# Study on evaluating involvment of adjacent major vessels by soft tissue masses deep in the extremities using mDixon-MRA*

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Abstract. Soft tissue masses deep in the extremities pose significant challenges due to their potential involvement with adjacent major vessels, impacting treatment decisions and prognostication. While MRI is valuable in diagnosing these masses, specific signs for differential diagnosis are lacking. This study focuses on the utilization of mDixon magnetic resonance angiography (mDixon-MRA) combined with compressed sensing (CS) to assess the involvement of adjacent major blood vessels by soft tissue masses deep in the extremities. The methodology involves preoperative imaging evaluation, including conventional MRI and mdixon-MRA, intraoperative observation, and statistical analysis. The study suggests that combining mDixon-MRA with conventional MRI findings improves diagnostic efficacy. Combining mDixon-MRA with conventional MRI enhances diagnostic accuracy, offering clinicians a reliable method for assessing vascular involvement in soft tissue masses, thereby improving patient outcomes.

Keywords: Soft tissue mass, involvement of vessels, mDixon-MRA.

## 1. Introduction

Soft tissue masses in the extremities are mostly tumors or tumor-like lesions, which mainly originate from the mesenchymal tissues, including benign, intermediate and malignant. Malignant soft tissue tumors, known as soft tissue sarcomas (STSs), account for about 1% of all malignant tumors in adults and 12% of malignant tumors in children [4].

MRI,with its high soft tissue resolution ,has become one of the most valuable imaging methods for the diagnosis of soft tissue masses in the extremities, but it still shows a lack of specific signs in differential diagnosis. There are also great differences in the clinical manifestations, treatment and prognosis of soft tissue masses of different nature [11]. Benign soft tissue tumors or tumor-like lesions in the extremities usually have clear boundaries, which reflects the characteristics of non-invasive growth and can often obtain a complete resection margin during Surgery. However, intermediate and malignant soft tissue tumors in the extremities tend to have fuzzy boundaries, infiltrate and grow into the surrounding tissues, and can involve the surrounding tissues, which are prone to recurrence after surgery [14,16,12,9]. The 2021 NCCN STS treatment guidelines emphasized that limb salvage surgery can effectively achieve local tumor control for the majority of STS patients, while vessels invasion of tumors is a contraindication of limb salvage surgery. There still exist variations in selecting the optimal surgical strategy. When major vessels in the extremities are involved, a decision must be made between extended resection (which may lead to patient defects) and limited resection (which may lead to incomplete mass resection) [10,15]. At the same time, the relationship between masses and adjacent major vessels is also considered to be an independent prognostic factor for recurrence [12]. While STSs can infiltrate vessels, benign and intermediate soft tissue masses can also surround vessels, which may not be completely resected during surgery. Therefore, preoperative evaluation of vascular involvement of soft tissue masses is crucial [8].

Digital subtraction angiography (DSA) is considered the gold standard for clinical examination of vascular diseases. However, due to its invasiveness and associated risks such as vascular damage, bleeding, arterial embolism, and ionizing radiation exposure, its application is somewhat limited [13]. Computed tomography angiography (CTA) is widely used in clinic, but its applicability is limited by ionizing radiation, poor soft tissue resolution and unsatisfactory display of venous structure. Conventional non-enhanced magnetic resonance angiography (MRA) may lead to errors by misinterpreting areas of slow blood flow as occluded regions [7]. Three dimensional contrast-enhanced angiography (3D CE-MRA) overcomes

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the artifacts caused by hemodynamic differences and is increasingly becoming the preferred method for assessing vascular diseases [8]. The imaging technologies selected by CE-MRA mainly include 3D contrast-enhanced technology, time-resolved imaging of contrast kinetics (TRICKS) and time-resolved cross stochastic trajectories (TWIST). These technologies all require the use of subtraction to correct for the problem that traditional fat saturation techniques cannot achieve complete fat suppression, thus increasing the risk of motion artifacts. mDixon-MRA can achieve accurate separation of water and fat, and its water phase diagram can obtain excellent fat suppression effect without subtraction, which not only avoids artifacts, noise and repeated examinations caused by subtraction, but also obtains higher contrast between vessels and background tissues. In addition, compressed sense (CS) technology can shorten the imaging time exponentially and obtain high-quality MR images by randomizing sparse sampling. mDixon-MRA combined with CS can easily achieve continuous and uninterrupted scanning of magnetic resonance angiography, with a single-phase scanning time controlled within a few seconds, so as to achieve dynamic observation of blood reflux process.

In this study, mDixon-MRA combined with CS was used to observe the major vessels adjacent to soft tissue masses deep in the extremities. Intraoperative findings and pathological results were used as the reference standard to evaluate the predictive ability of mDixon-MRA for evaluating involvemnet of adjacent major vessels by soft tissue masses deep in the extremities, so as to provide richer and more valuable information for subsequent treatment.

