285

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Anatomical Evaluation of Great Saphenous Vein as Material for Conduit in Bypass Surgery for Critical Limb Ischemia

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Abstract

The great saphenous vein (GSV) often presents partial hypoplasty. The present study elucidates the frequency of hypoplasty and the positional tendency with which GSVs present hypoplasty. GSVs taken from 41 lower limbs of embalmed cadavers were divided into four types according to the positions of their hypoplastic parts. They are, Type 1: GSVs that don't present hypoplasty; Type 2a: GSVs in which hypoplasty is located in the upper thigh; Type 2b: GSVs in which hypoplasty is located in the lower thigh; Type 2c: GSVs in which hypoplasty extends to both the upper thigh and lower thigh. The numbers of the specimens of these anatomical types were counted. For types presenting with partial hypoplasty, length of the hypoplastic parts and the distances between the hypoplastic parts and the knee were evaluated. The anatomical types occurred in descending frequency as follows: Type 2b (65.8%), Type 1 (24.3%), Type 2a (7.3%), and Type 2c (2.4%). The average length of hypoplastic parts was 10±3.3SD cm for Type 2b and 5.8±2.3SD cm for Type 2a. The average distance of the hypoplastic parts from the knee was 10.0±5.2SD cm for Type 2b and 10.5±6.5SD cm for Type 2a. A majority (75.6%) of GSVs present partial hypoplasty. For successful performance of bypass surgery for critically ischemic limbs, care should be taken not to include hypoplastic parts in conduits. The findings of the present study are useful to avoid hypoplastic parts when creating bypass conduits.

Keywords: Critical Limb Ischemia; Bypass; Graft; Great Saphenous Vein; Conduit; Anatomy; Cadaver

Abbreviations

GSV: Great Saphenous Vein;

SFJ: Sapheno-Femoral Junction;

MEF: Medial Epicondyle of the Femoral bone;

MMT: Medial Malleolus of the Tibia;

CLI: Critical Limbs Ischemia;

DMF: Deep Muscular Fascia;

MLH: Membranous Layer of the Hypodermis

Introduction

The current prevalence of high-calorie diets and sedentary lifestyles is accompanied by increasing numbers of patients with diabetes mellitus [1-4], and accordingly, increasing numbers of patients develop critical limb ischemia (CLI). CLI presents serious symptoms, such as ambulatory difficulty, pain, and infection of the lower limbs, which considerably impairs patients' quality of life [5,6]. Bypass surgery is conducted for stenotic parts of affected arteries to relieve patients of these symptoms and to increase blood flow to lower limbs [7,8]. In performing bypass surgery, the great saphenous vein (GSV) is often harvested to be used to form conduits for bypasses [9-12].

The GSV branches out from the femoral vein at the sapheno-femoral junction (SFJ), passes by the medial epicondyle of the femoral bone (MEF), and ends at the medial malleolus of the tibia (MMT) (see Figure 1). Variations in the anatomical structure of GSVs have been observed. In some persons, GSVs present partial hypoplasty during the course from the SFJ to the MMT. If the hypoplastic parts are included in a conduit, the conduit develops thrombosis, and the treatment fails. Therefore, to ensure optimal outcomes in bypass surgeries for CLI, hypoplastic parts should not be included in the conduit. To avoid the inclusion of hypoplastic parts in bypass conduits, it is essential to understand the locations within the GSV at which it is likely to present hypoplasty.

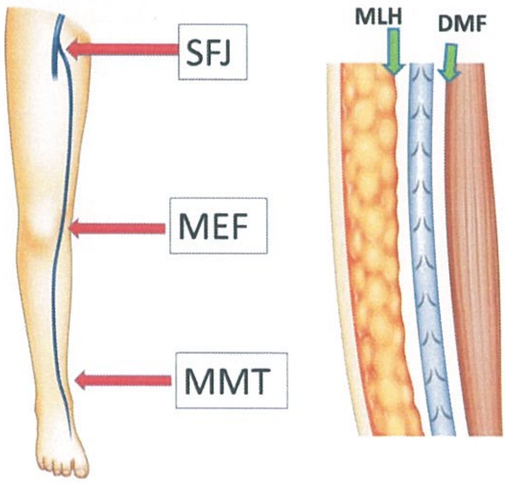

Figure 1. (Left) Locations of the great saphenous vein. SFJ, MEF, MMT in the figure indicate the sapheno-femoral junction, medial epicondyle of the femoral bone, and medial malleolus of the tibia, respectively. (Right) The GSV descends in the layer between the deep muscle fascia (DMF) and membranous layer of the hypodermis (MLH).

