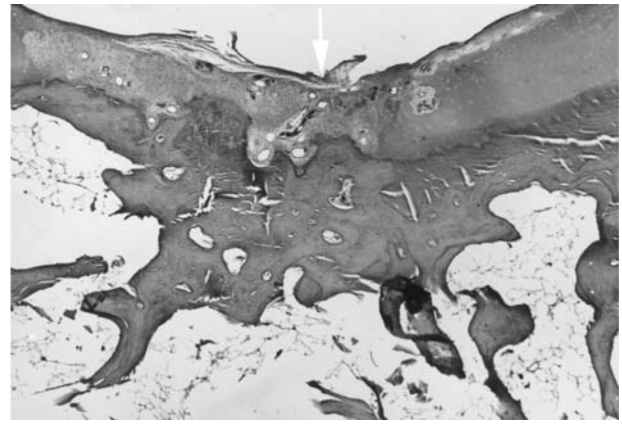

Fig 10 Small arteries run along the ulnar rim of the scaphoid into the bone penetrating cartilage and the corticalis (arrow). Stain: PAS. Enlargement: 45×.

Other vessels entered the cortex and continued into the bone. The proximal surface of the scaphoid was supplied by palmar and dorsal vessels. Microscopic investigations of the radial surface of the scaphoid showed most arteries to be in its middle and distal third. The number of vessel and the wall thickness increased from proximal to distal. At the ulnar articulation small arteries and arterioles entered the scaphoid directly through the cartilage (Fig 10). In the distal region of the articulation no blood vessels were found. The size of arteries entering the scaphoid was the same for the dorsal and palmar as well as the ulnar and radial regions.

DISCUSSION

This study demonstrates that the scaphoid has an extensive blood supply. Some of the supplying arteries are highly variable in their anatomy, but compensatory rami from other arteries are usually present if one branch is completely missing. Our findings do not support the results of Fasol et al. (1977) and Gelberman and Gross (1986) describing a sparse or marginal blood supply to the scaphoid.

Various methods have been used to investigate blood supply of the scaphoid bone (Table 1). Carstensen et al. (1962) injected particulates which were then polymerised. The success of this approach depends critically on the method because particle size determines which vessels are perfused. Furthermore, polymerisation occurs rapidly and is difficult to control; polymerisation can thus occur before small vessels are adequately perfused. Particle sizes were not mentioned in the publication. Sub-optimal particle size or excessively rapid polymerisation may explain why the investigators failed to identify as many vessels as we did and were

Table 1—Scaphoid publications and their preparation techniques

Author (year)	*n*	*Extraosseous*	*Intraosseous*
Carstensen et al. (1962)	9	Red plastoid	N/A
	3	N/A	Decalcified + stained (HE)
Taleisnik and Kelly (1966)	4	India ink (a)	Spalteholz technique
	6	Barium sulphate (b)	Spalteholz technique
	1	(a) and (b)	Spalteholz technique
Fasol et al. (1978)	4	MLE	Spalteholz technique
	7	MLE	N/A
	5	N/A	Spalteholz technique
Mestdagh et al. (1979)	50	Minium suspension in turpentine	N/A
Gelberman and Menon (1980)	15	Ward's blue latex solution	Modified Spalteholz technique
Gelberman et al. (1983)	17	Ward's blue latex solution	Modified Spalteholz technique
	4	Barium sulphate	Modified Spalteholz technique
	4	Batson's compound	Modified Spalteholz technique
Botte et al. (1988)	6	Ward's blue latex or esophatrast	Spalteholz technique
	24 (with Herbert screw)	Ward's blue latex or esophatrast	Spalteholz technique
Oehmke et al. (this manuscript)	12	India ink	Decalcified + stained (HE, PAS)

HE = hematoxylin eosin; MLE = milky latex emulsion coloured with red or black ink; N/A = not applicable; PAS = periodic acid Schiff.

unable to display the intraosseous path of the vessels in the histological preparations.

Latex solutions are popular because they are injectable and can be mixed with colours or dye. Once fixation is induced by formaldehyde, alcohol, or acidic solutions, they form an elastic mass that can be sliced and is corrosion resistant. The technique works well with fresh tissue, but cadavers are usually preserved with formaldehyde. A consequence is clotting of the latex particles when they contact preserved tissues which occludes smaller vessels (Romeis, 1989), potentially occluding the tiny vessels that perfuse the scaphoid bone. For example, Fasol et al. (1978) used colored latex emulsion and was unable to display the intraosseous path of the vessels in his histological preparations – and probably correctly attributed his difficulty to the decalcification and fixation process.

India ink provides good contrast with surrounding tissues, is stable at room temperature, and with particles smaller than 1 µm perfused even the smallest vessels (Romeis, 1989). We chose India ink for our study.

