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Deep venous reconstructive surgery

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ABSTRACT

Surgical correction of deep venous reflux is a valuable adjunct in treatment of selected patient with lower limb venous ulcer. Deep venous obstruction and superficial reflux is must be corrected first. Sustained venous ulcer healing and reduced ambulatory venous hypertension can be achieved in patients with both primary and secondary deep venous insufficiency. When direct valve repair is possible, valvuloplasty is the best option, but when this is not feasible, other techniques can be used, including femoral vein transposition into the great saphenous vein, vein valve transplant, neovalve construction, or nonautologous artificial venous valve.

1. Introduction

Venous ulcer (VU) physiopathology is based on the venous hypertension that leads to microcirculatory anomalies and subsequent trophic lesions [1]. Two hemodynamic anomalies —obstruction and reflux—are responsible for venous hypertension, either alone or in combination. The aim of any treatment addressing VU is to reduce venous hypertension to obtain healing and to prevent recurrence.

The following anatomical systems can be involved in the etiology of ambulatory venous hypertension: superficial venous system, the deep venous system, and perforator veins. Their involvement can be isolated or, as is more frequently the case, combined. Unfortunately, the available data do not describe the involvement of each system separately [2]. In addition, segmental and axial refluxes are not described as separate entities, and this crucially affects VU management. In other more limited series, the relative distribution and extent of reflux, both superficial and deep, have been described [3,4]. It should be noted that isolated perforator incompetence is uncommon (<4% in the larger series), and that their incompetence is almost certainly related to the presence of anomalies in the superficial or deep system [5]. To summarize, the respective involvement of each system is difficult to quantify; in most articles dealing with reflux, obstruction was still not identified as a leading cause of venous hypertension [6]. It is generally acknowledged that non−post-thrombotic etiology (termed *primary* in the CEAP [clinical, etiologic, anatomic, pathophysiologic] classification) can be identified in at least half of the patients with VU [7,8].

2. Pathophysiology

2.1. *Reflux*

Reflux is the most frequent cause of venous hypertension. Various reflux patterns were defined at the Vein Term Consensus Conference [9].

The extent and impact of reflux, both axial and segmental, varies depending on whether it affects superficial and/or deep venous systems. VU can be related to segmental superficial reflux, bearing in mind that it is more frequent in the axial

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reflux. Conversely, segmental deep reflux, isolated or combined, is rarely responsible for VU occurrence, and axial reflux is [5]. The role of perforator incompetence remains controversial.

2.2. Obstruction

The role of superficial obstruction is negligible. By contrast, recent studies have emphasized the significance of obstruction in deep veins, both in thrombotic and non–post-thrombotic disease [10]. Obstruction patterns were also defined by the Vein Term Consensus Conference [9]. Obstruction is frequently associated with reflux, mainly in post-thrombotic etiologies, but it can be identified as an isolated component.

Calf pump deficiencies, ankle stiffness, obesity, and systemic diseases can be responsible for hemodynamic venous alterations and can worsen existing venous anomalies [11,12]. The identification of each different anatomic, etiologic, and physiopathologic pattern is essential in optimizing VU assessment and in its management.

3. Venous reconstruction techniques

When a direct valve repair is possible, valvuloplasty is the best option, but when it is not feasible, the following techniques can be used: transposition of the femoral vein (FV) into the great saphenous vein (GSV) or into the deep femoral vein (DFV) as far as their terminal valve is competent, vein transplant (usually axillary vein transfer), neovalve, and nonautologous artificial venous valve.

3.1. Valvuloplasty

The aim of valvuloplasty is to restore the competence of the valve by correcting the anatomical defect. This is the first-choice operation in primary venous insufficiency. Internal valvuloplasty, first proposed by Kistner [13], is a technique that involves venotomy and correction of the valve leaflet defects under direct visualization.

