TITLE

Magnetic Resonance Angiography for Free Fibula Flap Transfer

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ABSTRACT

Recent refinements of magnetic resonance angiography (MRA) allow imaging vessels as small as the septocutaneous perforators (≤ 1-2mm diameter), but a Medline review reveals no report of septocutaneous vessel imaging for free-flap surgery. Challenges in fibula free flap preparation include knowledge of: 1) tibioperoneal anatomy, 2) the positions of the perforator vessels on the peroneal artery and their course in the posterolateral intermuscular septum and 3) the cutaneous distribution of the perforators. Questioning whether high resolution MRA could image these, we studied the lower extremities of 9 healthy volunteers. MRA demonstrated tibioperoneal anatomy in sufficient detail to exclude anatomic variants and significant peripheral vascular disease, and showed septocutaneous perforators arising from the peroneal artery and coursing in the posterolateral intermuscular septum to the skin. High resolution MRA provided anatomic and clinical information that conventionally has been impossible to obtain pre-operatively or has required multiple tests, often of an invasive nature.

(150 words)

Key Words:

Free fibula flap

Septocutaneous perforator

MRA

INTRODUCTION

The fibula osteocutaneous free flap is a vascularized composite graft composed of a segment of fibula and peroneal artery, plus a skin island derived from the lateral calf. The skin island is usually perfused by septocutaneous perforators that course transversely in the posterolateral intermuscular septum from the peroneal artery then ramify in the subcutaneous fascial plexus, although the configuration of the skin perforators can also be musculocutaneous, or septomusculocutaneous. The fibula free flap is widely used for composite reconstruction of the mandible and soft tissue of the jaw and neck. Osteotomy and plating render a mandible-like contour to the fibula, which is suitable for osseointegrated dental implantation, while the vascularized skin island is available for repair of internal and external soft tissue defects.

History:

Taylor in 1975 [1] first described the use of a vascularized free fibula flap along with a separate soft tissue flap to reconstruct defects of the tibia, fibula and overlying skin. Chen and Yan [2] harvested a composite flap of fibula plus a skin paddle for reconstruction of the upper and lower extremity, then Yoshimura [3, 4] suggested a small skin island ("buoy"), based on an underlying perforating vessel, to monitor the viability of the bone graft. After Wei [5] introduced the fibula osteocutaneous flap for bone and soft tissue reconstruction of the lower extremity by demonstrating that the skin island could be supplied solely by perforating vessels coursing within the posterolateral intermuscular septum, Hidalgo [6] initiated the use of the fibula osteocutaneous flap in the composite reconstruction of the mandible and oral soft tissues, but concluded that the septocutaneous blood supply was not adequate to support the skin island for intra-oral soft tissue replacement. Numerous papers appeared subsequently asserting the reliability of the flap in general and the vascular supply to the skin island in particular, [7, 8] among them Hidalgo's updated experience reversing his initially pessimistic assessment [9], but there remains disagreement over the technical measures necessary to insure overall graft and skin island survival.

Tibioperoneal anatomy: safety of peroneal artery harvest:

Tibioperoneal trunk variability and peripheral vascular disease have been the source of controversy as to whether arteriography is indicated prior to free fibula harvest. [10, 11] There is a 0.1-4% incidence of [11] peroneal artery absence and *peroneal arteria magna* (where the peroneal artery is the sole or dominant vessel to the lower leg) occurs in 0.2-7% [11, 12] of individuals. Normal pedal pulses are present in both anatomic variants. [11] Peripheral vascular disease with hemodynamically significant lesions of the trifurcation vessels is common in the same aging population that is at risk for oral malignancy. These conditions may result in flap ischemia, lower leg ischemia, or both, following flap harvest.

The skin island: septocutaneous blood supply:

Technical decisions in the design and elevation of a fibula free flap include where to harvest and how large to make the skin paddle and what types of perforator to include during skin paddle elevation. Governed predominantly by concern over the vascularity of the skin paddle, most surgeons place the skin paddle distally (where anatomic studies suggest a greater density of perforators is located), make the skin paddle large (to include as many perforators as possible) and incorporate all types of perforators encountered in the dissection.