Around 42% of the scaphoid bone is covered with cartilage. A critical part of our study was therefore displaying the path of vessels crossing from outside to inside the bone. Injection material is often degraded during decalcification and fixation (Fasol et al., 1978). Identifying vessels is difficult using Spalteholz technique. Therefore this study used standard stains in histological sections.

This study investigated as many scaphoids as some other studies did (Table 1) although Gelberman et al. (1983) and Mestdagh et al. (1979) examined more scaphoids. Often papers show small sets of preparations, each investigated with a different technique (Carstensen et al., 1962; Fasol et al., 1978; Taleisnik and Kelly, 1966). The technique used for our study was consistent for all 12 specimens.

The scaphoid's proximal palmar surface is supplied by branches from the palmar carpal artery (Fig 2). If no distal branch of the palmar carpal artery reaches the scaphoid, vessels of the superficial palmar artery running to the scaphoid's proximal palmar area are better developed to compensate (Fig 3). This finding is contrary to Fasol et al. (1977) and Gelberman and Gross (1986) who state that the scaphoid's proximal part has no relevant direct blood supply.

In the middle third, the scaphoid's palmar surface near the tubercle has a good blood supply from the superficial palmar artery and the small radial rami arteries as also demonstrated by Gelberman et al. (1989) and Taleisnik and Kelly (1966). The scaphoid's palmar distal surface is supplied by branches of the superficial palmar artery (Fig 5) and the small radial rami arteries, as reported by Botte et al. (1988). We also observed branches of the first dorsal metacarpal artery (Fig 7) in half of our preparations. This has not previously been described.

We reject the suggestion (Gelberman and Gross, 1986) of a poor arterial supply of the scaphoid's palmar surface. The scaphoid's dorsal surface is supplied by multiple arterial branches. The main supply is from the dorsal scaphoid artery (Figs 8 and 9) as previously described (Gelberman and Gross, 1986; Gelberman and Menon, 1980; Preiser, 1910; Taleisnik and Kelly, 1966). However, this is not the only artery supplying that region as stated by Gelberman and Gross (1986).

In accordance with Mestdagh et al. (1979) we consistently found a good blood supply of the proximal dorsal area provided by small branches of the dorsal scaphoid artery, often supported by branches from the styloid artery, with both arteries varying considerably in size. Our findings do not support the statement that the scaphoid's main blood supply comes from branches of the dorsal carpal artery (Mestdagh et al., 1979).

Fasol et al. (1978) described a branch of the dorsal carpal artery to the ulnar dorsal rim of the scaphoid, forming an anastomosis with the proximal branch of the dorsal scaphoid artery nourishing the scaphoid with rami at the middle third of the scaphoid. We found an extra supply of the proximal radial region from the styloid artery and the dorsal scaphoid artery as well as from vessels from the dorsal carpal artery to the distal or ulnar rim. This shows that the scaphoid's dorsal surface is also supplied by multiple blood vessels

There are a number of anatomical variations in the vessels supplying the scaphoid that have rarely been described (e.g. the anastomosis between the radial artery and the superficial palmar artery [Fig 6] or the branches of the first dorsal metacarpal artery). Each is an example of the scaphoid's partly redundant arterial blood supply which can provide nourishment even when one source is interrupted. We thus agree with Carstensen et al. (1962) and Lützeler (1932), and do not agree with authors who consider that a poor blood supply of the scaphoid bone can cause nonunion (Andreesen, 1965; Bray and McCarroll, 1984; Obletz and Halbstein, 1938).

This study also questions an inadequate blood supply of the scaphoid as a reason for Preiser's disease due to idiopathic avascular necrosis.

This study demonstrated slight differences between the small vessels of hand pairs in the dorsal metacarpal artery and the dorsal scaphoid artery. Macroscopic and microscopic findings correlated well with regard to the scaphoid's blood supply. There were areas with vessels that either enter the cortex or come very close with enhancement of the Haversian canal system in the neighbouring cortex. These two types of scaphoid blood supply are mentioned by Carstensen et al. (1962).

Distribution of the supplying vessels around the scaphoid was similar for all surfaces. Due to variation of vessels in the bone, we were unable to confirm Gelberman and Menon's (1980) statement that intraosseus blood supply is mainly derived from the dorsal rami since blood vessels enter the scaphoid from all sides.

The fact that a relatively large part of the scaphoid surface is articulating, compared to other human bones, raises the question whether the remaining area is sufficient for nourishment. Freedman et al. (2001) state that there are no blood vessels in the cartilage. In contrast, we found vessels close to the articulating surface and even penetrating the ulnar articulation (Fig 10) which suggest that there is sufficient space (around 58% of the non-articulating surface) to ensure blood supply and nourishment of the scaphoid.

We feel that inadequate vascularisation is unlikely to be the cause of scaphoid nonunion. The palmar and dorsal side had a sufficient blood supply and even the proximal third of the scaphoid, which is prone to necrosis, was supplied by multiple branches of the palmar carpal artery, the superficial palmar artery, the dorsal scaphoid artery and was supported by branches from the styloid artery.

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