Original article

A novel scoring system for lower-extremity venous pathology analysed using magnetic resonance venography and duplex ultrasound

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Abstract

***Objectives*:** To present a novel scoring system for lower-extremity venous pathology (the LOVE score) and our experiences using it in our clinical practice to identify venous pathology with duplex ultrasound (DUS) and magnetic resonance venography (MRV).

***Method*:** A total of 40 patients, 30 suspected of chronic venous disease and 10 with acute deep vein thrombosis (DVT) were examined from the inferior vena cava (IVC) to the popliteal vein using DUS and MRV. The image findings were reported using the LOVE score.

***Results*:** The majority of deep veins (368 out of 378 segments) were completely visualized by both our imaging techniques and could be analysed using the LOVE score. Both imaging techniques reported comparable findings with regard to the visualization of thrombus, obstruction, collaterals, trabeculations, anatomic variations and central venous compression (e.g. May-Thurner).

***Conclusions*:** The LOVE score can be used to expand and standardize the documentation of imaging the deep venous system beyond thrombosis, to help identify (optimal) treatment options in patients with venous disease, in both the clinical and research setting. This first assessment shows that both DUS and MRV are capable of systematically identifying a multitude of changes in the venous system.

Keywords: veins; deep vein thrombosis; classification; post-thrombotic syndrome

Introduction

For our clinical practice, we require safe and reliable diagnostic imaging tools to assess the venous system. In most cases, duplex ultrasound (DUS), with compression and Doppler provides the information required to evaluate the presence of deep vein thrombosis (DVT). DUS is routinely performed to identify thrombosis in the acute phase of the disease and has a proven high sensitivity and specificity.[1] In the chronic phase of DVT, it has a known reduced sensitivity and specificity for detecting DVT. The same applies in patients who are obese or oedematous and patients with casts.[1] Especially at the level of the iliac veins and inferior vena cava (IVC), accurate ultrasound assessment can be difficult, even for specialized technicians and radiologists. In the past decade many venous imaging modalities and their potential to replace DUS have been investigated.[2,3] Recently, in particular magnetic resonance imaging (MRI) has shown promising results, generating high-resolution images without the need for ionizing radiation.[4,5] Two groups have published their results in DVT imaging using novel contrast enhanced MRI protocols with Gadofosveset trisodium (Ablavar®).[6,7] Both studies compared their results with duplex

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ultrasound as their reference standard and concluded that magnetic resonance venography (MRV) is capable of detecting DVT both in the (upper) leg, pelvic and abdominal regions.

However, in our opinion detecting thrombosis is only the beginning. The spectrum of changes in the deep venous system in both the acute and chronic phase is more extensive than a lumen filled with thrombus.[8–12] In the acute phase it could be helpful to identify the exact level and extent of the thrombosis (location and thrombus load) as well as the morphology of thrombus. In addition to venous dilation due to thrombus and recanalization of the thrombus, these might be factors that influence the outcome of different treatment regimens, for example with regard to their ability to dissolve the thrombus quickly and the impact of the occlusion on the (residual) venous drainage.[9–14] These factors, if accurately identifiable with imaging, might be of importance to choose a treatment plan for DVT,[12] as we have hypothesized with the LET classification. Additionally, in the chronic phase, residual changes might be identified in the venous system, such as trabeculations (longitudinal fibrotic strands attached to the vein wall), and the long-term effects of (slow) post-thrombotic recanalization with a potentially reduced residual vein lumen and increased rigidity of the vessel wall. In order to investigate the capability of different imaging modalities to visualize these changes, we first have to establish what changes to visualize, whether or not these changes can be visualized accurately and how these changes relate to the patients clinical status.