Type of perforator:

At least three types of perforator that arise from the peroneal artery and perfuse the skin of the lateral calf have been defined.[13-17] Pure septocutaneous perforators course solely within the posterolateral intermuscular septum (Figure 1a). Musculocutaneous perforators take an intramuscular course, usually within the flexor hallucis longus or soleus (Figure 1b). Other types of perforator are neither purely septo- nor purely musculocutaneous in nature, but rather course largely within the septum and give off perforators into the muscle (Figure1c). [3, 13, 15, 18] The viability of the skin island depends upon the successful inclusion of a sufficient number of perforators, usually 1-2 perforators to support an island of approximately 15-20 cm. [5, 8] It is common for the surgeon to routinely leave adherent to the fibula a length of posterior muscle, usually a narrow (0.5-1 cm) cuff of soleus, with or without associated flexor hallucis longus. [18-20] This practice is intended to compensate for nescience of perforator type and location by including musculocutaneous perforators, but compromises the ideal of a flap based solely on a septocutaneous blood supply.

Location of the skin paddle:

Most surgeons also empirically restrict harvest of the skin island to the skin of the distal calf because the majority of anatomic studies have demonstrated that the septocutaneous perforators are concentrated in this region.[8, 13, 18, 19, 21, 22] Proximal perforators have been reported to be mostly musculocutaneous, but a proximally harvested skin paddle has such advantages as better suitability for sensitization and a greater chance of primary closure of the defect or the possibility of raising a larger skin island than the distal leg can afford.

Size of the skin paddle:

An additional strategy is to fashion a skin island larger than required for reconstructive purposes, to increase the likelihood of incorporating an underlying perforator. [23, 24] Although the ideal skin paddle size would be that which matches the size of the defect, oversized skin paddles are routinely harvested to incorporate as many perforators as possible.

Hypothesis:

Few, if any, of these compromises would be necessary if the location and identity of the perforators could be determined before surgery. We hypothesize that the preoperative use of Magnetic Resonance Angiography could allow the discrimination of septocutaneous perforators from perforators of other types. Before operating, the surgeon could see the origin of the perforators on the peroneal artery, and trace their course in the intermuscular septum to their termination near the skin. A skin paddle could be fashioned based on septocutaneous perforators only. It could be harvested from a location and elevated in a size that were dictated exclusively by the requirements of the reconstruction. Magnetic Resonance angiography could moreover replace conventional angiography in the exclusion of peripheral vascular disease and vascular variants which could jeopardize the donor leg or the flap.

MATERIALS AND METHODS

Nine healthy young volunteers (4 males and 5 females) underwent MRA of the lower extremity. Five volunteers (2 males and 3 females) had MRA of the right lower extremity using a knee surface coil and 4 volunteers (2 male and 2 females) had MRA of both lower extremities using a lower extremity phased-array run-off coil. A total of 13 legs were studied. Once the region of interest was identified on scout images, high resolution three dimensional images were acquired in the coronal plane before and after intravenous injection of 20 ml Gadolinium-DTPA. The use of Gadolinium-DTPA is associated with rare side effects such as: dry mouth, headache, metallic taste in the mouth, vomiting, nausea, and rash or hives and will happen to less than 1% of subjects. Data analysis was performed on axial, sagittal, coronal and 3 dimensional reconstructions, and on cine MRA sequences. The posterolateral intermuscular septum was identified on the axial plane and perforators that coursed in this septum from the peroneal artery to the skin were identified as septocutaneous perforators while those that entered or sent branches into the muscle at any point were omitted from the count. The point of origin of each septocutaneous perforator on the peroneal artery was noted and the location of its cutaneous terminus was measured as the distance from the head of the fibula.

RESULTS

MRA of the tibioperoneal trunk was obtained of sufficient detail to rule out absent peroneal artery, *peroneal arteria magna* or hemodynamically significant peripheral vascular disease although none of these variants of the conventional anatomy was seen in the 13 legs of the 9 volunteers. The tissues were demonstrated of the lateral and deep posterior compartments from which the fibula osteocutaneous flap is constructed. The peroneal artery was seen coursing medial to the fibula and giving rise to septocutaneous perforators which could be traced within the posterolateral intermuscular septum laterally to the skin. (Figures 2, 3a-b) The branching pattern of each perforator could be discerned allowing discrimination of pure septocutaneous perforators from perforators of other types. A mean of 2.54 septocutaneous perforators were identified per extremity. Every extremity had at least one septocutaneous perforator and the range of perforator number per extremity was 1-5. (Table 1) The mean distance of the septocutaneous perforators from the head of the fibula was 14.0 cm (Figure 4). (range 1.37- 27.66 cm) Dividing the length of the fibula of each extremity into equal thirds, the frequency of absent perforators was: proximal third, 9 extremities with no septocutaneous perforator (69%); middle third, 0 extremities; and distal third, 7 extremities (54%). The vertical span of the septocutaneous perforators, measured as the vertical distance between the point of origin on the peroneal artery and the cutaneous terminus averaged 1.4 cm. (range 0.3- 3.5 cm).