Advantages:
- Perfect exposure of the overall valve apparatus
- That valvuloplasty is easy to perform, including à la carte correction in presence of asymmetrical valve cusps

Disadvantage:
- Possible damage to the valve's apparatus during the phlebotomy
- That it is difficult to assess if the two free valve edges are perfectly in contact until the valvuloplasty is completed

Subsequent variations in the technique have been proposed by Raju [14], Sottiurai [15], and Tripathi and Ktenidis [16] to improve valve exposure and its surgical correction, mainly for reducing the risk of tearing the free edges during the phlebotomy (Fig. 1). All of these techniques relied essentially on the reefing of the incompetent, lax valve cusps. Recently, Tripathi et al [17] described the RIVal technique of excision valvuloplasty, in which the redundant valve margin is excised and repaired back to form a neocommissure.

3.2. External valvuloplasty

Valvuloplasty is also possible without phlebotomy by narrowing the lumen with some stitches at the cusp insertion angle, termed *transmural valvuloplasty*. Transcommisural valvuloplasty has the same purpose but requires stitching of the cusp insertion; transmural valvuloplasty does not. External valvuloplasty can be done with [18] or without endoscopic supervision.

Advantage:
- Absence of venotomy

Disadvantages:
- Less precision in valve restoring
- Modification of valvular apparatus shape, which more or less reduces the antireflux effect

3.3. External valve banding

Restoring valve competence without opening the vein is also the purpose of external banding (or prosthetic sleeve or external cuffing).

This procedure can be used alone or after transplantation or other reconstructive techniques. The principle is to reduce the caliber of the vein to restore valve competence [19]. This action is evident during vein dissection when the vein spasm occurs, the valve incompetence is corrected. If the valve is absent (agenesis or post-thrombotic syndrome) the Venturi's effect alone can play a transitional role. The Venturi's effect is based on the physical low whereby narrowing a vessel in a short portion leads to increased velocity in the narrowed segment.

Different materials have been used for banding the vein [20–24], including Dacron cuff, Venocuff I®, Venocuff II®, polytetrafluoroethylene, and bovine pericardium.

Advantages
- Easy to perform

Disadvantage:
- Potential narrowing of the vein lumen

3.4. Femoral transposition

This technique was first described by Kistner [25]. If ipsilateral DFV or GSV have a proximal competent valve and adequate caliber, the transfer of femoral vein distal to the competent valve can be performed. Although terminolateral anastomosis is more common, end to end anastomosis of FV into DFV or GSV can be used. When the FV is the seat of obstructive lesions and the DFV has become the axial vein, DFV can be transposed into competent proximal GSV [26].

Advantages:
- Easy to perform
- No direct action on the valve apparatus

Disadvantages:
- Adverse anatomy (caliber)

