Significance of the Soleal Vein and its Drainage Veins in Cases of Massive Pulmonary Thromboembolism

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In this report, we review the anatomical features of the crural veins and the importance of the soleal vein and its drainage veins for thrombi formation and propagation. The result of our investigation of 120 legs of 60 autopsy cases with fatal pulmonary thromboembolism showed that the soleal vein was the most frequent site of deep vein thrombosis, both for fresh and for organized thrombi. Furthermore, the detection rate of thrombi, both fresh and organized, showed that the most common site was in the soleal vein and then decreased progressively according to the drainage route of the soleal vein. Anatomical characteristics and physiological mechanisms play a major role in the occurrence and propagation of venous thrombi. Thus, an understanding of these features is essential for effective prophylaxis of venous thromboembolism.

Key words: pulmonary thromboembolism, deep vein thrombosis, soleal vein, crural vein, autopsy

INTRODUCTION

Pulmonary thromboembolism (PTE) is considered not only a primary disease but also a serious consequence of deep vein thrombosis (DVT). Therefore, both PTE and DVT are recognized as a result of a disease named venous thromboembolism.

There have been few clinical and pathological investigations of crural-vein thrombosis. Venography, formerly considered the standard technique for investigation of venous thrombosis, is not suitable for visualizing muscular veins such as the soleal vein and the gastrocnemius vein.

Recently, ultrasonography has improved the quality of crural vein images. Ohgi et al. have been emphasizing the significance of crural deep vein thrombosis, especially soleal vein thrombosis in cases of PTE.1) We have been investigating the histopathological features of venous thromboembolism in fatal cases of acute massive PTE in forensic autopsy.2–7) Our results indicated the highest frequency of crural-type DVT especially at the soleal vein.

In order to explain the significance of soleal vein thrombosis, it is important to understand the anatomical characteristics of the crural deep veins and their role in the occurrence and propagation of crural-type DVT.

In this report, we review the anatomical features of the crural veins and the importance of the soleal vein and its drainage veins in the formation of thrombi and their propagation. In addition, we suggest that the anatomical characteristic of crural-type DVT is responsible for the difference in the rate of detection of crural-vein thrombosis between drainage veins of the soleal vein and non-drainage veins.

ANATOMICAL CHARACTERISTICS OF CRURAL DEEP VEINS AND THE POPLITEAL TRUNK (Fig. 1)

Crural deep veins are anatomically classified into three groups: (1) veins receiving blood flow from the sole of the foot (peroneal vein, posterior tibial vein, anterior tibial vein), (2) intramuscular veins (soleal vein and gastrocnemius vein), (3) veins receiving from all crural deep veins and those draining to thigh veins (popliteal vein).

The most specific characteristic of crural deep veins as compared with thigh veins is that crural deep veins run as a pair accompanied with a single artery with the...
same name, except on the distal side of the intramuscular veins.

Veins receiving blood flow from the sole of the foot run as a pair vertically along with the fibula or tibia. Intramuscular veins run proximally with some bifurcations and connections. The gastrocnemius veins run through the two heads of the gastrocnemius muscle as medialis and lateralis. The soleal vein contains over ten multibranched veins in each leg, and they are roughly subclassified into three groups: (1) centralis, (2) medialis, and (3) lateralis.8)

Each pair of crural veins eventually connects together to form one vein and finally pours into the popliteal vein as a popliteal trunk. This complicated form of connection is advantageous because it avoids the turbulence produced by an abrupt venous connection or diffuse venous stagnation in the cases of obstruction at the connecting point (Fig. 1). First one pair combines, then further down the line another track joins, then a bit further along, another, etc.

The popliteal trunk consists of three parts (Fig. 1): (1) the peroneal vein and posterior tibial vein are combined to form the lower part of the popliteal trunk. Most of the centralis of the soleal vein pours into the peroneal vein and posterior tibial vein or lower part of the popliteal trunk. (2) The anterior tibial vein is connected to the middle part of the popliteal trunk after the connection to the peroneal and the posterior tibial vein. From the middle part of the popliteal trunk, the popliteal runs as a double vein: i.e., the wider medialis and the narrow lateralis.