## 2. Material and Method

### 2.1. Case Data

This study complies with the Helsinki guidelines, and the research plan has been approved by the Ethics Committee of Dalian Medical University (ethics No.2022113). Patients who were admitted to the First Affiliated Hospital of Dalian Medical University from July 2021 to February 2024 with suspected soft tissue mass or soft tissue tumor recurrence in the extremities were collected. All patients signed informed consent and underwent MRI examination. All patients received surgical treatment in our hospital. The inclusion and exclusion criteria are as follows, inclusion Criteria: 1. Standardized scanning was performed in Philips Ingenia CX 3.0T MR scanner before surgery. 2. Surgical treatment within two weeks after MR examination; 3. Surgical confirmation of extracompartmental masses in the extremities: the mass or peritumoral edema extends beyond the anatomical interval or fascia, or is located in a plane with no natural anatomical obstruction (e.g. popliteal fossa). Exclusion Criteria: 1. Intracompartmental nasses in the extremities: lesions in which the mass is completely located above the superficial and deep fascia, or only touches, does not break through the fascia, and is confined to a defined anatomical structure (entirely within a muscle or joint); 2. MR Image quality is not good.

### 2.2. MR Equipment and Technology

All patients underwent MR examination within two weeks before surgery and all scans were performed on Philips ingenia CX 3.0 T MR scanner using abdominal 32 channel coil. Patients were supine and head first when scanned, and rice bags were used to fix and immobilize the extremities and maintain a more uniform magnetic field.

MR scans include T1WI-mDixon(IP Water), T2WI-mDixon(IP Water), mDixon-MRA(6 phases), T1WI-mDixon+C. Among them T1WI-mDixon(IP Water), T2WI-mDixon(IP Water), T1WI-mDixon+C were scanned with the tumor as the center, including at least two scanning directions (horizontal + coronal and/or sagittal). mDixon-MRA should extend the scanning range to the cranial side as much as possible and perform coronal or sagittal imaging under the premise of complete tumor inclusion. mDixon-MRA scan was performed by fluoroscopic triggering technique after intravenous administration of contrast agent, which was meglumine gadopenate injection. A high-pressure syringe was used to push the drug, the injection dose was 0.2mmol/kg, the injection rate was 2.5ml/s, and the T1WI-mDixon+C (horizontal, coronal, and sagittal) sequences were scanned. mDixon-MRA was reconstructed according to MaxIP, and the three-dimensional MRA images of 6 phases were obtained. The MR scanning sequence and parameters are shown in Table 1.

### 2.3. Preoperative Imaging Evaluation

Two observers (ZLN, ZMT) independently observed and recorded the MR characteristics of the major vessels adjacent to the soft tissue masses deep in the extremities using a double-blind method before

Table 1. MR scanning sequence and parameters of soft tissue masses deep in the extremities

| | T1WI-mDixon | T2WI-mDixon | mDixon-MRA |
|---|---|---|---|
| Repetition time, ms | 4 | 2000-4500 | 4 |
| Echo time, ms | 1.4 | 80-110 | 1.4 |
| Field of view, mm2 | 160*160-400*400 | 160*160-400*400 | 480*400 |
| Acquisition voxel size, mm3 | 0.8*0.8*4-1.1*1.1*4 | 0.8*0.8*4-1.1*1.1*4 | 1.1*1.1*2 |
| Accelerated technique | CS | SENSE | CS |
| Accelerated factor | 2 | 2 | 7 |
| TSE factor | NA | 18 | NA |
| Bandwidth, Hz/pixel | 1250 | 706 | 1146 |
| Scan time | 30s | 2m30s | 2m14s |

surgery. In case of disagreement, a professor with 35 years of experience in MRI diagnosis of the osteomuscular system and 22 years of experience in surgery for soft tissue mass of extremities participated in the discussion and reached a consensus before surgery.

Conventional MRI combined with mDixon-MRA images were used to exclude typical hemangioma cases, besides, blood supply arteries and drainage veins around the mass were not included in the evaluation of this study. Patients with soft tissue masses deep in the extremities closely related to adjacent major vessels were selected for preoperative imaging evaluation. The observation indicators are as follows:

1.On the basis of conventional MRI, we assessed whether there was a spatial position relationship between the soft tissue mass deep in the extremities and the adjacent major vessels (i.e. whether they were in contact) and the extent of encasement between mass and circumference of vessels (a four-point scale were adopted, namely 1°-90°, 91°-180°, 181°-270°, and 271°-360°). The vascular involvement was scored on conventional MRI as follows: 0 score: no contact, defined as the presence of fat or other tissue gaps between mass and adjacent major blood vessels on all images; (2) 1 score: the mass contacts the vessels with no gap, and the extent of encasement is 1°-90°; (3) 2 score: the mass partially encases the vessels with encasement of 91°-180°; (4) 3 score: the mass partially encases the vessels with encasement of 181°-270°; (5) 4 score: most of the mass encases vessels or vessels completely located within the mass with encasement of 271°-360°.

2.Observed and recorded whether the major vessels adjacent to soft tissue mass deep in the extremities are displaced or stenosis (stenosis can be divided into no stenosis, 1%-25%, 26%-50%, 51%-75%, 76%-99%, and occlusion) in the 6-phrases mDixon-MRA reconstruction images. The maximum intensity projection of all patients was compared with the original image to exclude potential artifacts, and a score of vascular involvement was performed on mDixon-MRA: (1) 0 score: no displacement of vessels; (2) 1 score: vascular displacement, no stenosis; (3) 2 score: stenosis of 1%-25%; (4) 3 score: stenosis of 26%-50%; (5) 4 score: stenosis of 51%-75%; (6) 5 score: stenosis of 76%-99%; (7) 6 score: occlusion.