Material and methods

Patients

All patients suspected of having (chronic) venous disease that are referred to the Department of Vascular Surgery at our institution are scheduled for a standardized imaging work-up. This work-up consists of both DUS, performed by a dedicated technician, and MRV. Both examinations are used to visualize the deep venous system, reaching from the level of the popliteal veins upwards, including to the inferior vena cava (IVC). A total of 30 patients with suspected (chronic) venous disease (11 men, mean age 45, range 32–69 years) and 10 patients with clinical signs of acute DVT (8 men, mean age 47, range 46–73 years) were retrospectively analysed using our standardized scoring system. MRV and DUS examinations were acquired on the same day for all patients.

Imaging protocols

Magnetic resonance venography

All MRV examinations were performed on a 1.5-T MRI system (Intera, Philips Medical Systems, Best, The Netherlands). For signal reception a dedicated 12-element phased-array peripheral vascular coil with a craniocaudal coverage of 128 cm (Philips Medical Systems) was used. Patients were imaged in a supine position. A fixed dose of 10 mL gadofosveset trisodium (Ablavar®, Lantheus Medical Imaging, Billerica, MA, USA), a blood pool contrast agent, was administered intravenously as a single dose at a speed of 1.0 mL/second in the median cubital vein, using a remote controlled injection system (Medrad Spectris, Indianola, PA, USA). Contrast injection was followed by 20 mL saline flush injected at the same rate.

A five-station three-dimensional ultrafast gradient echo (TFE) sequence with fat suppression (SPIR) was used for high-resolution steady-state imaging of the venous vasculature, ensuring a coverage of at least the popliteal veins up to the entire IVC. Acquisition parameters were as follows: TR 7.8 ms, TE 3.8 ms, FOV 380 mm, matrix 400, 150 axial slices/station and voxel dimensions (reconstructed) were $0.95 \times 0.95 \times 1.50$ mm for all stations. Parallel imaging (sensitivity encoding, SENSE) was applied to reduce scan time (SENSE factor 2 in the anterior–posterior direction). For optimal signal intensity and reducing bowel and respiratory artefacts, a NSA of 2 was used. Total acquisition time for five stations was approximately 15 minutes.

Duplex ultrasound

DUS examinations were performed using a Hitachi Aloka ProSound ALPHA 7 Premier machine (Aloka, Tokyo, Japan). The standardized protocol involved machine settings using optimal contrast, adaptive image processing (AIP) and broadband harmonics. A convex array transducer, UST-9130 (frequency range 3–6 MHz), was used when studying the venous system from the vena cava down towards the venous tibial confluence below the knee, with the patient in a supine position. Consequently, the patient was examined in an upright standing position, scanning from upper groin to below the knee, using a high-frequency compound linear array transducer: UST-5411 (frequency range 5–16 MHz) where pulsed wave Doppler (5 MHz) was used to test for valvular incompetence. Throughout the examination, all colour modalities available on the machine were applied to determine flow, in particular directional E-flow™, in both transverse and longitudinal planes. Venous

compression in a transverse plane was used to determine the level of obstruction in each segment. Inspiration and expiration was used to enhance flow as well as to displace bowel gases when necessary. Optimal distal vena cava and iliac vein diameter distension were observed during enhanced flow with vertical leg extension when the patient was in supine position.