The present study clarifies these issues by anatomical evaluation of GSVs taken from cadavers. Specifically, three issues are elucidated. First, frequency of occurrence of partial hypoplasty is determined. Second, regions of GSVs where hypoplasty is likely to occur are clarified. Third, the lengths of hypoplastic parts are examined.

Materials and Methods

Study Samples

The present study was conducted under the approval of the institutional ethical committee of the authors' institute (Kagawa University) 21 embalmed cadavers (11 males and 10 females; the ages were 78.5±8.9SD y/o for males and 84.6±7.6SD y/o for females) were used as the study subjects. The GSV was identified for bilateral lower limbs of each of the 21 cadavers. One lower limb of a cadaver had been damaged because of previous injury. Hence, this lower limb was excluded from the study. Consequently, GSVs of 41 limbs (22 limbs of male cadavers and 19 limbs of female cadavers) were studied.

The GSV branches out from the femoral vein at the SFJ and goes in the inferior direction inside the layer between the deep muscular fascia (DMF) and the membranous layer of the hypodermis (MLH) (Figure 1). The GSV passes by the MEF at knee level and descends further, eventually ending at the MMT at the ankle level. The average lengths of the GSVs of the 41 limbs were 32.2±2.8SD cm for the SFJ-MEF segment and 34.6±3.7SD cm for the MEF-MMT segment.

Definition of Anatomical Types

GSVs were divided into four anatomical types based on the findings of dissection. GSVs with no hypoplasty throughout their courses from the SFJ to the MMT were defined as Type 1. GSVs presenting with partial hypoplasty were categorized as Type 2. Since embalmed cadavers were used in the present study, the parts that appear to be hypoplastic to the naked eye may merely contain artificial stenoses caused in the process of embalmment, not necessarily genuine hypoplasty. To exclude such "false-positives", sliced sections were harvested and were histologically observed to examine the condition of the part. A part was judged to be hypoplasic only when the part's sliced section presented even occlusion in all directions and was inappropriate as a conduit for bypass surgery (Figure 2). According to the superior-inferior position of thus-judged hypotrophic parts, GSVs belonging to Type 2 were further divided into three types (Type 2a, 2b, 2c). In conclusion, the GSVs of the 41 lower limbs were divided into the following four anatomical types (Figure 3).

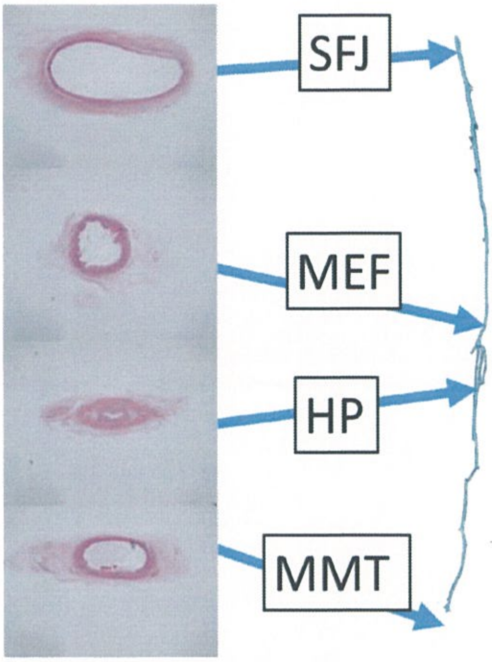

Figure 2. Hypoplastic parts were identified by histological observation. In the figure's sample, the part shown as HP is evaluated to be hypoplastic.

