# Topological Analysis for Arteriovenous Malformations via Computed Tomography Angiography: Part 1: Mathematical Concepts

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**Background:** Evaluating the progression of soft-tissue arteriovenous malformation (AVMs) is still problematic. To establish a quantitative method, we took a morphological approach.
**Methods:** Normal blood vessels in early-phase 3D-computed tomography angiography images are theoretically expected to be tree-like structures without loops, whereas AVM blood vessels are expected to be mesh-like structures with loops. Simplified to the utmost limit, these vascular structures can be symbolized with wire-frame models composed of nodes and connecting edges, in which making an extra loop always needs one more of edges than of nodes.
**Results:** Total amount of abnormal vascular structures is estimated from a simple equation: Number of vascular loops = 1 − ([Number of nodes] − [Number of edges]).
**Conclusion:** Abnormalities of AVM vascular structures can be mathematically quantified using computed tomography angiography images. *(Plast Reconstr Surg Glob Open 2014;2:e205; doi: 10.1097/GOX.0000000000000163; Published online 28 August 2014.)*

Soft-tissue arteriovenous malformations (AVMs) progress asymptomatically or recur indistinguishably from normal blood vessels. Despite that, understanding of their progression usually relies on approximate staging according to symptoms[1] or qualitative visual assessment of imaging examinations. Against this dilemma, numerous attempts have been made to establish quantitative evaluation methods.

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From a functional viewpoint, evaluation of total shunt blood flow using transarterial lung perfusion scans[2–4] and measurement of blood pool volume with whole-body blood pool scans by Lee et al[2,4,5] are the most quantitative methods. However, these methods based on nuclear medicine are problematic for their invasion and limited site of application.

From a morphometric viewpoint, Kaji et al[6] used magnetic resonance imaging and World Health Organization Response Criteria (product of lesion major and minor axes in cross-section). However, it is difficult to apply it to vascular malformations, which are irregular in shape with indistinct borders, easily expanding and collapsing.

Considering these unmet needs, we searched for another approach to meet the anatomical nature of AVMs and set the first research objective to establish a morphological solution to quantify abnormalities of AVM vascular structures.

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## METHODS

We anticipated utilization of computed tomography angiography (CTA) results for retrospective evaluation because it is a widespread, less-invasive method of testing AVMs. Moreover, because of their relatively higher contrast, obtaining clear and stable vascular segmentation[7] is easier than Magnetic Resonance Angiography (MRA).[8–10]

We also applied 2 mathematical theories, namely topology and graph theory, to quantify abnormalities of vascular structures.

### Simplification via Topological Homeomorphism

Topology is a relatively new field of geometry that focuses on the continuity of regions. For example, as both a coffee cup and a donut share the feature of having only one hole (loop), they are considered homeomorphic with deformation.

Viewed through homeomorphic simplification, the number of loops in an early-phase 3D-CTA image of a normal blood vessel is theoretically expected to be close to zero except for physiological vascular rings, such as at the base of the brain. It is because arteries branch off repeatedly from the aorta and are not rendered with the standard CT resolution after they become arterioles (approximate diameter, 0.1–0.2 mm) (Fig. 1).

Meanwhile, the presence of a described arteriovenous shunt is depicted on early-phase 3D-CTA images as a series of pathways from the feeding artery to the drainage vein. Furthermore, the more abnormal intervascular shortcut appears, the more external loop develops or an existing loop divides.

### Quantification of Connectivity with Graph Theory

The appropriate method for loop measurement is graph theory, which is being utilized for engineering problems such as electric circuits and train routes.

If one focuses only on connectivity and dispenses with all other data such as thickness and length, the vascular structure can ultimately be symbolized into a "graph" composed of nodes and edges joining them. The number of loops in the graph can be calculated by a simple calculation using the number of nodes and edges. The principle can be verified and understood by using our "spaghetti and marshmallows vascular model." This model can be actually manipulated according to only one rule that a marshmallow (node) must be positioned on the tip of each piece of spaghetti (edge).

When a model only diverges and expands repeatedly like the branches or roots of a tree, the total number of nodes keeps one more than edges. It is because one node is needed for every new edge when branches are added or divided (Fig. 2A).

However, when nodes and edges are added to increase the number of loops, the number of edges will only increase by one extra piece each time. This is because even if a new loop is added or the existing loop is divided, one more edge is needed compared with nodes (Fig. 2B).