Study interpretation

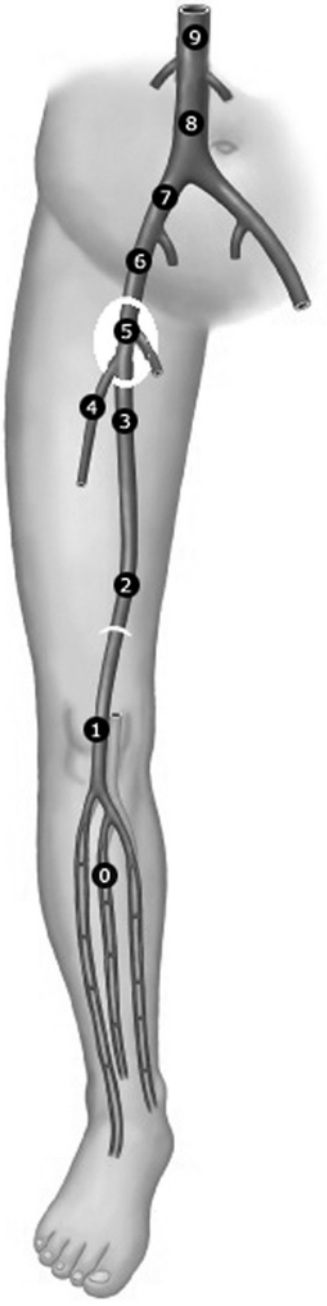
Both the technician performing and interpreting the DUS as well as the radiologist interpreting the MRV images had access to the clinical data of the patient; both were aware of the previous history and current clinical condition. Image interpretation was done independently by one radiologist (MRV) and one technician (DUS), both experienced in venous imaging. The MRV studies always included both legs; however, due to time constraints the DUS examination was often limited to the leg or legs corresponding with the clinical condition. The radiologist evaluated both legs in all patients using the scoring system. Evaluation of the results was, however, limited to those legs examined by both techniques.

Scoring system

Segmentation

The deep venous system of the lower extremities was divided into anatomically distinguishable segments, starting with the popliteal vein, up to the IVC. Due to their limited size (diameter) and incomplete visualization (not standard included in the scanning protocols), it was decided not to analyse the calf veins in this study. This resulted in segmentation into nine segments; (1) the popliteal, (2) distal femoral vein, (3) proximal femoral vein, (4) deep femoral vein, (5) common femoral vein, (6) external iliac vein, (7) common iliac vein, (8) IVC – infrarenal and (9) IVC – suprarenal. These segments are listed in Table 1.

Table 1 Description of the venous segments used in the LET classification, with exclusion of the calf veins for the purpose of this study



Segment 0: calf veins
Segment 1: popliteal vein
Segment 2: distal femoral vein
Segment 3: proximal femoral vein
Segment 4: deep femoral vein
Segment 5: common femoral vein
Segment 6: external iliac vein
Segment 7: common iliac vein
Segment 8: inferior vena cava, infrarenal (below the level of the renal veins)
Segment 9: inferior vena cava, suprarenal (above the level of the renal veins)

Diagnostic quality

In order to evaluate the quality of the images obtained we scored the image quality as good, limited, bad or not evaluable. Good implied the imaging of that specific segment was of diagnostic quality without any artefacts or limitations in scoring the required items. Limited implied it was still of diagnostic quality overall but with minor artefacts or reduced visibility of the vessel contour. Bad meant there were images obtained of the segment but it was partly not of diagnostic quality. Not evaluable was reserved for those segments that had images of non-diagnostic quality because of artefacts, scanner or equipment limitations. For example, a few patients could not be fitted into the MRI gantry entirely because their circumference in combination with the body coil exceeded that of the gantry. Duplex ultrasound could not be applied in some segments because of obesity, severe oedema or wounds.

Acute DVT versus chronic venous disease

Our patient population could be divided into two main groups, the acute DVT group and the chronic venous disease group. In the first group, assessment of the vein segments was mainly focused on identifying thrombus/thrombosis, the morphology of the signal in the thrombus and the degree of obstruction of the veins. Thrombus material/thrombosis was either scored as present or not present. The morphology of the signal in thrombus was scored as either homogeneous (low intensity on MRV/hypo-echogenic on DUS) or heterogeneous (both low and high signal intensity on MRV, hyper- and hypo-echogenic on DUS). The hypothesis was that a homogeneous thrombus signal could be suggestive of relatively fresh thrombus material and heterogenic thrombus signal more suggestive of old(er) thrombus material. The segments containing (a lot of) thrombus were additionally scored with regard to the presence of (venous) dilation. Since the variation in venous diameter varies a lot and no objective standard measurements are available, labelling a segment as dilated was done at the interpreter's discretion. Furthermore, the degree of obstruction was scored as 90–100% (no obstruction), 50–90% (mild obstruction), 10–50% (severe obstruction) and 0–10% ([near] total obstruction). The degree of obstruction was calculated using volume measurements at the level of the obstruction, by drawing circular regions of interest (ROI) around the vein and in the vein around the obstruction. An example of an obstruction measurement is shown in Figure 1. Additionally, recanalization was scored as present or not, based on the configuration of the vein lumen in relation to the thrombus. DUS used additional flow characteristics to evaluate obstruction and recanalization.