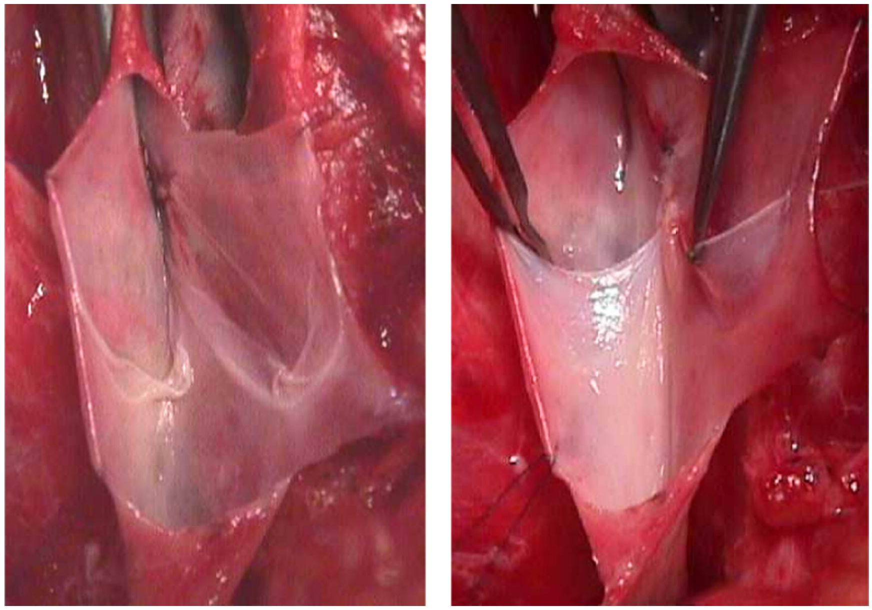

Fig. 1 – Intraoperative images of internal valvuloplasty by Trapdoor method of Tripathi. Left: before valvuloplasty; right: after valvuloplasty.

Incompetent DFV or GSV terminal valve are frequently associated with FV incompetence, subsequent dilatation, and reflux due to the different structure of the DFV valve [26].

3.5. *Vein transplant*

Vein transplant principle consists of inserting a segment of a competent valvulated vein in the incompetent deep venous network.

The donor segment can be the axillary vein or brachial vein. The axillary vein transplant was first described by Raju [27] and the brachial vein transplant by Taheri et al [28].

The best-matched size for transplant at femoral level is the axillary vein, while the brachial vein can be utilized in a small-caliber popliteal vein.

The valve transplantation technique must be meticulous, avoiding any torsion, any tension, and any stenosis of the sutures. This technique can be associated with excision of trabeculae inside the lumen of the host vein to obtain a sufficiently wide lumen in post-thrombotic syndrome. Despite appropriate techniques, the valve transplant can fail in the follow-up for nonidentified reason.

Advantages:

To insert a segment with a competent valve at popliteal level, below the FV and the possible re-entry of associated refluxes (DFV)

Disadvantages:

40% of axillary vein valves are incompetent and require bench repair; an external sleeve should be applied to prevent later dilatation of the segment

3.6. *Neovalve*

The principle is to construct an autologous valve by using the patient's venous tissue. In Plagnol et al's technique [29], the

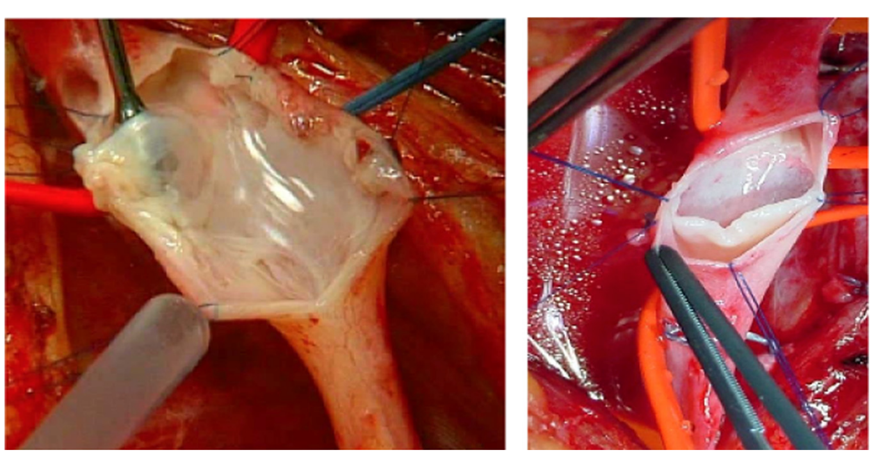

Fig. 2 – Intraoperative images of the Maleti Neovalve procedure of vein valve reconstruction. Left: creation of a subintimal pocket valve. Right: completed monocuspid valve reconstruction.

Table 1 – Deep vein reconstruction results.