## RESULTS

Aforementioned mathematical concepts lead to a principle that abnormal connectivities within an AVM lesion can be quantified with the increase of difference between the number of nodes and edges comprising its wire-framed network model. This principle is depicted by the following simple equation:

$$\text{Number of vascular loops} = 1 - \left([\text{Number of nodes}] - [\text{Number of edges}]\right).$$

## DISCUSSION

### Fundamental Limitation

In clinical applications, there is an inevitable limitation that the number of vascular loops calculated from CTA images is not necessarily the histological amount of arteriovenous shunts within the actual lesion but "describable" shunts to the utmost. However, it is rather the common fundamental limitation for all imaging examinations.

### Resolution Constancy

There are 2 important points regarding this technique. The first is that image resolution affects the detection of continuity. For example, the relationship of a blood vessel with its accompanying vessel 0.3 mm away can be sometimes correctly displayed on an image with 0.27 × 0.27 mm pixel size but invari-

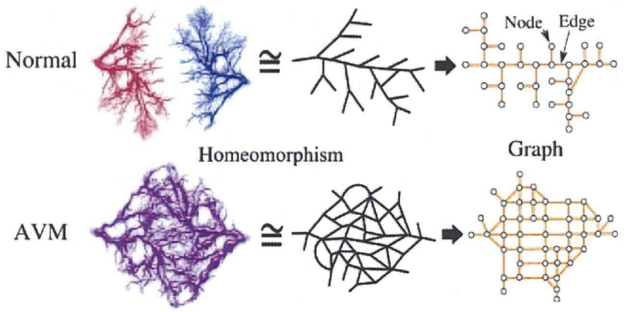


**Fig. 1.** Conceptual workflow images of homeomorphic simplification and symbolization of vascular structures. AVM graphs are assumed to be more perforated than normal blood vessel graphs.

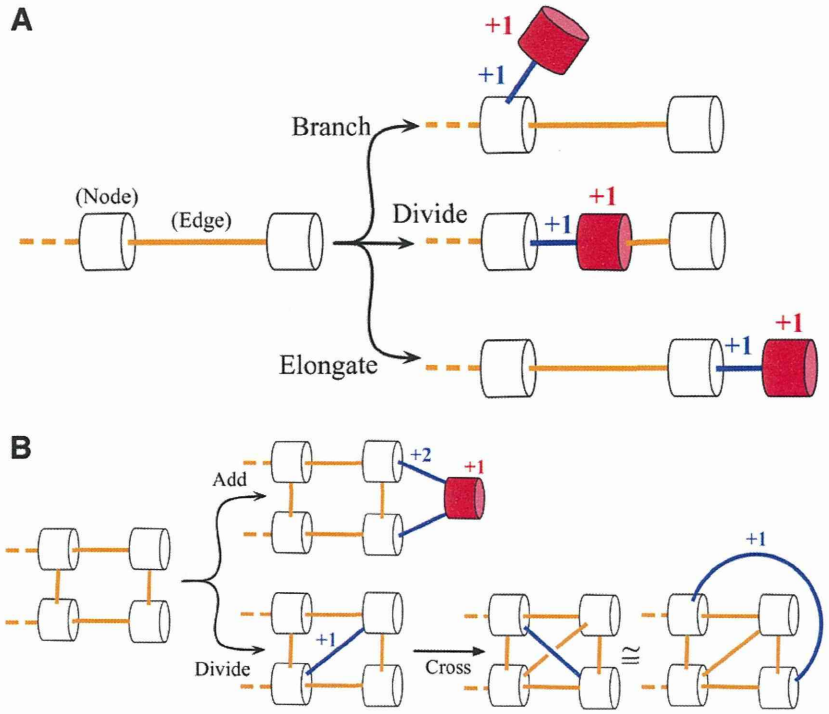


**Fig. 2.** Verification of graph theory with "spaghetti and marshmallows vascular models." A, Tree-type growth: when a model only diverges and expands repeatedly like the branches or roots of a tree, the gap of nodes and edges never changes. B, Mesh-type growth: when nodes and edges are added to increase the number of loops from that of the original model, the number of edges will only increase by one extra piece each time. This principle holds true even in 3-dimensionally (3D) complex angioarchitecture because an internal 3D crossing is topologically homeomorphic with an external handle.