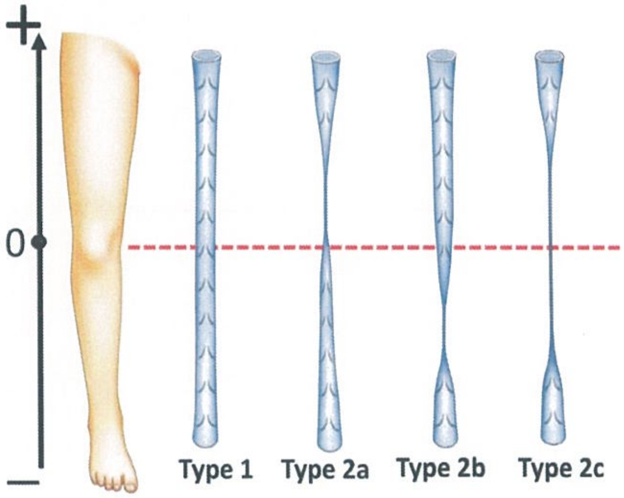

Figure 3. 41 GSVs were divided into four groups based on the levels in the lower limb at which they present hypoplasty. GSVs that have no hypoplastic parts were grouped as Type 1; GSVs that present hypoplasty in the upper thigh were grouped as Type 2a; GSVs that present hypoplasty in the lower thigh were grouped as Type 2b; GSVs in which hypoplasty involves both the upper thigh and lower thigh were grouped as Type 2c. The positions of hypoplasty were measured referring to a one-dimensional coordinate system where the origin is placed at the medial epicondyle of the femoral bone (Leftmost).

Type 1: Those that don't present hypoplasty throughout the course from the SFJ to the MMT.

Type 2a: Those in which partial hypoplasty exists in the upper thigh region (the region between the SFJ and the MEF)

Type 2b: Those in which partial hypoplasty exists in the lower thigh region (the region between the MEF and the MMT)

Type 2c: The type in which hypoplasty extends to both the upper and lower thighs. Based on this anatomical grouping, the following evaluation was conducted.

Evaluation

Frequencies of GSV Types

The number of GSVs belonging to each of the four groups was counted.

Sex-Related Differences in Type Distribution

The difference in the distribution of anatomical types between males and females was evaluated using Pearson's Chi-Square test. SPSS Version 20.0 (SPSS, Inc, Chicago, IL, USA) was used for the statistical calculation.

Anatomical Patterns of Hypoplastic Parts

Hypoplasty of the GSV is caused by three anatomical patterns (Figure 4). In Pattern 1, the GSV narrows after passing through the DMF and terminates in the underlying muscles (Figure 4 Left); in Pattern 2, the GSV ramifies and narrows in the layer between the MLH and the DMF (Figure 4 Center); in Pattern 3, the GSV narrows when passing through the MLF and terminates in the subdermal fat and the skin (Figure 4 Right). For GSVs belonging to Types 2a to 2c, frequencies of the three hypoplastic patterns were counted.

Diameters of GSV Lumens

Luminal diameters of GSVs were measured under microscopic observation with a fluorescent microscope (BioRevo BZ-9000, KEYENCE Co., Osaka, Japan) at the level of the SFJ, MEF, and MMT. The average and standard deviation of the luminal diameters at these measuring points were calculated.

Location and Length of Hypoplastic Parts

To evaluate the location of hypoplastic parts, a one-dimensional coordinate system was defined with the origin of the axis set at the MEF. In this one-dimensional coordinate system, above the knee was defined as positive; below the knee was defined as negative (Figure 3 Left). The most superior and most inferior points of the hypoplastic parts were evaluated in reference to the one-dimensional coordinate system. For instance, when the part between 6 cm above the knee and 8 cm below knee the presents hypoplasty, the most superior and inferior points of hypoplastic part were evaluated as 6 cm and -8 cm, respectively. The length of the hypoplastic part was evaluated to be 14 cm. The averages and standard deviations of thus-measured locations and lengths were calculated for Type 2a, Type 2b, and Type 2c GSVs. Furthermore, the lengths of the hypoplastic parts for each anatomical type were calculated in the form of means and 95% confidence intervals.