### 2.4. Intraoperative Findings

The surgery was performed randomly by two surgical teams (leading physicians QW and FCY with 30 and 22 years of experience in soft tissue mass surgery, respectively). The relationship between the vessels and masses observed during the surgery was used as the reference standard: vascular involvement was considered as positive (positive during the surgery) when the adjacent major vessels could not be dissected from the mass or the vascular reconstruction or amputation surgery was required; the vascular involvement was considered as negative (negative during the surgery) when there is no adherence or adherence or even encasement between the mass and vessels but can be dissected during the surgery.

### 2.5. Statistical Analysis

Statistical analysis was performed by using surgical findings in surgically resected tumors as the reference standard. Sensitivity, specificity, positive predictive value, negative predictive value, and accuracy of conventional MR imaging and mDixon-MRA findings were calculated separately for the presence of partial or complete encasement, stenosis, and occlusion. Statistical analyses were performed by using computer software (SPSS, version 25.0).

## 3. Result

This study included a total of 33 patients with soft tissue mass deep in the extremities closely related to adjacent major vessels, including 19 males and 14 females, aged 23-82 years, with a median age of 59 years. Two vascular bundles were included in 12 patients, resulting in a total of 45 vascular evaluations in this study. Among the 33 cases, there were 14 cases of benign or intermediate lesions (6 cases of schwannoma, 3 cases of lipoma, 1 case of desmoid fibroma nodular tendon sheath fibroma tendon sheath cyst and lymphatic fluid cyst). 19 cases of soft tissue sarcoma (6 cases of liposarcoma, 5 cases of mucinous fibrosarcoma, 3 cases of malignant schwannoma, 2 cases of undifferentiated pleomorphic sarcoma and smooth muscle sarcoma, and 1 case of synovial sarcoma). 2 patients with STSs recurred after surgery, underwent palliative surgery for refusing amputation (case 4, 17), and underwent amputation for recurrence (case 19, 29). Both preoperative examinations and surgeries were included in our study. An additional case of STSs (case 13) recurred locally after previous surgery and underwent surgery again.

### 3.1. Conventional MRI Findings of the Involvement of Vessels

Conventional MR imaging findings of the involvement of vessels is shown in Table 2. There were 5 cases showed no contact between vessels and mass. Vessels were encased by mass at 1°-90° in 9 cases at 91°-180° (Fig. 1) in 3 cases and at 181°-270° (Fig. 2 and Fig. 3)in 3 cases, respectively. During surgery, 2 cases (cases 6 and 9) were found a adherence and unable to dissected the vessels. A total of 25 cases of vessels were encased by mass at 270°-360°. During surgery, 5 cases (cases 11, 12, 16, 21, 28) were able to be dissected and protected, while other 5 cases (cases 3, 7, 17, 18, 22) were completely encased by masses but successfully dissected.

### 3.2. mDixon-MRA Findings of the Involvement of Vessels

mDixon-MRA findings of the involvement of vessels is shown in Table 2. There was no displacement or stenosis of the vessels in 7 cases, however, 1 liposarcoma (case 32) was found to completely encase the branch of the deep femoral artery and could not be dissected during the surgery, so resection was performed. Vascular displacement but no stenosis in 12 cases(Fig. 1), while 2 cases (cases 13, 20) were performed the resection because that they were supplied by adjacent major vessels and the vessels could not be dissected during the surgery. Besides, there are displacement with stenosis of 0%-25% in 7 cases, stenosis of 26%-50% in 6 cases , stenosis of 51%-75% in 1 case , stenosis of 76%-99% in 3 cases , complete occlusion in 9 cases, and vessels were dissected and protected during the surgery in 12 cases.

### 3.3. Surgery Findings of the Involvement of Vessels

Surgery findings of the involvement of vessels is shown in Table 2. There was no relationship between the major vessels and the mass in 4 cases. The major vessels were compressed or pushed by the masses with no adherence during the surgery and the masses was finally resected completely without any treatment of the vessels in 11 cases. Of the 11 cases of vascular adherence to the masses, vessels (cases 6, 9, 14) were resected in 3 cases because they could not be dissected, while the remaining vessels in 8 cases were dissected and released. The vessels were encased by mass in 19 cases, and 14 of them underwent vascular resection anastomosis or amputation because the major vessels could not be dissected during the surgery. The other 5 vessels could be dissected and released, but 1 case (case 17) received palliative care for partial mass resection because the mass also encased other major vessels and could not be dissected.

### 3.4. The Value of Conventional MRI and mDixon-MRA in Evaluating the Involvement of Adjacent Major Vessels by Soft Tissue Masses Deep in the Extremities

The vascular involvement scored on conventional MRI and mDixon-MRA were compared with the intraoperative observation, and the diagnostic efficiency of preoperative images to determine whether vessels were involved was calculated according to the different grouping criteria of the scores, as shown in Table 3.