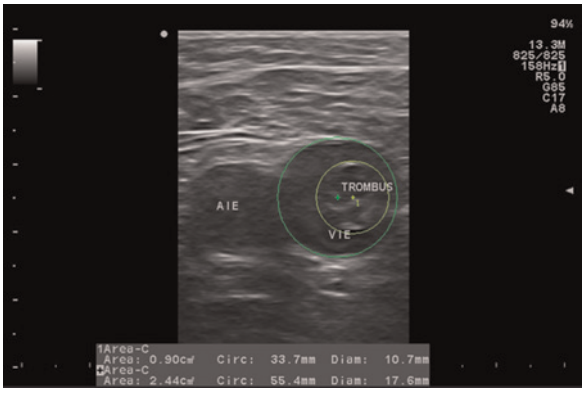


Figure 1 Example of obstruction measurement with duplex ultrasound at the level of the external iliac vein (VIE). A normal external iliac artery (AIE) is depicted on the left of the VIE

In the chronic group the focus was on identifying trabeculation, residual thrombus (with or without obstruction), the residual lumen and prominent collateral pathways. An example of trabeculation is shown in Figure 2. With regard to the residual lumen we used the same cut-off values as were used for obstruction. Residual lumen was determined in those segments suspected of being affected by DVT in the past, or iatrogenic damage. On MRV, both legs could be compared to assess luminal changes as well as the segments proximal and distal to the diseased veins. DUS compared segments proximal and distal to the disease segments and used compression to quantify the residual lumen. We screened for collateral pathways in the trajectory of the azygos or hemiazygos vein, the ovarian vein, the inferior epigastric vein, the pudendal (crossover) vein, the circumflex vein, the superior mesenteric vein, the ischiadic vein and the Giacomini vein. An example of collaterals at the level of the external iliac vein is shown in Figure 3.

In all patients we searched for signs of a potential underlying cause that might have caused the (re)thrombosis and/or venous insufficiency (e.g. May-Thurner disease, an [abdominal] mass compressing one or more vein segments, atresia of the vena cava inferior or signs of iatrogenic venous damage). Figure 4 shows an example of May-Thurner disease and Figure 5 an example of atresia of the vena cava inferior. Figure 6 shows the entire lower extremity venous pathology scoring system as a whole.

Results

The patients included in this study mostly presented with unilateral disease (38) and in two cases with bilateral disease. In total, 368 (out of 378) vein segments were evaluated with both techniques without significant artefacts limiting diagnostic interpretation. No contrast-associated complications were reported.

Image quality

The overall diagnostic quality for the venous segments on MRV was rated as good with a score of 2.9 out of 3 (SD 0.4). DUS diagnostic quality for all segments was rated comparable with an average score of 2.9 (SD 0.3). In three cases patients had received stents in the deep venous system; a total of eight segments were not interpretable with MRV due to susceptibility artefacts caused by these (metal) stents. DUS reported no issues with evaluation of these particular segments and