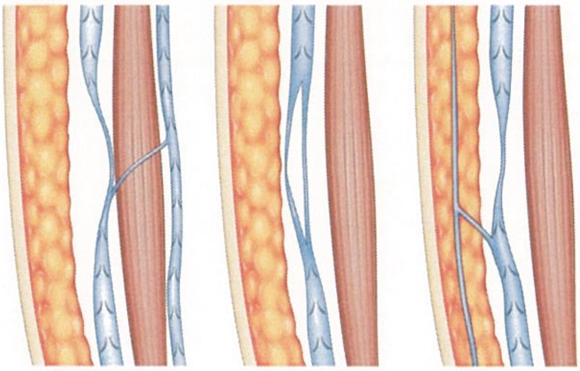

Figure 4. Hypoplasty of GSVs presents three anatomical patterns. Pattern 1: the GSV terminates in the deep muscle (Left); Pattern 2: the GSV narrows after ramifying in the intra-membranous layer (Center); Pattern 3: the GSV terminates in the skin (Right).

Results

Frequency of GSV Types

Type 2b was the most frequent type, appearing in 65.8% of the samples (27/41), followed by Type 1 (24.3%; 10/41), Type 2a (7.3%; 3/41), and Type 2c (2.4%; 1/41) (Table 1). These findings suggest that GSVs tend to present hypoplasty in the lower thigh.

Table 1. Positions of Ends of Hypotrophic Part, and Length of Hypotrophic Part (Average and Standard Deviation: cm).

	Specimen Numbers (Male/Female)†	Most Superior Point of Hypotrophic Part (cm)††	Most Inferior Point of Hypotrophic Part (cm)††	Lengths of Hypoplastic Parts (cm)
Type 1	10(10/0)	NA	NA	NA
Type 2a	3(1/2)	16.3±8.8SD	10.5±6.5SD	5.8 [0.6, 11.0]
Type 2b	27(15/12)	-10.0±5.2SD	-20.0±5.0SD	10.0 [2.5, 17.5]
Type 2c	1(0/1)	-5.0±0.0SD	13.0±0.0SD	18.0 [18.0, 18.0]

†-The figures in the parentheses for Specimen Numbers indicate the numbers for male / female specimens.

††-The numbers for Most Superior Point of Hypoplastic Part indicate the averages and standard deviations.

†††-The first numbers for Lengths of Hypoplastic Parts indicate the average values; the range between the values given in the following parenthesis indicate the confidence interval for 95%.

Sex-Related Differences in Anatomical Type Distribution

The distribution of anatomical types showed statistically significant differences (p=0.025) between males and females. As shown in Table 1, Type 1 (the type without stenosis) is more common in males (10 cases) than in females (0 cases).

Anatomical Patterns of Hypoplastic Parts

Pattern 1 (in which GSVs terminate in deep muscle) and Pattern 3 (in which GSVs terminate at the subdermal fat) were respectively shown in 48.4% (15/31) and 41.9% (15/31), presenting two main patterns of hypoplasty (Table 2).

Table 2. Frequencies of Anatomical Patterns of Hypoplastic Parts.

	Pattern 1	Pattern 2	Pattern 3	Sum
Type 2a	2	1	0	3
Type 2b	12	2	13	27
Type 2c	1	0	0	1
Sum	15	3	13	31

Table 3. Diameters of GSVs at Anatomical Marking Points (Average and Standard Deviation: mm).

	SFJ	MEF	MMT
Type 1	2.5±0.4SD	2.1±0.77SD	2.3±0.6SD
Type 2a	2.2±0.3SD	0.9±0.2SD	2.1±0.7SD
Type 2b	2.5±0.8SD	1.5±0.6SD	1.6±0.6SD
Type 2c	1.6±0.0SD	1.5±0.0SD	0.9±0.0SD

Diameters of GSV Lumens

In all anatomical types, GSV was thickest at the SFJ. Diameters at the MEF were thinner than those at the GSV and the MMT (Table 3).