In conventional MRI, the Yodon index (0.52) was the highest in the diagnosis of involvement of adjacent major vessels by soft tissue masses deep in the extremities when the vessels were found to be mostly or completely encased (encased $> 270°$, i.e. 4 points), with a sensitivity of 88%, specificity of 64%, positive predictive value of 60%, negative predictive value of 90%, and accuracy of 73%. In mDixon-MRA,

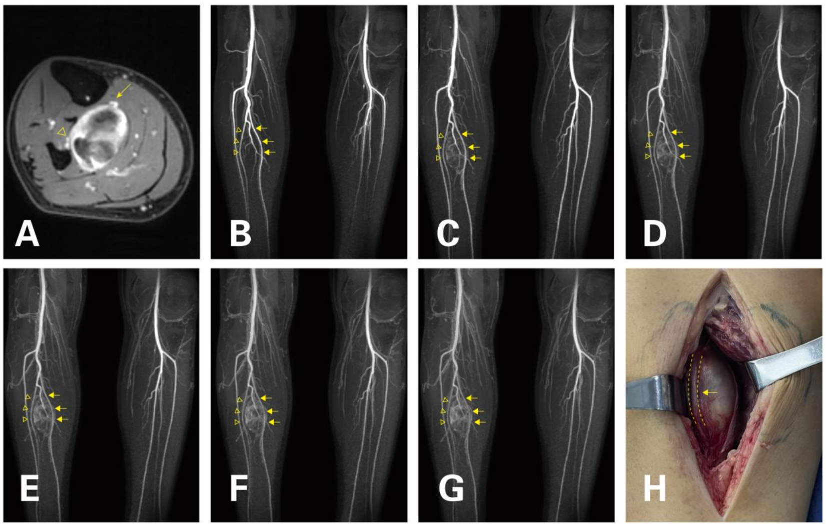


Fig. 1. A. Axial T1WI-mDixon+C shows a soft tissue mass deep in the lower leg, encasing the posterior tibial artery (long arrow) at 1-90° and the peroneal artery (triangle) at 91-180°. B-G. 6-phase mDixon-MRA reconstruction images show the soft tissue mass pushes the adjacent peroneal artery(triangle) and posterior tibial artery (long arrow), however, there was no lumen stenosis and a thin gap between the mass and the peroneal artery was observed. H. The posterior tibial artery (dotted line, long arrow), which was attached to the surface of the tibial schwannoma, was dissected during the surgery.

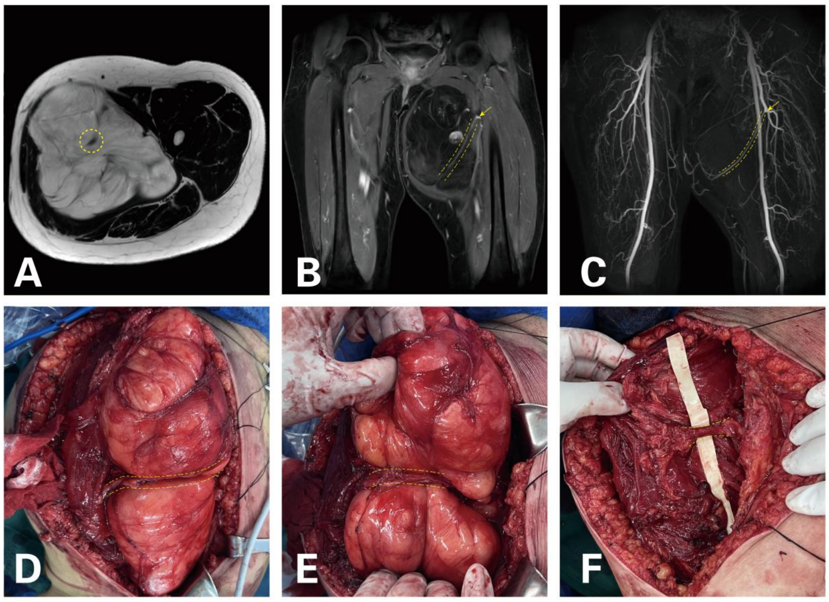


Fig. 2. A. Axial T2WI shows that the perforating branch of the deep femoral artery of the left thigh (circle) is completely encased by an adipose mass. B. Coronary T1WI-mDixon+C showed that the main femoral deep artery (long arrow) was in contact with the mass, and the perforating branch of the femoral deep artery was passing through the mass (dotted line). C. mDixon-MRA phase 1 reconstruction showed slight compression and displacement of the main (long arrow) and perforating branches (dotted line) of the deep femoral artery, and no significant lumen stenosis. D-F. During the surgery, it was found that neurovascular bundles (dotted line) formed by the perforating branches of the deep femoral artery and the obturator nerve branches passed through the surface of the tumor envelope, but were encased by lobulated masses. The neurovascular bundle was separated and the soft mass was slowly pulled from below the neurovascular bundle to the top. The neurovascular bundle was completely dissected after resection of the tumor.