Author, year	Surgical technique	No. of limbs (no. of valves repaired)	Etiology, PDVI/ total	Months of follow-up, range (mean)	Ulcer recurrence or nonhealed ulcer (%)	Hemodynamic result	
						Competent valves (%)	AVP-VRT
Lehtola, 2008 [38]	VI	12	5/12	24–78 (54)	—	(55)	—
	VE Transmur	7	3/7				
	VI+VE Transmur	1	0/1				
Masuda, 1994 [39]	VI	32	27/32	48–252 (127)	(28)	24/31 (77[a])	AVP ↑ 81% (m) VRT ↑ 50% (m)
Perrin, 2000 [40]	VI	85 (94)	65/85	12–96 (58)	10/35 (29)	72/94 (77)	AVP normalized 63% (m)
Raju, 1996 [41]	VI	68 (71)	—	12–144	16/68 (26)	30/71 (42)	—
Raju, 1996 [41]	VE Transmur	47 (111)	—	12–70	14/47 (30)	72/111	—
Raju, 2000 [42]	VE Transco	141(179)	98/141	1–42	(37)	(59)	AVP ↑ 15% (m) VRT normalized 100%
Rosales, 2006 [43]	VE Transmur	17 (40)	17/17	3–122 (60)	3/7 (43)	(52)	AVP ↑ 50% (m)
Sottiurai, 1996 [44]	VI	143	—	9–168 (81)	9/42 (21)	107/143 (75)	—
Tripathi, 2004 [45]	VI	90 (144)	118	(24)	(32)	(79.8)	—
	VE Transmur	12 (19)			(50)	(31.5)	—
Wang, 2006 [46]	VE Transmur	(40)	40/40	(36)	—	(91)	VRT ↑ 50% (m)
Tripathi, 2014 [17]	VI RIVal	25(44)	44/44	1–24 (12)	3/25 (12)	42/44 (95.4)	—

↑, increased; AVP, ambulatory venous pressure; m, mean; PDVI, primary deep venous insufficiency; VE Transco, external transcommissurale valvuloplasty; VE Transmur, external transmurale valvuloplasty; VI, internal valvuloplasty; VRT, venous return time.
[a] Reflux absence or moderate (<1 s).

Table 2 – Banding, cuffing, external stent, wrapping results.

Author, year, material	No. of limbs (no. of valves repaired)	Site	Etiology, PDVI/ total	Months of follow-up, range (mean)	Ulcer recurrence or nonhealed ulcer (%)	Hemodynamic results	
						Competent valves (%)	AVP-VRT
Akesson, 1999 [20], Venocuff I®	20 (27)	F, P	7/20	5–32 (19)	2/10 (20) PTS	PVI 7/7 (100) PTS 7/10 (70)	PVI: AVP ↑ 10% (m) VRT ↑ 10% (m) PTS: AVP ↑ 10% (m) VRT ↑ 100% (m)
Camilli, 1994 [24], Dacron®	54	F	54/54	4–63	—	41/54 (76)	—
Lane, 2003 [21], Venocuff II®	42 (125)	F, P	36/42	64–141 (93)	(20)	(90)	AVP ↑ ? VRT ↑ 100% (m)
Raju, 1996 [41], Dacron®	(96)	F, P, T	—	12–134	6/22 (27)	60/72 (83)	—

↑, increased; AVP, ambulatory venous pressure; F, femoral; m, mean; P, popliteal; PDVI, primary deep venous insufficiency; PTS, post-thrombotic syndrome; T, posterior tibial; VRT, venous return time.

neovalve is created with the GSV termination, opportunely sectioned, shaped, and invaginated into the femoral vein in order to function as a valve.

In Maleti's technique [22,30], the neovalve (Fig. 2) is obtained by dissecting the vein wall in order to obtain a flap that will work as a valve after adequate fixation. The wall dissection is possible because of the thickened vein wall. In the event of valve agenesis, the entire wall can be utilized, restoring the vein continuity using a bovine pericardium [31]. The post-thrombotic lesions frequently create an intraluminal fibrotic septum that facilitates the neovalve elaboration. The technique for constructing a neovalve is not always the same; it depends on the anatomical condition of the wall and, therefore, the most suitable option is determined only after phlebotomy.