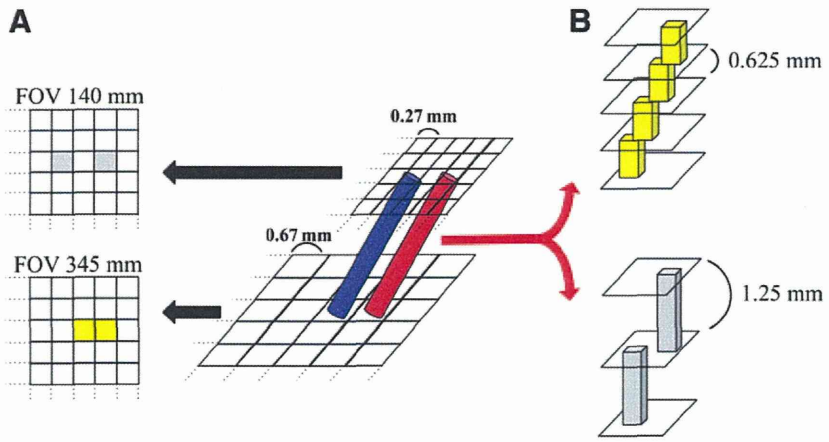


**Fig. 3.** The influence of imaging conditions. A, When a computed tomography section is provided as a 512×512 pixel image, the relationship of a blood vessel with its accompanying vessel 0.3 mm away can be sometimes correctly displayed on a 140-mm field-of-view (FOV) (pixel size, 0.27×0.27 mm) image of the peripheral extremities, while the same 2 vessels can invariably be displayed as being connected on a 345-mm FOV (pixel size, 0.67×0.67 mm) image of the trunk. B, Vessels rendered as continuous on images with a section thickness of 0.625 mm might appear to be not continuous on images with section thicknesses of 1.25 mm.

ably be displayed as being connected on an image with 0.67 × 0.67 mm pixel size (Fig. 3A).

Conversely, oblique vessels rendered as continuous on images with a section thickness of 0.625 mm might appear to be not continuous on images with section thicknesses of 1.25 mm (Fig. 3B).

Field of view and section thickness must be identical to compare test results obtained at different times from a same patient. In addition, even in patients with a common lesion site, the closer the test field of view and section thickness are, the more meaningful the comparison is.

**Region of Interest Constancy**

The second point is that one cannot be sure that region of interest has been uniformly maintained through the series of results especially when efficient procedure causes drastic change to the lesion hemodynamics. Region of interest must be identical before and after treatment, which is possible if clear, fixed points such as the junctions of well-known blood vessels or feeding arteries are used as reference points.

## CONCLUSIONS

It seems that the mathematical concepts of topology and graph theory can be used to quantify abnormalities of AVM vascular structures from CTA images. Careful assessment of validity through practical application is necessary for this novel concept.[11]

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# Percutaneous sclerotherapy for venous malformations in the extremities: clinical outcomes and predictors of patient satisfaction

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**Abstract**

The purpose of this study is to retrospectively evaluate the clinical outcomes and to identify the predictors ofpatient satisfaction after percutaneous sclerotherapy for venous malformations (VMs) in the extremities. A totalof 48 patients with VMs in the extremities over 10 years of age underwent sclerotherapy to relieve symptoms, such as pain, swelling, functional limitations, and cosmetic problems. Self-assessment questionnaires were sentto rate the degree of symptom improvement and level of satisfaction. Clinical and imaging data from medicalrecords were analyzed to obtain information about VMs and sclerotherapy. The predictors for patientsatisfaction were determined by univariate and multivariate analysis of clinical variables. Forty patients (meanage, 28.2 years; range, 11-69 years) responded to the survey. Sixteen patients had VMs in the upper extremities, and 24 patients had VMs in the lower extremities. In 12 patients (30%), adjacent bone change was seen. After amean of 2.6 (range 1-10) sclerotherapy sessions, good response to pain, swelling, dysfunction, and cosmeticproblems was obtained in 83%, 74%, 79%, and 50% of patients, respectively. Thirty-two patients (80%) weresatisfied with their outcomes. On univariate analysis, absence of adjacent bone change, maximum diameter (<6.7 cm), and number of sclerotherapy sessions (<3) were significantly associated with patient satisfaction.Multivariate analysis revealed absence of adjacent bone change (odds ratio, 7.56; 95% confidence interval, 1.02-55.8) as an independent predictor for satisfaction. Thus, adjacent bone change significantly portended adissatisfied patient. In conclusion, percutaneous sclerotherapy was effective to relieve symptoms of VMs in theextremities, and most patients were satisfied with the outcomes. However, adjacent bone change was asignificant predictor of patient dissatisfaction.

**Keywords:** Venous malformation; Sclerotherapy; Extremity; Adjacent bone change; Predictor

## Introduction

Venous malformations (VMs) are the most common type of vascular malformations. VMs are comprised of dilated, thin walled, sponge-like abnormal channels with deficient smooth muscle (Mulliken & Glowacki 1982). They are located in any portion of the body, and the main locations are the extremities (40%), the head and neck (40%), and the trunk (20%) (Dubois & Garel 1999). VMs in the extremities are sometimes asymptomatic but often present with various symptoms of pain, swelling, functional limitations, cosmetic disfigurements, and so on (Mendonca et al. 2010). Surgery, sclerotherapy, laser therapy, and conservative treatments such as elastic compression garments have been used for the management of VMs (Van der Vleuten et al. 2014). Sclerotherapy has also played a central role as a minimally invasive and effective treatment (Van der Vleuten et al. 2014; Berenguer et al. 1999; Tan et al. 2007).