Table 2. Clinical data, imaging and surgery findings of soft tissue masses deep in the extremities.

| Case number/gender/age(years) | Parts | I | II | Pathological type | Name of adjacent major vessel | III | IV | V |
|---|---|---|---|---|---|---|---|---|
| 1/male/57 | thigh | 2 | 3 | liposarcoma | femoral artery and vein | 4 | 3 | 6 |
| 2/male/72 | calf | 2 | 3 | Myxofibrosarcoma | distal branch of peroneal artery and vein | 4 | 6 | 6 |
| 3/male/82 | upper arm | 1 | 3 | dedifferentiated liposarcoma | brachial artery | 4 | 0 | 5 |
| | | 2 | | | brachial vein | 4 | 6 | 6 |
| 4/female/72 | upper arm | 3 | 3 | Leiomyosarcoma | axillary vein and basilic vein | 4 | 6 | 6 |
| | | 3 | | | brachial artery | 4 | 6 | 6 |
| 5/male/68 | upper arm | 1 | 1 | schwannoma | brachial vein | 1 | 2 | 2 |
| | | | | | basilic vein | 2 | 2 | 2 |
| 6/female/79 | calf | 2 | 3 | Myxofibrosarcoma | great saphenous vein | 3 | 5 | 4 |
| 7/male/45 | hip | 2 | 1 | lymphatic hydrocele | femoral artery | 4 | 2 | 5 |
| | | 1 | | | femoral vein | 3 | 5 | 3 |
| 8/male/70 | calf | 2 | 3 | Myxofibrosarcoma | small saphenous vein | 4 | 6 | 6 |
| 9/female/61 | elbow | 2 | 2 | aggressive fibromatosis | superior ulnar accessory artery | 1 | 2 | 4 |
| 10/male/23 | elbow | 1 | 1 | nodular fasciitis | brachial artery and vein | 3 | 0 | 3 |
| 11/female/28 | feet | 1 | 1 | tendon sheath fibroma | dorsalis pedis artery and vein | 4 | 2 | 3 |
| 12/male/34 | ankle | 1 | 1 | ganglion cyst | posterior tibial artery and vein | 4 | 1 | 2 |
| 13/female/75 | thigh | 2 | 3 | undifferentiated pleomorphic sarcoma | profunda femoral artery perforator | 4 | 1 | 6 |
| 14/male/34 | upper arm | 1 | 3 | malignantschwannoma | axillary artery | 1 | 0 | 3 |
| | | 2 | | | axillary vein | 4 | 6 | 4 |
| 15/female/62 | thigh | 1 | 3 | undifferentiated pleomorphic sarcoma | femoral artery and profunda femoral artery | 0 | 1 | 1 |
| | | 1 | | | femoral vein | 1 | 3 | 3 |
| 16/male/68 | wrist | 1 | 1 | schwannoma | ulnar artery | 4 | 2 | 2 |
| 17/male/82 | elbow | 3 | 3 | malignantschwannoma | brachial artery | 4 | 3 | 5 |
| | | 2 | | | brachial vein | 4 | 5 | 6 |
| 18/female/58 | ankle | 1 | 1 | lipoma | great saphenous vein | 4 | 6 | 5 |
| 19/female/72 | upper arm | 4 | 3 | leiomyosarcoma | axillary artery | 4 | 6 | 6 |
| | | 4 | | | axillary vein | 4 | 6 | 6 |
| 20/female/73 | thigh | 2 | 3 | well differentiated liposarcoma | profunda femoral artery perforator | 4 | 1 | 6 |
| 21/female/49 | thigh | 1 | 3 | well differentiated liposarcoma | profunda femoral artery perforator | 1 | 1 | 3 |
| | | 1 | | | profunda femoral artery | 4 | 1 | 1 |
| 22/male/59 | elbow | 1 | 1 | lipoma | median cubital vein | 4 | 0 | 5 |
| 23/male/53 | armpit | 1 | 1 | schwannoma | axillary artery | 1 | 1 | 2 |
| | | | | | axillary vein | 1 | 4 | 2 |
| 24/male/52 | calf | 1 | 1 | schwannoma | arteria peronea | 2 | 1 | 2 |
| | | 1 | | | posterior tibial artery | 1 | 1 | 3 |
| 25/female/60 | upper arm | 1 | 1 | schwannoma | brachial artery | 0 | 1 | 2 |
| | | | | | axillary vein | 1 | 3 | 2 |
| 26/male/55 | thigh | 2 | 3 | well differentiated liposarcoma | profunda femoral artery perforator | 4 | 3 | 6 |
| 27/male/68 | upper arm | 1 | 3 | myxofibrosarcoma | basilic vein | 0 | 0 | 1 |
| 28/female/57 | ankle | 1 | 3 | synovial sarcoma | posterior tibial artery and vein | 4 | 2 | 2 |
| 29/male/82 | upper limbs | 4 | 3 | malignantschwannoma | brachial artery | 4 | 3 | 6 |
| 30/male/57 | armpit | 1 | 1 | schwannoma | subclavian artery and vein | 0 | 1 | 2 |
| 31/female/68 | hip | 1 | 3 | myxofibrosarcoma | inferior gluteal artery and vein | 0 | 0 | 1 |
| 32/female/67 | thigh | 2 | 3 | liposarcoma | profunda femoral artery | 4 | 0 | 6 |
| 33/male/44 | upper arm | 1 | 1 | fibrolipoma | deep brachial artery | 2 | 1 | 3 |

I. Surgical method. 1-Tumor resected; 2-Tumor resected and revascularization or ligation: 3-Partial resection of tumor, palliative care; 4-Amputation.