Location and Length of Hypoplastic Parts

For hypoplasty both in the upper thigh (Type 2a) and in the lower thigh (Type 2b), the hypoplastic parts start at positions about 10 cm away from the knee (Table 1). The average length of the hypotrophic part was shorter for Type 2a (average 5.8 cm) than for Type 2b (average 10.0 cm), meaning that hypoplastic parts tend to be shorter when hypoplasty exists in the upper thigh than in the lower thigh.

Discussion

The GSV is a workhorse in bypass surgeries; the GSV is not only used as the material for conduit in bypass surgeries for CLI, but also for cardiac bypasses to treat ischemic heart disease. Because of the clinical importance of GSVs, many studies have been conducted to clarify the anatomical structures of GSVs. Shah reviewed phlebography findings of patients and demonstrated that GSVs present anatomical variation [13]. Ruoff showed the usefulness of real-time duplex ultrasound examination in evaluating the availability of GSVs for bypass conduits [14]. Fligelstone studied whether or not the availability of GSVs is impaired after flush-sapheno-femoral ligation in varicose treatment [15]. Van-Dijk-reviewing clinical experience with 44 cases-demonstrated that ultrasonography is an effective tool in verifying the quality of GSVs as conduits for in-situ bypass for CLI [16]. Caggiati-performing an anatomical study of 32 cadaver limbs and USG examination of 102 limbs of live persons-demonstrated that GSVs present anatomical variations [17]. These existing studies are credited with having provided information useful in employing the GSV to form bypass conduits. However, information about the superior-inferior levels of the lower limb at which GSVs tend to present hypoplasty still remains unclarified, despite its clinical significance. For further improvement of effectiveness in bypass surgery for CLI, this issue needs to be clarified. The present study is original in that it is the first study to elucidate the positional-tendency of hypoplastic parts from a clinical standpoint.

In the present study, 41 embalmed lower limbs were used as study subjects. Study of cadavers enables direct and minute observation of specimens. Furthermore, the number of specimens used is statistically sizable. These advantages support the reliability of the present study's findings. On the other hand, the diameters of GSVs obtained in the study don't accurately reflect those in physiological conditions, since vessels shrink in the embalming process. For this reason, discrepancy exists between the diameter data of the present study and those of other studies. For instance, Schanzer states that long-term patency is not guaranteed for conduits made of GSVs with diameters smaller than 3.5 mm, whereas the average diameters measured in the present study were 0.9-2.5 mm [18] (Table 3). If we directly apply Schanzer's criteria to our raw data, most GSVs are not suitable as bypass conduits. In our clinical experiences, however, the diameter of the GSV in living patients ranges from about 3 to 5 mm. Hence, we surmise the diameters of GSVs had shrunk by about 50 percent in our samples. In making surgical plans, the diameters obtained in the present study need to be translated taking the data-gap due to shrinkage into consideration.

The findings of the present study are summarized as four items. First, in a majority of cases, GSVs present partial hypoplasty. This finding derives from the fact that hypoplastic parts are absent in only 24.3% (=Type 1) of subjects and that the other 75.5% of subjects present partial hypoplasty. Second, hypoplasty is most likely to occur in the lower thigh, which is derived from the finding that a much greater percentage presents as Type 2b than Type 2a. Third, hypoplastic parts are about 10 cm away from the knee when they exist in both the lower thigh and the upper thigh. Fourth, the ratio of GSVs that don't present hypoplasty is higher for males than for females.

In performing bypass surgery for CLI, conduits should made to match the lengths of the stenotic arteries. The above-stated three items are useful in deciding the GSV parts from which the grafts for conduits are harvested. Specifically, considerations are made as follows.

For CLI cases in which the stenotic region isn't long, the lengths of the conduits required for the bypass accordingly aren't so long,. Hence, the conduit can be made using a single-segment graft. Harvesting a single-segment graft from the upper thigh is more advantageous than from the lower thigh, because the second finding indicates that the lower thigh is likely to present hypoplasty, limiting the length of the graft that can be harvested. In all anatomical types, the diameters of GSVs are greater at the SFJ than at the MEF and MMT as shown in Table 3. This indicates thicker grafts can be harvested from the upper thigh than from the lower thigh, which is advantageous for anastomosis. For these reasons, priority should be placed on the upper thigh over the lower thigh when harvesting single-segment grafts.