Not all the outcomes of sclerotherapy for VMs have been satisfying, however, and overly aggressive treatment can make the condition worse rather than improve it and result in serious complications (Lee et al. 2008). A few studies (Berenguer et al. 1999; Yun et al. 2009) have evaluated predictors of response after sclerotherapy by

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multivariate analysis. Identification of response predictors is clinically useful to help guide patient selection and might thereby help improve treatment results and minimize complications. The clinical manifestations of VMs vary according to anatomic locations. However, predictors for response to sclerotherapy for extremities VMs have not yet been identified. The aim of this study was to evaluate clinical outcomes and predictors for patient satisfaction after sclerotherapy for VMs in the extremities.

## Materials and methods

### Patients

Following approval from the Institutional Review Board, we performed a retrospective study of a clinical database for 128 patients treated with sclerotherapy in our department between December 2002 and May 2012. The inclusion criteria for the present study population were: patients over 10 years of age who had undergone sclerotherapy for VMs in the extremities; the sclerotherapy treatment was considered to be finished; and more than 6 months had passed since the last treatment. Patients with combined vascular malformations (e.g., capillary VMs, lymphatic VMs, capillary-lymphatic VMs, Klippel-Trenauney syndrome) were excluded. Six patients who underwent surgical resection after sclerotherapy were also excluded.

VMs were diagnosed by a combination of clinical examination and noninvasive studies, such as magnetic resonance imaging (MRI), duplex ultrasonography (US), and plain film radiography, and were confirmed by fluoroscopic imaging using direct puncture. The treatment modality was determined by a multidisciplinary team in our vascular malformation clinic, involving interventional radiologists, plastic surgeons, orthopedists, pediatric surgeons, dermatologists, and pathologists. The indications for invasive treatment included worsening pain, increased swelling, reduced function, and severe cosmetic disfigurement, based on balance between the degree of symptoms and the risk of intervention.

Among 128 patients treated with sclerotherapy, 48 patients who met the inclusion criteria were contacted by telephone and were sent a questionnaire. Forty patients who submitted self-assessment data were included in the study.

### Procedures

After proper counseling and after obtaining written informed consent from patients/parents, treatment of VMs was performed using direct percutaneous injection of 3% polidocanol, absolute ethanol, or 5% ethanolamine oleate (EO). Treatment for VMs was typically tailored to each lesion and to each patient; therefore, it was not possible to utilize a uniform treatment protocol. As sclerosants, 3% polidocanol foam was mainly used. When polidocanol was not effective, we tended to use ethanol or EO. General anesthesia was used when performing ethanol injection. Otherwise, conscious sedation and local anesthesia were chosen for pain control.

Direct puncture of the lesion was performed using a 21- to 27-gauge needle under ultrasound guidance or by direct observation. Multiple punctures were performed to inject sclerosant into the majority of the lesion. The volume injected was based on the patient's weight and on the size of VM. The maximum dose of polidocanol, ethanol, and EO injected per person was 10 ml, 0.4 ml/kg, and 0.4 ml/kg, respectively.

The decision to perform repeat sclerotherapy was based on a discussion with the patient. The goal of treatment was not to eliminate the lesion, but rather to improve symptoms. Thus, even if the lesion persistent, treatment was discontinued if those goals were achieved (Figures 1).

Complications were classified into major or minor complications, according to Society of Interventional Radiology reporting standards (Omary et al. 2003). Major complications were those that resulted in an unplanned increase in the level of care, permanent adverse sequelae, or death. Minor complications were those that resulted in no sequelae with or without nominal therapy requirement.

### Questionnaire

A self-assessment questionnaire was sent to the patients in December 2012. The questionnaire contained items assessing symptoms and satisfaction levels. In the questionnaire, patients were asked for specific symptoms (e.g., pain, swelling, functional limitations, and cosmetic disfigurements), and a four-point scale was used to rate the degree of symptom improvement as follows: markedly improved, moderately improved, no change, and worsening (van der Linden et al. 2009). Similarly, patients were asked whether they were satisfied with sclerotherapy as follows: very satisfied, satisfied, dissatisfied, or neither. "Markedly improved" and "improved" were defined as a "good response", and "very satisfied" and "satisfied" were defined as "satisfaction".