The medialis of the gastrocnemius vein pours into the medialis of the popliteal vein, and the lateralis of the gastrocnemius vein pours into the lateralis of the popliteal vein at the upper part of the popliteal trunk. (3) Finally, the two popliteal veins are united as a single popliteal vein that continues to the femoral vein.9)

**Significance of the Soleal Vein in the Case of Crural-type DVT**

Our previous investigation indicated that most cases of fatal pulmonary thromboembolism without initial leg symptoms were a consequence of crural-type DVT and that, among the crural veins, the soleal vein is the most important as the initial site of thrombi formation.2, 4-7)
As far as hydrostatic pressure is concerned, there is no difference between the various crural veins for possibly inducing venous thrombi. Nevertheless, the soleal vein and its drainage veins show a significantly higher frequency of thrombi production than the veins that do not receive flow from the soleal vein. The reason for this higher thrombus formation is caused by specific anatomical characteristics of the soleal muscle and soleal vein.\(^1,5,9\)

The soleal muscle works only at the ankle joint. In contrast, the gastrocnemius vein works at both the ankle joint and the knee joint. Therefore, the soleal muscle would not be active in the case of prolonged sitting, e.g., during a hospital stay or long plane flights, which can easily cause venous stagnation of the soleal vein.

In addition, from the viewpoint of the venous valve, the gastrocnemius vein has paired complete valves at both the stem of the vein and at the connecting point of the distal narrow vein. In contrast, the soleal vein possess few or no functioning valves, with the single exception of the connecting point of the distal narrow vein. Thus, once the soleal vein is dilated by venous stagnation, it easily can lead to venous valve insufficiency.

The soleal vein, acting as a storage vein (so-called venous sinus), is initially more prone to circulatory stasis, but it becomes less susceptible than other crural veins in the case of excessive venous stagnation. Furthermore, in contrast to proximal venous thrombi that stem from the valve pocket,\(^10\) soleal vein thrombi are made from a fibrin membrane templated circumferentially by the dilated vein.

**The Anatomical Form of Connection of the Crural Vein Affects the Propagation of Venous Thrombi**

Despite the high incidence of crural-type DVT, most of them remain focal thrombi and are usually resolved by thrombolysis or are organized to form fibrous remnants. However, about one-fifth of the crural-type DVT propagates to a proximal site.\(^10\) In contrast to primary thigh vein thrombi, like the iliac type or femoral type DVT, these secondarily-propagated thrombi tend to be free-floating thrombi which grow progressively to the proximal side, with little adherence to the vessel wall.\(^5,12\) Diffusely propagated thrombi from crural-type DVT might be detached and become proximal free-floating thrombi. The soleal vein is the most important among the crural veins as the first site of thrombi formation.

In contrast to the involvement of hydrostatic pressure and the structure of venous valves, the anatomic characteristics of connections in the crural vein play a key role in the etiology of thrombus propagation.

The connecting form of the three veins receiving blood flow from the sole of the foot (peroneal vein, posterior tibial vein, and anterior tibial vein) is gradual, one vein joining at a time, and thus progressively developing to the popliteal trunk. Two gastrocnemius veins pour into the same lateral vein of the popliteal vein, medialis to medialis and lateralis to lateralis.

The soleal vein pours into the peroneal vein or the posterior tibial vein, either at a proximal or distal site. Among them, the centralis of the soleal vein usually pours into the proximal site of the peroneal vein or the lower side of the popliteal trunk after joining to the peroneal or posterior tibial vein. Because the centralis of the soleal vein is usually the dominant soleal vein, thrombosis of the soleal vein tends to propagate to the centralis of the soleal vein, and, as a consequence, drainage veins of the centralis of the soleal vein (i.e., the peroneal vein and the posterior tibial vein) show a high frequency in the detection of venous thrombi.\(^2,7\)

**Thrombi Occurrence and Propagation at Non-drainage Veins of the Soleal Vein**

Most cases of crural-type DVT with massive PTE had soleal vein thrombi. A few cases of crural-type DVT that did not have soleal vein thrombi instead had thrombi from the gastrocnemius vein or from the peroneal vein.\(^7\) Thrombi at non-drainage veins of the soleal vein (i.e., the gastrocnemius vein and the anterior tibial vein) were found in about 40% of crural-type DVT withsoleal vein thrombosis.\(^2,7\)