On the other hand, when a stenotic region extends over a certain length-for instance from the middle part of the femoral artery to the lower part of the posterior tibial artery, long grafts are needed for bypass. When the patient's GSV belongs to Type 1, a long graft can be harvested as a single segment to meet this requirement. Thus-harvested grafts can be used either in-situ or in reversed fashion to bypass the stenotic regions of the artery. (Figure 5).

However, only 24.3% of GSVs present Type 1 anatomy. In the other 75.5%, it is impossible to harvest a long single-segment graft without including hypoplastic parts. The sex-related difference observed in the distribution of anatomical types is another consideration. As shown in Table 1, Type 1 is more likely to occur in males than in females. Herein, whether this difference is congenital or acquired is discussed. Although vascular anatomy often presents individual differences, little is proven about the effect of sex factors on the differences. We speculate that the difference regarding the sex-related anatomical distribution is not congenital, but acquired. Fat tissues of the lower extremities are thicker for females than for males. In contrast, muscle is thicker for males than for females. Therefore, the GSV receives less mechanical support from surrounding tissues in females than in males. Because of the reduced support, a greater burden works on the valves of the GSV of females to maintain blood flow against gravity, which potentially leads to the dysfunction of the valves of the GSV. When valve function is impaired, reverse flow can cause the development of collateral paths. For this reason, the GSVs of females can ramify by developing branches, as shown in Patterns 1-3. As a result of this potential transformation, it is speculated that in females, GSVs that had been congenitally Type 1 can change into other types. This hypothetical explanation is supported by the fact that varicose veins are more likely to develop in females than in males [19]. The present study was conducted on cadavers of old persons. The age factor might have enhanced the sex-difference, since ramification is expected to increase with age.

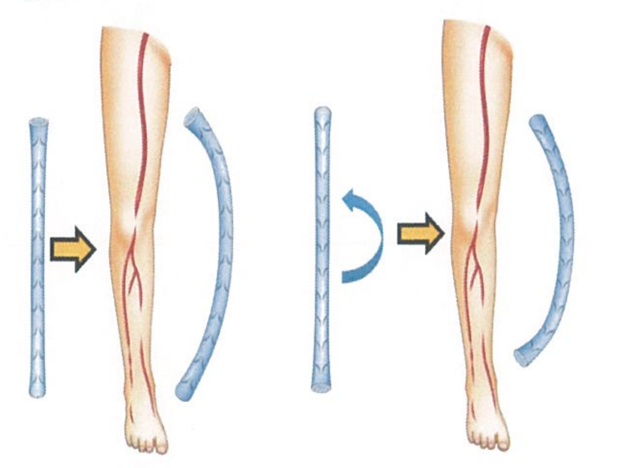

Figure 5. For CLI cases where arterial stenosis extends over long distances, accordingly long conduits need to be used. With GSVs belonging to Type 1, a single segment graft can be harvested and meet this requirement. The graft can be used either in-situ (Left) or in reversed fashion (Right).

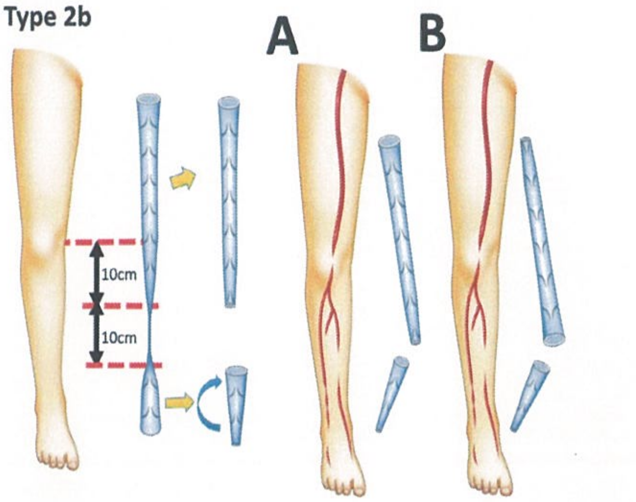

Figure 6. When performing bypass surgery for long arterial stenosis by using Type 2b GSVs, two grafts-a long graft from the upper thigh and a short graft from the lower thigh-are harvested, avoiding the hypoplastic part that begins 10 cm below the knee and extends for over 10 cm. The two grafts can be combined in two ways (A and B) to form a single conduit.