### Clinical variables

Data with regard to patient demographics, clinical assessments, imaging studies, treatments, and treatment complications were obtained from the medical charts and imaging, as collected by two of the authors (MN and KO). All patients underwent pre-MRI. Clinical variables included demographic (sex), and imaging variables (VM location, VM size, VM margin, adjacent bone change, and anatomical pattern of draining veins on direct puncture venography), and procedure variables (the number of sclerotherapy, and sclerosants). Parameters that were proposed as predictors of outcomes in previous studies were evaluated in the present study (Berenguer et al. 1999; Puig et al. 2003; Yun et al. 2009; Jin et al. 2009; Mimura et al. 2009; Mendonca et al. 2010). Although adjacent bone changes, such as periosteal reaction,

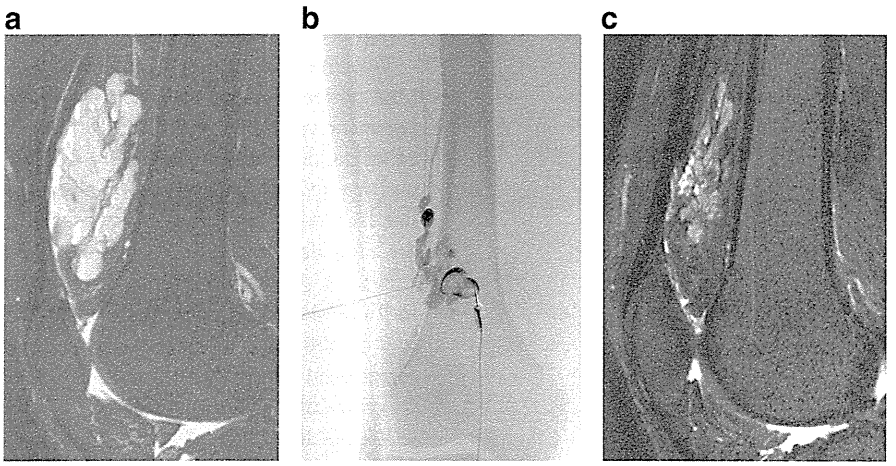


**Figure 1 A 30-year-old-male with pain, swelling, and dysfunction of the right knee joint. A**. The sagittal fat-saturated T2-weighted MR image before treatment shows a lobulated high-intensity mass in the suprapatellar bursa. **B**. Direct puncture phlebography shows the lesion cavity and the conducting vein (Type 2). Sclerotherapy was performed with 3% polidocanol foam. **C**. After two sessions, MR imaging shows a decrease in size and signal intensity of the mass. The patient had improvement of symptoms and indicated satisfaction on the questionnaire.

cortical irregularity including thickening or erosion, and medullary signal change, are often seen in VMs involving deep tissues (Ly et al. 2003), this change has not been evaluated a predictors of outcomes in previous reports. Thus, we studied whether "adjacent bone change" on MRI and plain film radiography was a predictor of outcomes in our study. The diameters of lesions were measured using MR images. Based on MRI, VMs were categorized into two margin types: a well-defined margin was defined as a sharp transition from surrounding tissue (n = 17), whereas an ill-defined margin was defined as an irregular interface with surrounding tissue (n = 23) (Jin et al. 2009). With regard to anatomical pattern of draining veins on direct puncture venography, we classified VMs into to the four types; Type 1 – isolated malformation without peripheral drainage, Type 2 – malformation that drains into normal veins, Type 3 – malformation that drains into dysplastic veins, Type 4 – malformation that represents a dysplasia (Puig et al. 2003). In our study, no lesions of Type 4 were included.

### Statistical analysis

We evaluated predictors of patient satisfaction, performing uni- and multivariate analysis of the clinical variables. The cut-off score for patient age, VM size, and the number of sclerotherapy treatments were determined by receiver operating characteristic (ROC) curve analysis. Univariate analysis was performed to compare variables between the "satisfaction" group and the "non-satisfaction" group using the chi-square test and the Kruskal-wallis test. For multivariate analysis, a binary logistic regression model was used to identify independent predictors. P values of less than 0.05 were considered to indicate statistical significance. Statistical analysis was performed using SPSS Statistics 21 software (IBM Corporation, USA).

## Results

Patient demographics and clinical data were summarized in Table 1. Distribution of the lesions in the extremities was given in Table 2. A total of 105 treatment sessions

**Table 1 Patient demographics and clinical data**

| Variables | n = 40 |
|---|---|
| Age[a] | 28.2(11–69) |
| Sex (male:female) | 11:29 |
| Location of VM[b] | |
| Upper extremity | 16(40) |
| Lower extremity | 24(60) |
| Previous treatment[b] | |
| Operation | 11(28) |
| with sclerotherapy | 2(5) |
| with TAE | 1(3) |
| Number of sclerotherapy treatments[a] | 2.6(1–10) |
| Sclerosants (partially overlapped)[b] | |
| Polidocanol | 37(93) |
| Absolute ethanol | 11(28) |
| Ethanolamine oleate | 6(15) |
| Dose of sclerosants (ml)/session[a] | |
| Polidocanol | 2.8(0.4-7.0) |
| Absolute ethanol | 7.4(4.0-13) |
| Ethanolamine oleate | 11.1(4.5-20) |

[a]Data are means. Numbers in parentheses are the range.
[b]Data represent number (percentages) of patients.