II. Nature. 1-benign; 2-betweenness; 3-malignant.

III. Conventional MRI findings of the involvement of vessels. 0-No contact; 1-Encasement of 1°-90°; 2-Encasement of 91°-180°; 3-Encasement of 181°-270°; 4-Encasement of 271°-360°.

IV. mDixon-MRA findings of the involvement of vessels. 0-No displacement of blood vessels; 1-Vessel displacement without stenosis; 2-Vessel displacement with stenosis of 1% -25%; 3-Vessel displacement with stenosis of 26%-50%; 4-Vessel displacement with stenosis of 51%-75%; 5-Vessel displacement with stenosis of 76%-99%; 6-Vascular occlusion.

V. Surgery findings of the involvement of vessels. 1-No contact; 2-Compress or push blood vessels; 3-Adherence can be dissected; 4-Adherence cannot be dissected; 5-Fully encasement and can be dissected; 6-Completely encasement and can be dissected.

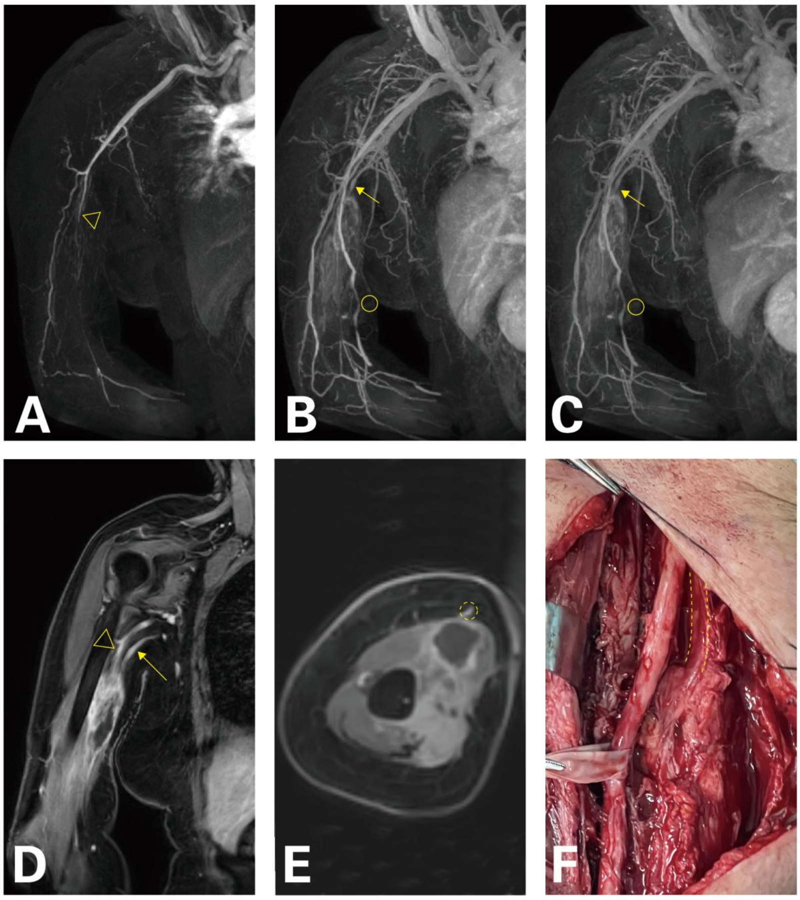


Fig. 3. A. mDixon-MRA phase 1 showed local truncation complete lumen occlusion (triangle). B-C. mDixon-MRA phase 3 and 5 showed occlusion of axillary, brachial and important veins (long arrow), and local compression and narrowing of the cephalic vein(circle). D. Coronal T1WI-mDixon+C showed that the vascular bundles (triangle,long arrow) of the upper arm were all encased by the mass E. Axial T1WI-mDixon+C show that the medial vascular bundle could not be identified and the compressed cephalic vein in front of the mass was visible (circle) . F. During the surgery, it was found that the mass completely encased the brachial artery (dotted line), and the artery wall was brittle and could not be completely removed. The patient refused amputation and partial resection was performed of the tumor.