DISCUSSION

For the purpose of excluding a vascular variant or peripheral vascular disease, MRA of the tibioperoneal trunk is qualitatively equivalent to a conventional arteriogram[25]. Conventional arteriography is routine at many institutions and has higher risk of morbidity and mortality related to complications from arterial puncture (hemorrhage, arterial dissection, embolization) and systemic effects of iodinated contrast (anaphylaxis, renal failure) compared to MRA. The peripheral arterial system of the lower extremity was the first in which the feasibility of magnetic resonance angiography was demonstrated [26] and reports [27, 28] assert the near equality of MRA to conventional arteriography in the planning of vascular surgery in the ischemic lower extremity. The two dimensional limitation of conventional angiography does not provide the spatial resolution critical to planning a reconstructive procedure, although vessels as small as the septocutaneous perforators are frequently incidentally seen. One report has previously appeared of MRA of tibioperoneal trunk vessels in advance of vascularized fibular grafting [29] and excellent correlation between magnetic resonance and intraoperative findings was found with respect to tibioperoneal branching pattern, but septocutaneous perforators were not noted. The use of preoperative Doppler ultrasound to localize where perforators terminate in the skin is routine in many centers, but this study cannot distinguish between the different types of perforator [8, 30]. MRA possesses all the assets of Doppler and conventional angiography but none of their liabilities specific to the requirements of vascularized free fibula grafting. (Table2)

MRA successfully demonstrated the septocutaneous perforators upon which the skin island of the free fibula osteocutaneous flap is based. Anatomic data of comparable detail has previously been available only from cadaver studies or intraoperative dissections; the noninvasive demonstration of these vessels *in vivo* has not been previously reported.

Several important differences emerge comparing MRA findings to cadaver and clinical dissections reported in the literature. MRA, along with a number of dissection-based studies, revealed that every extremity had at least one septocutaneous perforator. [7, 30] Other dissection studies, however, found a frequency up to 25% of extremities with no perforators. (Table 3) The frequent presence of proximal perforators was established by MRA. In contrast, dissections have emphasized a paucity or absence of proximal perforators, which has discouraged the majority of surgeons from locating the skin island more proximal than the distal third of the lateral calf.[8, 13, 18, 21, 31, 32] The absent perforator represents a more serious problem than the "invisible" one, as a skin island raised with no blood supply will not be viable. MRA disclosed that in the distal third of the calf, 54% of extremities (7 of 13) had no septocutaneous perforator. Beppu [13] also found that when only pure, non-branching septocutaneous perforators were counted, 65% of extremities were without a septocutaneous perforator distally. The reported complete absence of septocutaneous perforators from 6-25% of individuals [5, 8, 13, 18] correlates with the skin island failure rate in some clinical series. [18, 33]

There is controversy whether the skin island should be based on septal perforators alone or should include muscle perforators as well. The dissection is most efficient when the substance of the surrounding muscle need not be violated or integrated into the flap. Moreover the skin island has the greatest mobility when it is tethered to the fibula only by the paper-thin septum from which the surrounding muscle has been completely dissected free. Nevertheless, construction of a skin island based on a purely septocutaneous blood supply is thwarted by difficulty in determining the location of the perforators and their type. Many surgeons incorporate a muscle cuff (flexor hallucis longus with or without soleus) along the septum.[31] Any efficacy of the muscle cuff may relate to the protection of the septocutaneous perforators from intraoperative injury, or to the inclusion of musculocutaneous perforators. Schusterman found that 33% of flaps survived based on a purely septocutaneous supply but that when a muscle cuff was used, flap survival rose to 93%. [18] Another group of practitioners does not routinely incorporate a muscle cuff, but will if an inadequate number of septocutaneous perforators is found fashion a musculocutaneous flap instead. [33, 34] Recognizing that coupling posterior muscle to the fibula at least partially abrogates rotational ability and the "reach" of the septum-tethered skin island, Wei *et al* [5] perform an intramuscular dissection of musculocutaneous perforators if septocutaneous perforators cannot be found. Anthony resects the majority of the fibula then performs a subperiosteal resection of the excess distal portion, which he claims preserves a greater number of perforators in the spared, nearly full-length septum; he also leaves a 1 cm cuff of soleus and flexor hallucis longus muscle. [19]