**Table 2 Distribution of the lesions in the extremities**

| Sites | | N | Total |
|---|---|---|---|
| Upper extremity | | | 16 |
| | Shoulder | 2 | |
| | Upper arm | 4 | |
| | Elbow | 3 | |
| | Forearm | 1 | |
| | Hand | 4 | |
| | Multiple | 2 | |
| Lower extremity | | | 24 |
| | Buttock | 2 | |
| | Upper leg | 6 | |
| | Knee | 2 | |
| | Lower leg | 6 | |
| | Foot | 7 | |
| | Multiple | 1 | |
| Total | | | 40 |

were performed (mean, 2.6 sessions per patient; range, 1–10 sessions). The mean number of punctures per session was 5.9 (range, 1–27). The sclerosants used for treatment are listed in Table 1. Polidocanol was used in a majority (37 of 40) of patients. In five patients, pneumatic cuff tourniquets were used beyond the lesion's venous outflow. The mean follow-up period was 2.3 years (range, 7 months-7.5 years).

Two major complications occurred after sclerotherapy. One patient treated with 10.5 ml of absolute ethanol had peroneal nerve paralysis for 9 months (Figures 2). The other patient treated with 20 ml EO had acute renal failure and needed temporary hemodialysis. Minor complications like local swelling and pain were experienced in most cases for a few days and were well controlled with NSAIDs.

Patient self-assessment questionnaire results are given in Table 3. Before treatment, 36 of the 40 patients (90%) had disabling pain, 34 (85%) had swelling, 24 (60%) had functional limitation, and 16 (40%) had cosmetic disfigurement. Patients reported "good response" in pain (83%; 30/36), swelling (74%; 25/34), functional limitation (80%; 19/24), and cosmetic disfigurement (50%; 8/16). "Markedly improved" was noted in at least one category in 48% (19 of 40) of patients. None of the patients responded "worse" for any symptoms. In addition, 32 of 40 patients (80%) reported being "very satisfied" or "satisfied" with the treatment; these patients were defined as the "satisfaction" group.

On univariate analysis of variables to predict satisfaction with sclerotherapy, absence of adjacent bone change, maximum diameter (<6.7 cm), and number of sclerotherapy sessions (<3) were significantly associated with patient satisfaction (Table 4).

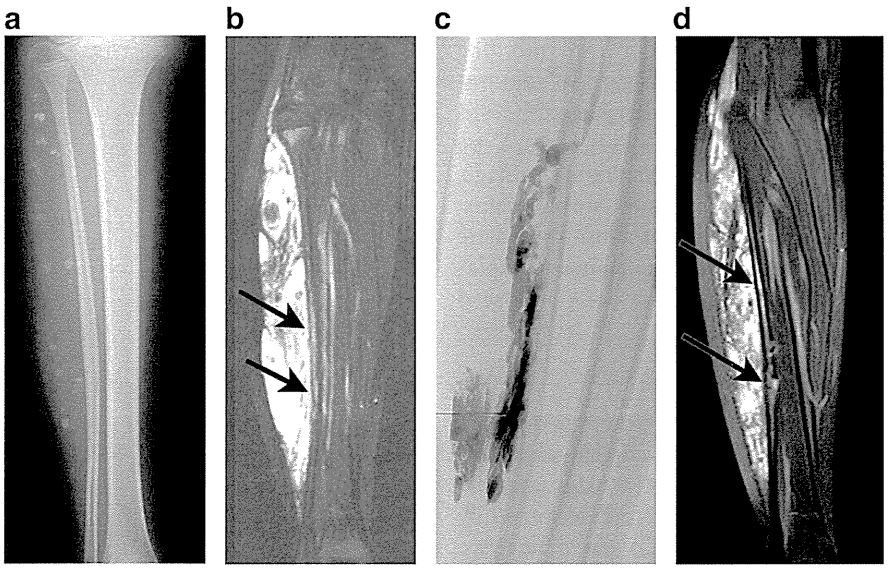


**Figure 2 A 12-year-old-female with symptoms of pain and swelling of the right calf. A**. Radiograph of the right calf demonstrates phleboliths and cortical irregularity in the fibula. **B**. The coronal fat-saturated T2-weighted MR image before treatment shows a large and infiltrating mass adjacent to the fibula with diffuse marrow signal abnormality (arrows). **C**. Direct puncture phlebography reveals VM with dysmorphic veins and early venous return of the peroneal vein (Type 3). After sclerotherapy with ethanol, the patient had onset of temporary peroneal nerve paralysis. **D**. Although the lesion shows a decrease in thickness and signal intensity on MRI, the marrow signal abnormality (arrows) remains unchanged. She reported no change in symptoms and indicated dissatisfaction on the questionnaire.