Table 3. Diagnostic efficacy of conventional MRI and mDixon MRA in preoperative diagnosis of vascular involvement.

| Image score reference standard | 28 cases negative for vascular involvement | 17 cases positive for vascular involvement | Sensitivity | Specificity | positive predictive value | negative predictive value | Jordan index | Accuracy |
|---|---|---|---|---|---|---|---|---|
| Conventional MRI score | | | | | | | | |
| Score of 1-4 | 23 | 17 | 1.00(17/17) | 0.18(5/28) | 0.43(17/40) | 1.00(5/5) | 0.18 | 0.49 |
| Score of 2-4 | 15 | 16 | 0.94(16/17) | 0.46(13/28) | 0.52(16/31) | 0.93(13/14) | 0.40 | 0.62 |
| Score of 3-4 | 12 | 16 | 0.94(16/17) | 0.57(16/28) | 0.57(16/28) | 0.94(16/17) | 0.51 | 0.71 |
| Score of 4 | 10 | 15 | 0.88(15/17) | 0.64(18/28) | 0.60(15/25) | 0.90(18/20) | 0.52 | 0.73 |
| mDixon-MRA score | | | | | | | | |
| Score of 1-6 | 22 | 16 | 0.94(16/17) | 0.21(6/28) | 0.42(16/38) | 0.86(6/7) | 0.15 | 0.45 |
| Score of 2-6 | 12 | 14 | 0.82(14/17) | 0.57(16/28) | 0.54(14/26) | 0.84(16/19) | 0.39 | 0.67 |
| Score of 3-6 | 6 | 13 | 0.76(13/17) | 0.79(22/28) | 0.68(13/19) | 0.85(22/26) | 0.55 | 0.78 |
| Score of 4-6 | 3 | 10 | 0.59(10/17) | 0.89(25/28) | 0.77(10/13) | 0.78(25/32) | 0.48 | 0.78 |
| Score of 5-6 | 2 | 10 | 0.59(10/17) | 0.93(26/28) | 0.83(10/12) | 0.79(26/33) | 0.52 | 0.80 |
| Score of 6 | 1 | 8 | 0.47(8/17) | 0.96(27/28) | 0.89(8/9) | 0.75(27/36) | 0.43 | 0.78 |
| Conventional MRI(score of 4) and mDixon-MRA (score of 3-6) | 2 | 12 | 0.71(12/17) | 0.93(26/28) | 0.86(12/14) | 0.84(26/31) | 0.64 | 0.84 |
| Conventional MRI(score of 4) or mDixon-MRA (score of 3-6) | 14 | 16 | 0.94(16/17) | 0.50(14/28) | 0.53(16/30) | 0.93(14/15) | 0.44 | 0.67 |

the Yoden index (0.55) was the highest in the diagnosis of involvement of adjacent major vessels by soft tissue masses deep in the extremities when vascular displacement was found with stenosis> 25% (i.e., 3-6 points), with a sensitivity of 76%, specificity of 79%, positive predictive value of 68%, negative predictive value of 85%, and accuracy of 78%.

The combination of conventional MRI findings of mostly or completely encased vessels (i.e. 4 points) with mDixon-MRA findings of vascular displacement with stenosis> 25% (i.e. 3-6 points) in the diagnosis of involvement of adjacent major vessels by soft tissue masses deep in the extremities had a Yorden index of 0.64, sensitivity of 71%, specificity of 93%, positive predictive value of 86%, negative predictive value of 84%, and accuracy of 84%. And the presence of the conventional MRI found that the vessels were mostly or completely encased (i.e.4 points) or the mDixon-MRA found vascular displacement with stenosis> 25% (i.e. 3-6 points) in the diagnosis of involvement of adjacent major vessels by soft tissue masses deep in the extremities had a Yorden index was only 0.44 with the sensitivity of 94%, specificity of 50%, positive predictive value of 53%, negative predictive value of 93%, accuracy of 67%.

Conventional MRI findings showed that the vessels were mostly or completely encased (encasement of more than 270°, i.e. 4 scores) in 25 cases, 10 of which were considered to have negative vascular involvement during the surgery. 5 of the vessels (cases 11, 12, 16, 21, 28) were mostly encased by the mass (encasement of 270-359°). Another 5 cases (cases 3, 7, 17, 18, 22) were completely enveloped by the mass (encasement of 360°), 2 of them (cases 17 and 18) had mDixon-MRA results showing vessel displacement with stenosis > 25%. And the results of conventional MRI findings showed mass contact with vessels (encasement of 1-90°) and the results of mDixon-MRA showed vascular displacement with stenosis < 25% (case 9). 1 case (case 9) showed mass contacted with vessels on conventional MRI (1°-90°) with mDixon-MRA showing vessel displacement with stenosis< 25% (case 9) and the other case showed mass encased vessel on conventional MRI (181-270°) with mDixon-MRA showing vessel displacement with stenosis > 75% (case 6) were observed non-releasable adherence during surgery.

mDixon-MRA found vessel displacement with stenosis > 25% (i.e., 3-6 points) in 19 cases, of which 6 vessels (cases 7, 15, 17, 18, 23, 25) were observed to be freed and released from the mass during surgery. And the mass was found a adherence or encasement with vessel and could not be dissected during surgery in 1 case without vessel displacement (case 32), 2 cases without vessel stenosis (cases 13, 20), and 1 case with vessel displacement with stenosis < 25% (case 9).