The prejudice toward distal positioning of the skin island may have contributed to false concern over the reliability of a purely septocutaneous blood supply. Hidalgo's 60-80% failure rate [6] (despite the use of a muscle cuff) and Schusterman's failure rate of 2/3 [18] are notable for engendering early pessimism. A potential failure rate of 13 - 65% could be predicted based on the number of distally based skin islands found by Wei [5] and Beppu [13] to have no septocutaneous perforator. At an opposite extreme, Jones [8] attributed the 100% survival rate of 34 skin islands based on a purely septocutaneous blood supply to distal placement of their harvest site. Anatomic studies showing a predominately distal concentration of septocutaneous perforators have, in general, discouraged the use of proximal skin paddles [13, 17, 35].

Technical maneuvers intended to compensate for lack of knowledge of perforator type and location have several drawbacks. Incorporation onto the flap of a muscle cuff adds bulk that may limit the ability to inset the skin island. [5] Empiric restriction of skin island harvest to the distal calf disregards the potential opportunity to construct a more proximally based island. Design of a large skin island in excess of the dimensions required for reconstruction is more likely to require a skin graft to close the donor defect and may increase the morbidity of the procedure [32, 36] Paradoxically, a large skin island may be more prone to failure because of its greater perfusion requirement. Design decisions are often based on previous studies indicating where septocutaneous perforators are found in greater number. However preoperative localization of septocutaneous perforators by MRA will make these assumptions unnecessary in the designing and positioning of the osteocutaneous fibula free flap.

CONCLUSION

Precision mapping with MRA of the septocutaneous perforators from their origin to their termination under the skin may allow the surgeon to position the island precisely over known septocutaneous vessels, and to fashion it from cutaneous regions not heretofore felt safe to employ. The use of muscle cuffs and intramuscular dissection may be avoided.

MRA as a single test accomplishes all the goals anticipated of Doppler combined with conventional angiography, and adds important data concerning the septocutaneous perforators that neither of the other tests can provide. We recommend additional clinical study of MRA with the expectation that it will surpass and supplant the other modalities in the preoperative evaluation of patients undergoing free fibula osteocutaneous flap surgery.

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Figure 1a-c: 1a. Pure septocutaneous perforators, 1b. Musculocutaneous perforators, 1c. Perforators neither purely septo- nor purely musculocutaneous in nature but course largely within the septum

Figure 2: Septocutaneous perforator arising from the peroneal artery (arrow) and entering the posterolateral septum. The septum lateral to the fibula can be traced out to the skin. (tiny arrows)

Figure 3a-b: 3a. Septocutaneous perforator cutaneous terminus in coronal(left) and sagittal(right). 3b. Septocutaneous perforator cutaneous terminus in trasverse image.

Figure 4: Perforator distribution and frequency as distance from the head of the fibula (HOF): All 33 perforators in numerical order are marked at the distance from HOF where they were observed (scatter plot) and the frequency is summed at every 1 cm interval (bar graph).