**Table 3 Clinical outcomes and degree of satisfaction after sclerotherapy**

| Symptom | Marked improvement | Improvement | No change | Worse | Total |
|---|---|---|---|---|---|
| Pain | 13(36) | 17(47) | 6(17) | 0 | 36 |
| Swelling | 11(32) | 14(41) | 9(26) | 0 | 34 |
| Functional limitations | 10(42) | 9(38) | 5(20) | 0 | 24 |
| Cosmetic disfigurements | 3(19) | 5(31) | 8(50) | 0 | 16 |
| | Very satisfied | Satisfied | Neither | Dissatisfied | Total |
| Satisfaction | 16(40) | 16(40) | 4(10) | 4(10) | 40 |

Note. Numbers in parentheses are percentages.

Table 5 shows the result of multivariate analysis. Absence of adjacent bone change (odds ratio, 7.56; 95% confidence interval, 1.02-55.8) was the only independent predictor of patient satisfaction. Among 27 (68%) patients with VMs adjacent to the bones, 12 patients (30%) showed the adjacent bone change (Figures 3).

**Table 4 Univariate analysis of variables to predict satisfaction with sclerotherapy**

| Variables | Satisfaction | Non-satisfaction | P value |
|---|---|---|---|
| *Patient demographics* | | | |
| Sex | | | 0.051 |
| Male | 11 | 0 | |
| Female | 21 | 8 | |
| Location of VM | | | 0.333 |
| Upper extremity | 14 | 2 | |
| Lower extremity | 18 | 6 | |
| *Imaging variables* | | | |
| Maximum diameter of VM | | | 0.018 |
| <6.7 cm | 19 | 1 | |
| ≥6.7 cm | 13 | 7 | |
| Margin on MRI | | | 0.055 |
| Limited | 16 | 1 | |
| Infiltrating | 16 | 7 | |
| Adjacent bone change | | | 0.002 |
| Absent | 26 | 2 | |
| Present | 6 | 6 | |
| Anatomical pattern of draining veins | | | 0.361 |
| Type 1 | 19 | 3 | |
| Type 2 | 8 | 2 | |
| Type 3 | 5 | 3 | |
| *Procedure variables* | | | |
| Session number of sclerotherapy[a] | | | 0.014 |
| <3 | 23 | 2 | |
| ≥3 | 9 | 6 | |
| Sclerosants | | | 0.32 |
| Polidocanol only | 22 | 4 | |
| Other | 10 | 4 | |

[a]The Kruskal-wallis test.

## Discussion

A comprehensive classification of vascular anomalies was accepted by the International Society for the Study of Vascular Anomalies (ISSVA) in 1996 (Enjolras & Mulliken 1997). Two major categories of lesions emerged: vascular tumors and vascular malformations. Differentiating between vascular tumors and malformations is essential, as their clinical, radiological and pathologic features differ. Further, their associated morbidity and their management are quite different. VMs are low-flow vascular malformations and can infiltrate skin, muscles, joints, and sometimes bones. In 2013, a "modified" Hamburg classification was adopted to emphasize the importance of extratruncular vs. truncular sub-types of VMs; ISSVA Classification was reinforced with an additional review on syndrome-based classification (Lee et al. 2014). The new classification incorporated the embryological origin, morphological differences, unique characteristics, prognosis and recurrence rates of VMs based on this embryological classification.

Symptoms are dependent on the anatomic location of the lesion. Pain and swelling are common symptoms associated with all VMs. With craniofacial lesions, cosmetic disfigurement may be more debilitating than functional limitations (Lee & Chen 2005). In contrast, the management of VMs in the extremities is often difficult due to functional problems rather than cosmetic concerns (Mendonca et al. 2010). In this series, 24 patients (60%) reported functional limitations. Thus, we focused on VMs in the extremities.