Generally, in the presence of a double channel, the first option is a neovalve, using the intraluminal septum; when the vein wall is thickened neovalve is created according to the usual manner by dissecting the vein wall. If we find none of these conditions, the vein wall is invaginated to create a flap featuring a valve and the vein itself is reconstructed with a bovine pericardium [31] or with polytetrafluoroethylene [32]. The flap is maintained in position by stitches fixed at its both corners. We have applied this method using bovine pericardium to reconstruct the wall in a few cases when it was impossible to create a neovalve using the classical technique.

Opie [32] routinely uses this method using polytetrafluoroethylene to reconstruct the vein wall, and the valve is formed by a sculptured flap of the vein wall.

Advantages:

To create an antireflux apparatus with the patient's venous tissue
To offer a further possibility when vein transposition or vein transplant are not performable

Disadvantages:

Technique not standardizable
The best site to create the valve is not always preoperatively predictable
Frequently requires an associated endophlebectomy

Table 3 – Published results of vein transposition reconstruction.

Author, year	No. of limbs	Etiology, PTS/total	Months of follow-up, range	Ulcer recurrence or nonhealed ulcer, n (%)	Hemodynamic results	
					Competent valves, n (%)	AVP-VRT
Cardon, 1999 [50]	16	16/16	24–120	4/9 (44)	12/16 (75)	—
Johnson, 1981 [51]	12	12/12	12	4/12 (33)	—	AVP unchanged VRT unchanged
Lehtola, 2008 [38]	14	12/14	24–78	—	(43)	—
Masuda, 1994 [39]	14	—	48–252	7/14 (50)	10/13 (77)	AVP ↑ 70% (m) VRT ↑ 70% (m)
Perrin, 2000 [40]	17	16/17	12–168	2/8 (25)	9/17 (53)	—
Sottiurai, 1996 [44]	20	—	9–149	9/16 (56)	8/20 (40)	—

↑, increased; AVP, ambulatory venous pressure; m, mean; PTS, post-thrombotic syndrome; VRT, venous return time.

Table 4 – Results of vein transplantation reconstruction.

Author, year	No. of limbs (no. of valves repaired)	Site	Etiology, PTS/total	Months of follow-up, range (mean)	Ulcer recurrence or nonhealed ulcer, n (%)	Hemodynamic results	
						Competent valves, n (%)	AVP-VRT
Bry, 1995 [52]	15	P	—	15–132	3/14 (21)	7/8 (87)	AVP unchanged VRT unchanged
Eriksson, 1988 [55]	35	F, P	35/35	6–60	—	11/35 (31)	VRT unchanged
Lehtola, 2008 [38]	29	F, P	25/29	24–78 (54)	—	(16)	—
Mackiewicz, 1995 [56]	18	F	—	43–69	5/14 (36)	—	VRT ↑ ?
Nash, 1988 [57]	25	P	25/25	—	3/17 (18)	18/23 (77)	AVP ↑ 18% (m)
Perrin, 2000 [40]	32	F	31/32	12–124 (66)	9/22 (41)	8/32 (25)	VRT ↑ 19% (m)
Raju, 1999 [58]	83	F, P, T	83/83	12–180	(40) 6 years	(38) 4 years	AVP unchanged
Raju, 1996 [41]	54	F	—	12–180	—	16/44 (36)	—
Rosales, 2008 [54]	22 including 3 double Tr	F, P	22/22	6–108	—	Tr GSV 14/26 Tr AV 3/6	—
Sottiurai, 1996 [44]	18	F, P	—	7–144	6/9 (67)	6/18 (33)	—
Taheri, 1986 [53]	71	F, P	—	—	1/18 (6)	28/31 (90)	AVP ↑ 15% (m)
Tripathi, 2004 [45]	35	F, P	35/35	24	(45)	(41)	—

↑, increased; AV, axillary vein; AVP, ambulatory venous pressure; F, femoral; GSV, great saphenous vein; m, mean; P, popliteal; PTS, post-thrombotic syndrome; T, posterior tibial; Tr, transplantation; VRT, venous return time.