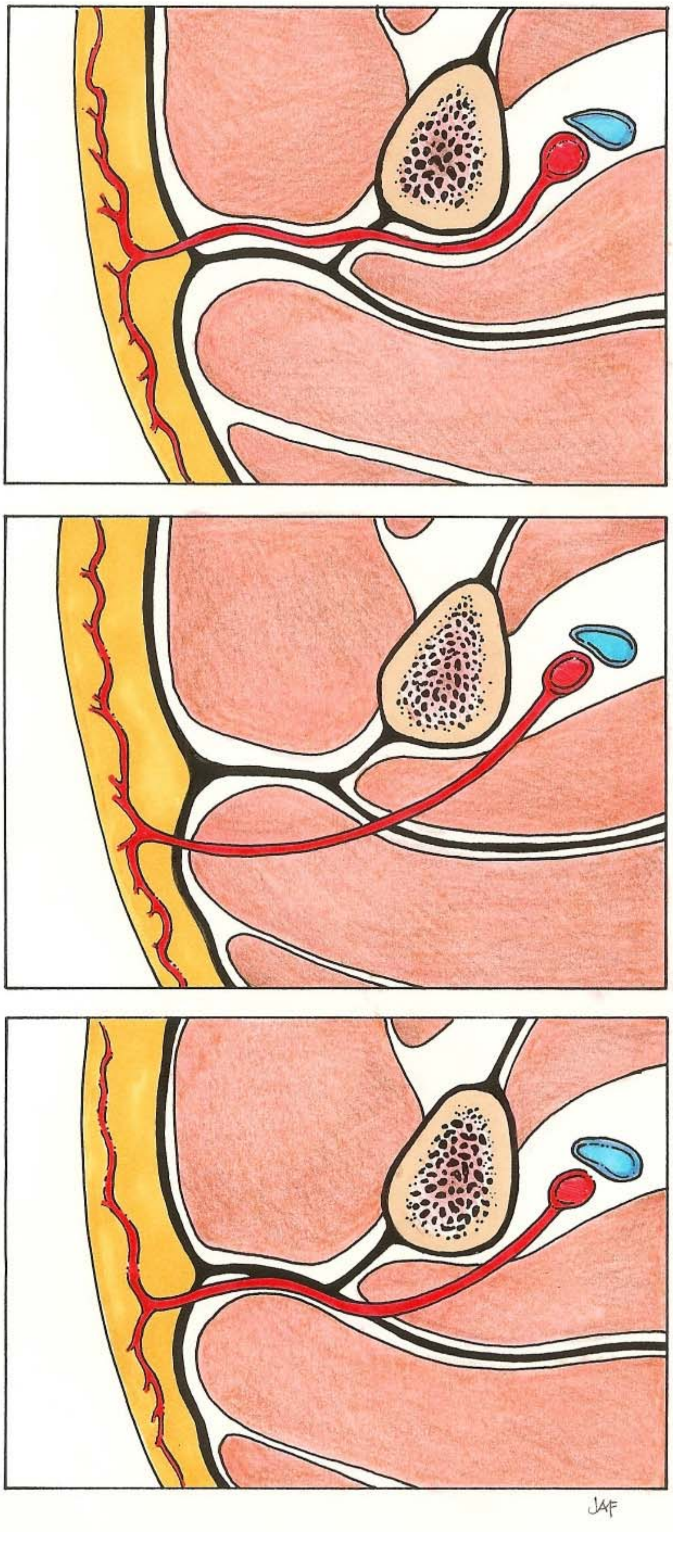

Fig.1

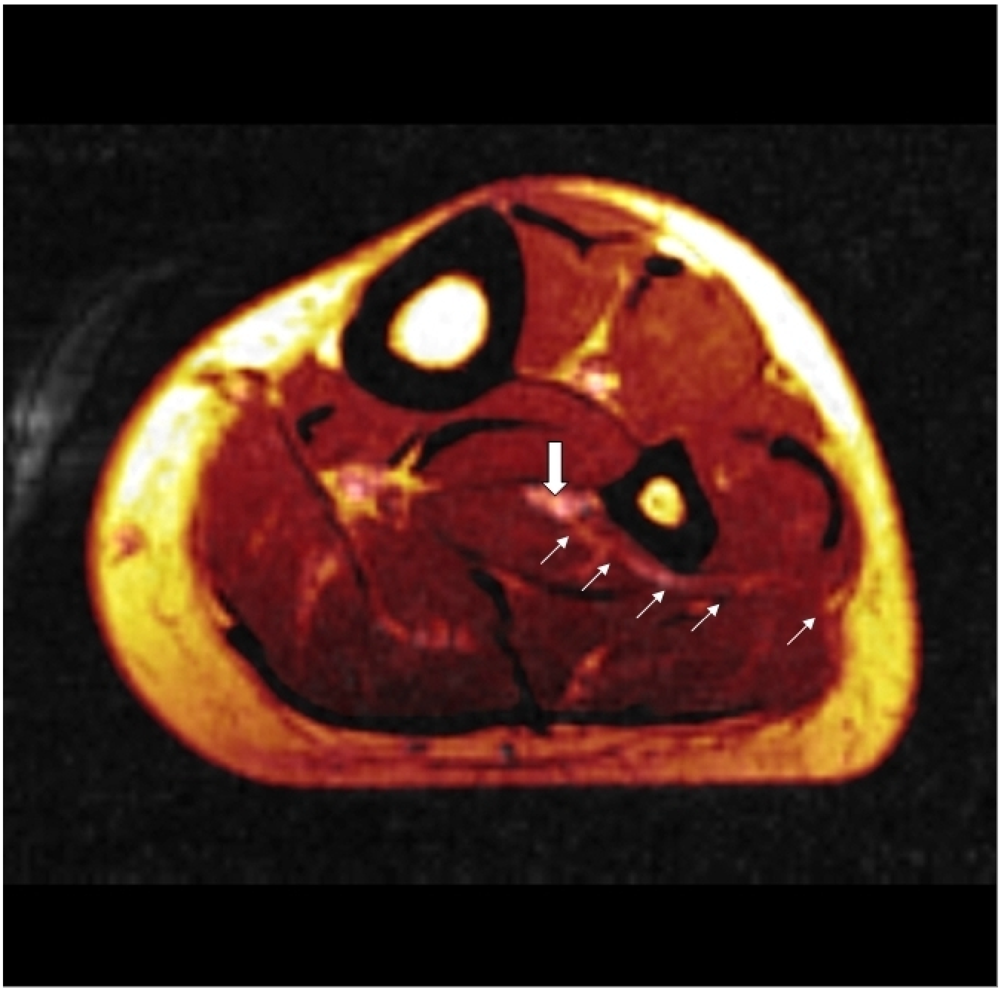

Fig.2