Sclerotherapy is now the primary treatment of choice for VMs. Several sclerosants have been proven effective and vary in their mode of action and relative toxicity (Van der Vleuten et al. 2014). Currently, there is no consensus as to the best sclerosant. All sclerosants are associated with potential complications, including skin necrosis, peripheral nerve injury, hemoglobinuria, thromboembolism, infection and delayed muscle fibrosis (Burrows 2013). We mainly use polidocanol, because it has sufficient effect and because it is associated with lower major complication rates (Blaise et al. 2011). Indeed, in our

**Table 5 Multivariate analysis of variables to predict satisfaction with sclerotherapy**

| Variables | P value | Odds ratio | 95% confidence interval |
|---|---|---|---|
| Absence of adjacent bone changes | 0.048 | 7.56 | 1.02-55.8 |
| Maximum diameter (<6.7 cm) | 0.308 | 3.70 | .299-45.8 |
| Session number of sclerotherapy (<3) | 0.240 | 3.56 | .429-25.5 |

cohort, there were no major complications after sclerotherapy using polidocanol.

The efficacy of sclerotherapy for VMs is difficult to evaluate, as there are no standard assessment criteria (Rautio et al. 2004). We attempted to evaluate treatment outcomes according to overall patient satisfaction and subjective patient response using a self-assessment questionnaire rather than attempt to quantify morphologic response (van der Linden et al. 2009). This is because lesion sizes and symptoms of VMs vary widely and there is often discrepancy between the clinical and morphologic responses to sclerotherapy (Tan et al. 2007; Yun et al. 2009).

Our analysis of a cohort of 40 patients who responded to follow-up questionnaires showed that 80% of patients were satisfied with treatment outcome and that only two major complications (5%) occurred. Pain, swelling, and functional limitations were improved in about 80% of patients, whereas cosmetic improvement was seen in 50% of patients. Van der Vleuten et al. (2014) conducted a systematic review of studies investigating treatment for VMs. They reported that sclerotherapy was effective in 65% to 90% of cases. Our results are comparable to those seen in previous reports and indicate that sclerotherapy was minimally invasive and effective as a primary treatment for VMs.

Identification of predictors of response to sclerotherapy is important to optimize outcomes through appropriate

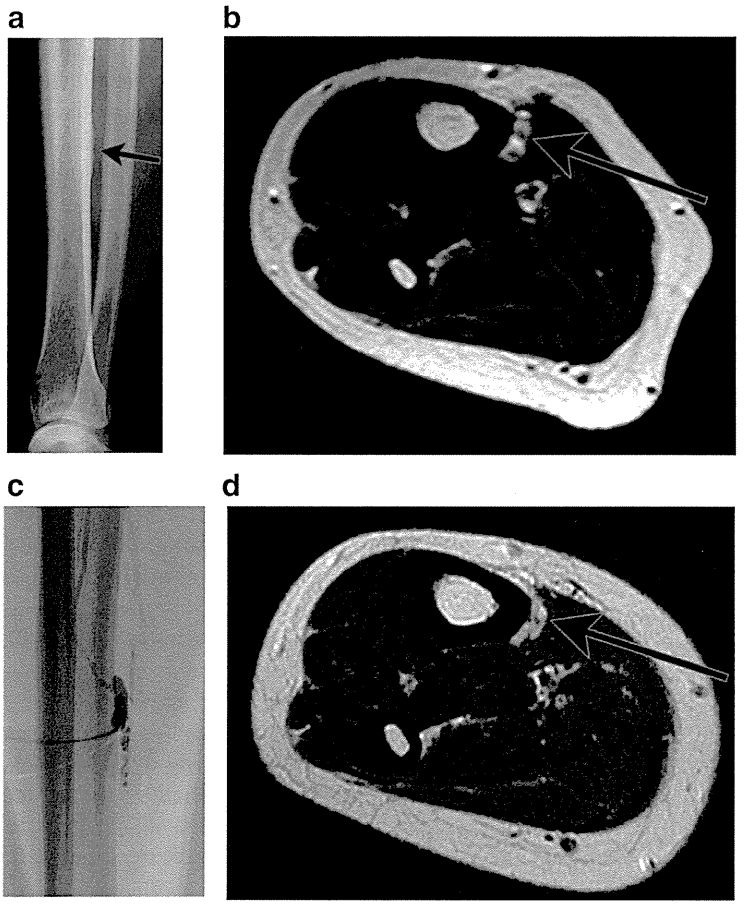


**Figure 3 A 37-year-old-female with symptoms of severe pain of the right lower leg. A**. Radiograph of the right lower leg demonstrates tiny periosteal reaction in the tibia (arrows). **B**. The axial T2-weighted MR image before treatment shows a tiny lesion adjacent to the tibia with cortical irregularity (arrows). **C**. Direct puncture phlebography reveals VM with normal veins and early venous return (Type 2). Sclerotherapy was performed with 3% polidocanol foam. **D**. Although the lesion decreased in size and signal intensity on MRI (arrows), she answered no change in symptoms and dissatisfaction on the questionnaire.