The venous thrombi propagate through the blood flow in continuity. Thus soleal vein thrombosis rarely propagates to the non-drainage veins. However, thrombotic occlusion of the popliteal trunk may produce a retrograde propagation of soleal vein thrombi to the non-drainage veins.\(^5,9\) These thrombi, therefore, are a secondary by-product that are created only if the popliteal trunk is massively occluded, so that the detection rate of thrombi is relatively lower in the non-drainage veins than in drainage veins of the soleal vein. The investigation of the three non-drainage veins (anterior tibial vein, medialis of the gastrocnemius vein, and lateralis of the gastrocnemius vein) revealed that the detection rate for venous thrombi tended to be similar in the anterior tibial vein and the medialis of the gastrocnemius vein but lower in...
the lateralis of the gastrocnemius vein.

This result is explained anatomically by the fact that the anterior tibial vein and medialis of the gastrocnemius vein join to the popliteal vein at its broad medialis, whereas the lateralis of the gastrocnemius vein connects to the narrow lateralis of the popliteal vein (Fig. 1). Soleal vein thrombi that propagate to the popliteal trunk cause secondary thrombosis at the anterior tibial vein and the medialis of the gastrocnemius vein, but secondary thrombi are less frequently formed at the lateralis of the popliteal vein and the lateralis of the gastrocnemius vein.

**SOLEAL VEIN THROMBOSIS AND CONCORDANCE RATE OF THROMBI IN THE CASE OF PULMONARY THROMBOEMBOLISM (Fig. 2)**

We examined 120 legs of 60 autopsy cases with fatal PTE. DVT was detected in 117 legs, and 115 legs of those contained soleal vein thrombi. The concordance rates of deep vein thrombi of leg to soleal vein thrombi were examined. The concordance rates of fresh thrombi in 87 legs that contained soleal vein thrombi were as follows: peroneal vein, 62 legs (71.3%); posterior tibial vein, 62 legs (71.3%); popliteal vein, 50 legs (57.5%); femoral vein, 21 legs (24.1%); iliac vein, 0 legs (0%); anterior tibial vein, 31 legs (35.6%); medialis of the gastrocnemius vein, 30 legs (34.5%); lateralis of the gastrocnemius vein, 11 legs (12.6%) (Fig. 2A). The concordance rates of organized thrombi in 91 legs that contained soleal vein thrombi were as follows: with the peroneal vein, 52 legs (57.1%); posterior tibial vein, 47 legs (51.6%); popliteal vein, 19 legs (20.6%); femoral vein, 3 legs (3.3%); iliac vein, 0 legs (0%); anterior tibial vein, 16 legs (17.6%); medialis of the gastrocnemius vein, 20 legs (22.0%); lateralis of the gastrocnemius vein, 5 legs (5.5%) (Fig. 2B).

As described above, the soleal vein was the most frequent site of DVT both for fresh and for organized thrombi. Furthermore, the detection rate of thrombi, both fresh and organized, was the highest at the soleal vein and then decreased progressively according to the drainage route of the soleal vein: i.e., soleal vein > peroneal vein > posterior tibial vein > popliteal vein. The detection rate of thrombi at the proximal thigh vein was not high, probably because thrombi were detached at the time of examination. The rate of detection of venous thrombi in non-drainage veins of the soleal vein was low. Among them, the anterior tibial vein and the medialis of the gastrocnemius vein showed similar detection rates, but rates were lower in the lateralis of the gastrocnemius vein.

These results are consistent with expectations derived from the anatomical characteristics of crural veins, especially those of the soleal vein and its connecting form to the popliteal vein.

**CONCLUSION**

Anatomical characteristics and physiological mecha-
Significance of Soleal Vein in Fatal PTE Cases

Mechanisms play a major role in the occurrence and propagation of venous thrombi, and trying to understand these features is essential for the effective prophylaxis of venous thromboembolism.

The characteristics of the crural veins have not been sufficiently investigated yet, partly because of a lack of clinical interest and partly because of difficulties in investigation. Clinical verification of crural vein thrombosis by recently developed diagnostic imaging, such as ultrasonography or magnetic resonance imaging, are required.

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