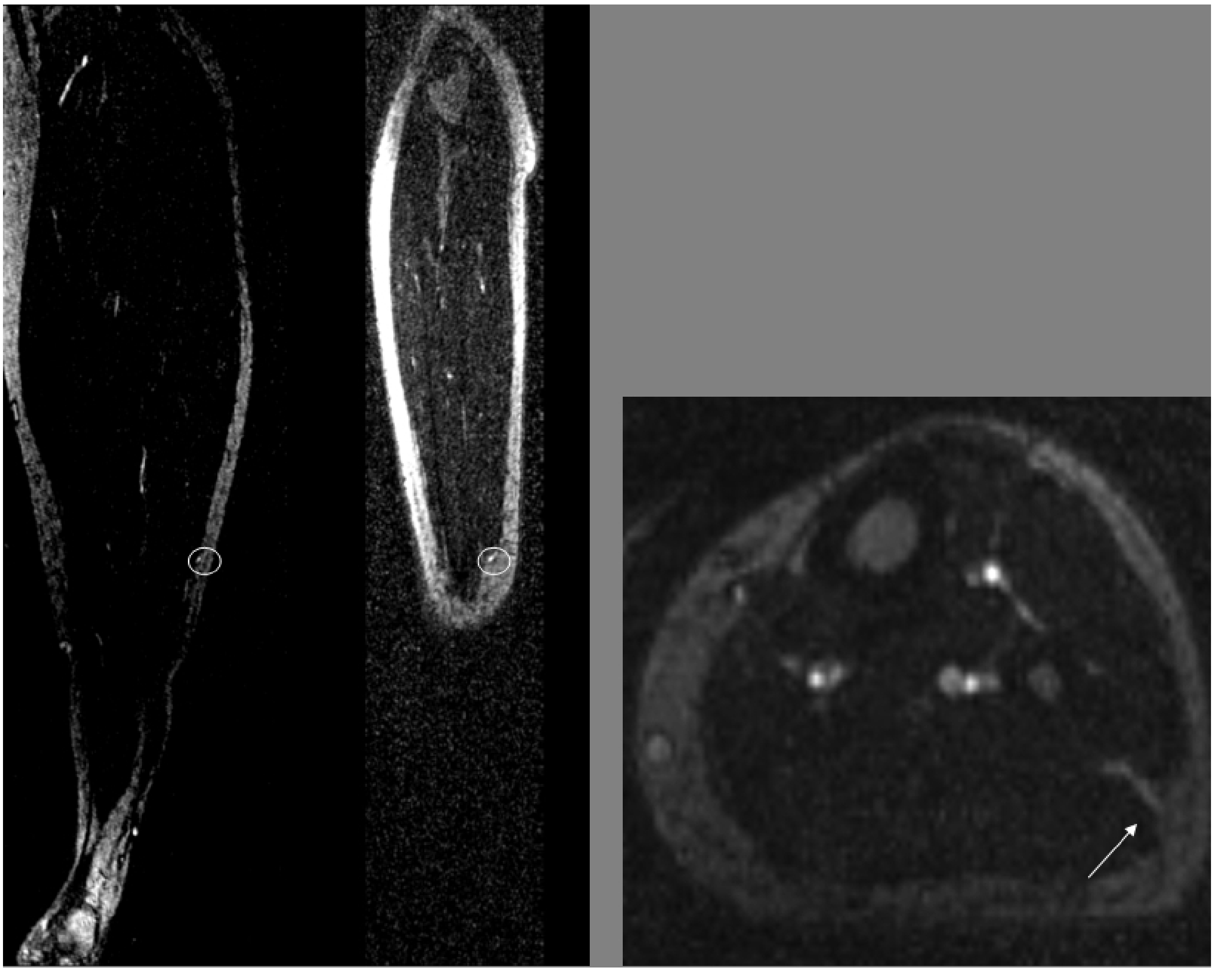

Fig.3

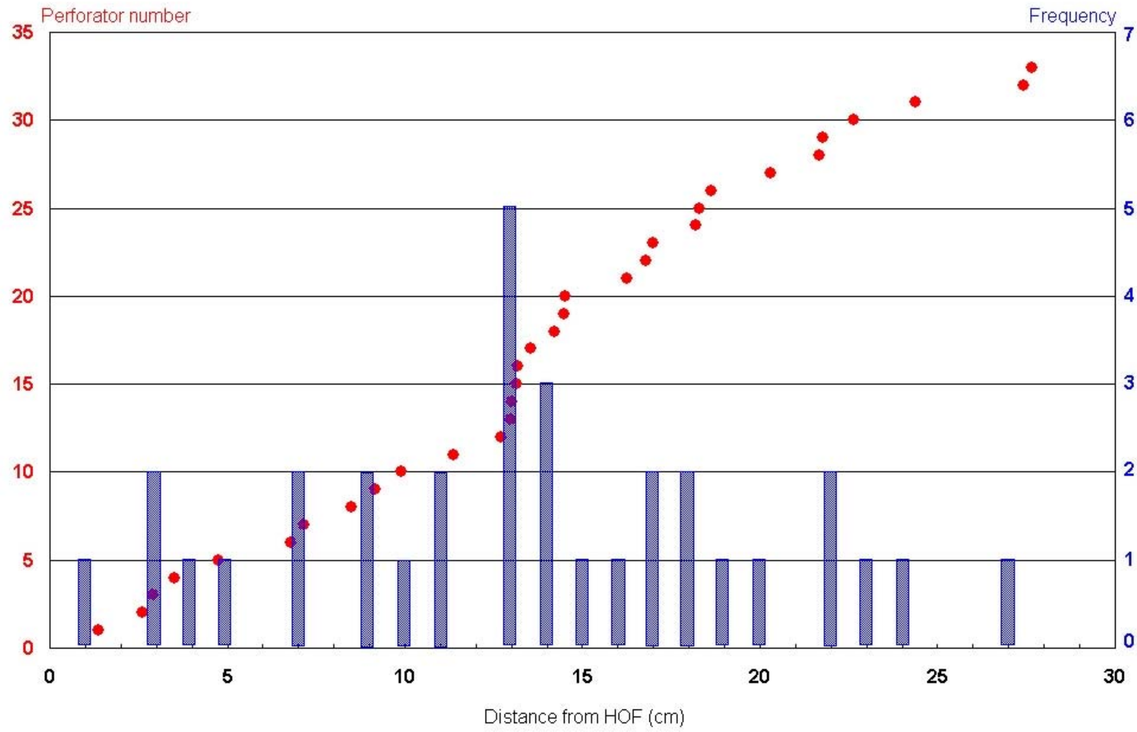
Perforator number
Frequency
35
30
25
20
15
10
5
0
7
6
5
4
3
2
1
0
0
5
10
15
20
25
30
Distance from HOF (cm)

Fig.4