## 4. Result Discussions

Soft tissue masses deep in the extremities may have different degree of vascular involvement or even invasion due to the anatomical characteristics of the site of the disease. Vascular invasion of malignant tumor is closely related to tumor recurrence, metastasis, prognosis and surgical selection [1]. Although benign soft tissue masses are not considered to cause vascular invasion, some benign soft tissue masses may encase the vessels and are difficult to fully dissect, which requires vascular ligation or resection during surgery. One of the most important factors that surgeons need to consider when treating patients with soft tissue masses deep in the extremities is the relationship between the mass and adjacent major vessels. To our knowledge, previous studies have mainly focused on the relationship between STSs and major vessels, while our study focused on all soft tissue masses that occur deep in the extremities, rather than being limited to malignant tumors.

It is crucial to accurately determine the involvement of adjacent major vessels by soft tissue masses deep in the extremities using imaging methods. Intravascular ultrasound (IVUS) is widely used for obtaining high-resolution cross-sectional images of blood vessels and surrounding tissues. Hünerbein et al. [6] used IVUS to accurately predict the vascular involvement of 10 out of 11 patients during the surgery, showing the accuracy of IVUS in evaluating vascular involvement by soft tissue masses. However, as an intraoperative angiography, its application is limited due to its high operator level requirements and unavailable non-invasive preoperative evaluation. Holzapfel et al. [5] compared the preoperative MRI features of 174 STSs patients with intraoperative observations and histopathological results, and found that it has the highest accuracy in diagnosing arterial, venous, and nerve involvement when the distance between tumor and neurovascular structure was less than 5mm and the extent of encasement between tumor and vascular and nerve circumference was more than 180° on axial T2WI, which suggests the value of preoperative MRI in evaluating vascular involvement by tumors. However, four cases of suspected small vessel involvement in the forearm and foot showed false positive results for artery and vein encapsulation, which may be related to the small vessel diameter and difficulty in identification by MRI. And Faizi et al. [2] found that the negative predictive value reached 100%, while the positive predictive value was only 33% when they used the contact of 180° between the tumor and neurovascular structure on MRI as the standard to predict whether there was invasion of neurovascular structure by 20 cases of STS, suggesting the limited evaluation effect of MRI. mDixon-MRA utilizes water-lipid separation technology, which eliminates subtraction in vascular imaging, increases signal-to-noise ratio, avoids motion artifact interference and magnetic susceptibility artifact at the edge of visual field, and has short scanning time and high temporal resolution, enabling continuous and uninterrupted scanning of magnetic resonance angiography. In this study, we used mDixon-MRA combined with compressed sensing technology (CS) to further shorten the scanning time and obtain reliable image quality, which has clinical practicability.

The reason for this is to consider that previous studies have explored the involvement of vessels by malignant tumors of bone and soft tissue, and soft tissue masses (benign lesions, benign tumors and malignant tumors) with different involvement of vessels may lead to differences in the selection of surgical methods. Therefore, the samples in this study included soft tissue masses that may encases vessels, including benign cases. Due to the inclusion of benign cases, the predicted encase degree of vessels involved in the mass on MRI increased from 180° to 270°, suggesting that compared with malignant tumors, benign lesions with encasement more than 270° of vessels are more likely to be difficult to dissect during surgery, and clinicians should consider taking corresponding surgical protocols.

The concept of involvement of major vessels by tumors in the extremities has not been expressed uniformly in previous studies. Previous studies have compared the consistency between imaging methods in evaluating tumor involvement of vessels and surgical or pathological results, but there is no consensus on the criteria for MRI evaluation of the relationship between tumor and vessels [5]. This study compared the accuracy of different grouping criteria on MRI and mDixon-MRA in the interpretation of involvement of vessels by tumor for the first time, and proposed that the extent of encasement between soft tissue mass and blood vessels on MRI was more than 270° as the best standard for predicting the involvement of vessels by soft tissue mass, which was higher than previous studies [5,3]. The reason for this is to consider that previous studies have explored the involvement of vessels by malignant tumors of bone and soft tissue, and soft tissue masses (benign lesions, benign tumors and malignant tumors) with different involvement of vessels may lead to differences in the selection of surgical methods. Therefore, the samples in this study included soft tissue masses that may encases vessels, including benign cases. Due to the inclusion of benign cases, the predicted encase degree of vessels involved in the mass on MRI increased from 180° to 270°, suggesting that compared with malignant tumors, benign lesions with encasement more than 270° of vessels are more likely to be difficult to dissect during surgery, and clinicians should consider taking corresponding surgical protocols.

The results of mDixon-MRA showed that a vascular stenosis of over 25% is the best criterion for predicting the involvement of vessels by soft tissue masses, which is also higher than previous studies [3], indicating that in benign cases, higher vascular stenosis is associated with involvement of vessels by masses. When combining the conventional MRI vascular involvement score and the degree of mDixon-MRA vascular stenosis, the optimal diagnostic efficacy for soft tissue masses involving blood vessels is obtained.

## 5. Conclusions

In summary, the results of this study suggest that it may indicate that the major vessels adjacent to the soft tissue masses deep in the extremities are involved if conventional MRI indicates that the encasement is over 270° of vessels by soft tissue masses and mDixon-MRA shows vascular stenosis is over 25% for patients with soft tissue masses deep in the extremities.

## Conflict of Interest

No potential conflict of interest was reported by the authors.

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