3.7. *Nonautologous artificial venous valve*

Several attempt have been made to create a nonautologous valve [33–36], but research is still underway and application in humans is not yet recommended [37].

4. Results

Outcomes are different in primary deep venous insufficiency when the valve is restorable compared with outcomes in post-thrombotic syndrome, where the valves are usually destroyed. It is sometimes difficult to evaluate the results of deep venous reconstructive surgery for reflux, and generally the outcomes are based on pain decrease, absence of ulcer recurrence, and restored valve competence.

4.1. *Treatment of primary deep valve insufficiency*

The results of internal and external valvuloplasty in primary deep valve insufficiency are shown in Table 1 [38–46].

The valvuloplasty is credited at 5 years of follow-up and with a success rate of >70%. External valvuloplasty on the whole achieved less satisfactory results, if we consider the absence of ulcer recurrence and the competence of repaired valves. In all of the published series, an excellent correlation can be noted between clinical outcomes and valve competence. The outcomes of other techniques, such as angioscopy-assisted valvuloplasty [18,47–49] and cuffing [20,21,24,41] (Table 2), are more difficult to assess, knowing that the follow-up is not long enough, with the exception of the series reported by Lane et al [21].

4.2. *Treatment of post-thrombotic syndrome*

Outcomes of the application of vein transposition are shown in Table 3 [38–40,44,50,51]. Successful clinical outcomes are between 50% and 75%, with valve competence between 40% and 77%.

4.3. *Transplant results*

Transplantation results are provided in Table 4 [38,40,41,44,45,52–57]. Successful outcomes are between 33% and 82% (follow-up period >1 year), with valve competence between 16% and 87%, and hemodynamic performance little changed. It would appear that transplant to the popliteal vein yields better results [44,54]. Transplant generally achieves less satisfactory results than transposition.

Table 5 – Results of neovalve reconstruction.

Author, year	Technique	No. of limbs	Etiology, PTS/total	Months of follow-up, range (mean)	Ulcer recurrence or nonhealed ulcer, n (%)	Hemodynamic results	
						Competent valves, n (%)	AVP - VRT
Plagnol, 1999 [29]	Bicuspid neovalve	44	44/44	6-47 (17)	3/32 (17)	38/44 (86)	
Maleti, 2009 [31]	Monocuspid or bicuspid neovalve	19+21=40	36/40	2-78 (28.5)	7/40 (17)	13/19 (68) 21/21 (100)	75 VRT improved
Opie, 2008 [32]	Monocuspid neovalve	14	/	(48)	0/6	13/14 (92)	

AVP, ambulatory venous pressure; PTS, post-thrombotic syndrome; VRT, venous return time.

4.4. *Neovalve results*

Neovalve results are displayed in Table 5 [29,32,59].

One might be surprised by Opie's [32] results, knowing that as the flap is not fixed laterally on both sides and, consequently, leak is inevitable.

4.5. *Cryopreserved valves and bioprosthetic valves*

The results obtained with cryopreserved valves are not so satisfactory [33,34,]. At 9 months, patency and competence are 78% and 67%, respectively. The clinical outcomes are also difficult to assess, knowing that postoperative thrombosis provisionally improves the patient's condition by suppressing the reflux. A comprehensive study was recently carried out on bioprostethic valves [60] . The bioprosthetic venous valve III, developed by the Portland team, was the subject of phase 3 clinical experimentation on 15 patients. At 1 year, none of the valves implanted was competent, but the patients improved in clinical terms in 60% of cases.

5. Summary

Correction of deep venous reflux is the corner stone of VU treatment as long as the deep venous obstruction and superficial reflux are corrected first. VU healing can be achieved with very good results in both primary and secondary deep venous pathology by these techniques.

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