To prepare a long conduit in types other than Type 1, two segments are harvested from the GSV, avoiding hypo plastic parts. The harvested segments are combined to form a composite conduit [20]. For instance, for GSVs belonging to Type 2b-the most frequent among the four anatomical types-the conduit is produced as shown in Figure 6. Long grafts cannot be harvested from the lower thigh of Type 2b GSVs, because of partial hypoplasty. Hence, short and long grafts are respectively harvested from the lower thigh and upper thigh, and the two grafts are combined to form a single conduit. When harvesting a graft from the lower thigh, the third finding-that the hypoplastic part is likely to begin at about 10 cm below the knee-is useful. The graft harvested from the lower thigh is reversed so that the valves don't resist arterial flow. The piece harvested from the upper thigh can be used either as a reversed graft (Figure 6A) or as an in-situ graft (Figure 6B).

Similar consideration is made in harvesting grafts from Type 2a GSVs (Figure 7). In Type 2a GSVs, hypoplastic parts begin at 10 cm above the knee and extend on average for 5.8 cm. Referring to this finding, hypoplastic parts should not be included in the graft. A pair of long and short grafts are harvested from the upper and lower thighs respectively, and combined to form a conduit.

Thus, in producing conduits for CLI bypass surgery, appropriate operation plans need to be made, taking account of the anatomical structures of each patient's GSV. The findings of the present study are useful information in making such operation plans. Although the anatomical structures of GSVs can also be evaluated by using ultrasonography, the evaluation is often difficult in obese patients, hindered by thick subdermal fat. By using the information obtained in the present study and supplementary evaluation with ultrasonography, we'll be able to produce conduits effectively, and to improve treatment outcomes of CLI bypass surgeries.

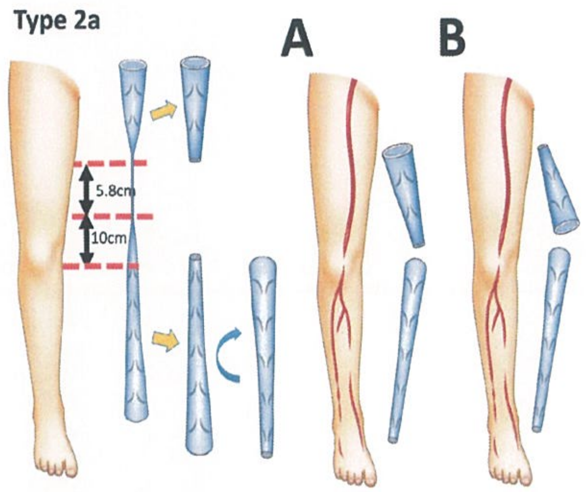

Figure 7. When performing bypass surgery for long arterial stenosis by using Type 2a GSVs, two grafts-a short graft from the upper thigh and a long graft from the lower thigh-are harvested, avoiding the hypoplastic part that begins 10 cm above the knee and extends for over 5.8 cm. The two grafts can be combined in two ways (A and B) to form a single conduit.

Conclusion

This anatomical study-by evaluating 41 lower limbs of embalmed cadavers-clarifies the frequency and positional tendencies of partial hypoplasty in the great saphenous vein. A majority of GSVs (75.6%) present partial hypoplasty. Hypoplasty is more likely to occur in the lower thigh (65.8%) than in the upper thigh (7.3%). When hypoplastic parts exist either in the upper thigh or in the lower thigh, the hypoplastic parts are located away from the knee by about 10 cm. These findings are useful in harvesting optimal grafts from the great saphenous vein as material to produce conduits for CLI bypass surgeries.

Conflict of Interest

None

Acknowledgment

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