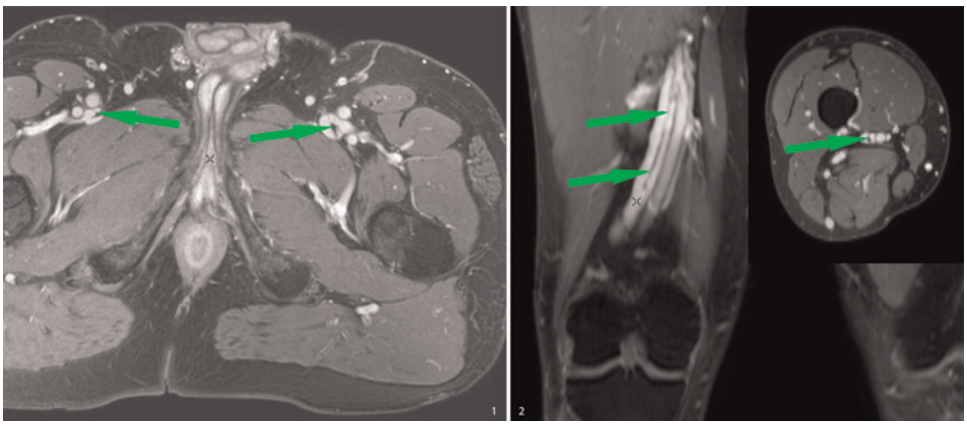


Figure 2 Examples of trabeculation visualized with magnetic resonance venography: (1) axial reconstruction showing trabeculation in the common femoral vein, both left and right (2) coronal and axial reconstruction showing trabeculation in the femoral vein

scored the diagnostic quality as good with a score of 3 for all eight segments.

Looking at the abdominal and pelvic segments separately, image quality still scored 2.9 out of 3 (SD 0.3) for MRV and 2.9 (SD 0.1) for DUS. The image quality of the femoral, popliteal and calf vein segments scored 2.9 (SD 0.5) for MRV and 2.9 (SD 0.5) for DUS. Artefacts due to *in situ* prosthesis (knee, hip) only reduced the image quality score for the corresponding vessel segments slightly on MRV (lowest score was 2) but never resulted in non-diagnostic images.

Acute DVT

In the acute DVT cases MRV detected thrombus in 73 segments, and DUS in 77 segments. The segments containing thrombus material were also scored with regard to the degree of obstruction. Both techniques seemed to agree whether or not a vessel segment was obstructed, both scoring 71 segments as obstructed in the acute DVT cases. However, quantification of the degree of obstruction varied a lot between the two techniques. On average, MRV interpretation seemed to score the obstruction of the lumen as slightly more severe than DUS (average of 77% [SD 28%] vs. 55% [SD 40%] obstruction).

Chronic venous disease

In the chronic venous cases, a total of 21 segments contained thrombus on DUS and a total of 13 on MRV. For DUS this included the eight stented segments, which were all thrombosed on DUS and not interpretable on MRV due to artefacts. On DUS a total of 42 collateral pathways were identified, on MRV a total of 29. The most commonly identified collateral pathway was the pudendal/crossover, which was identified on both DUS and MRV in 11 cases, followed by the inferior epigastric, which was identified in nine cases. Collateralization

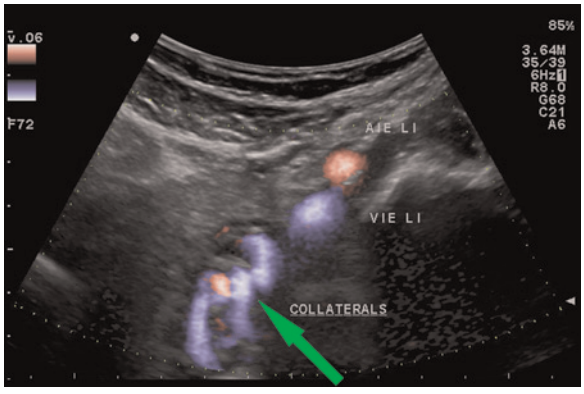


Figure 3 Example of collaterals visualized with duplex ultrasound at the level of the external iliac vein (VIE). A normal external iliac artery (AIE) is depicted on the left of the VIE

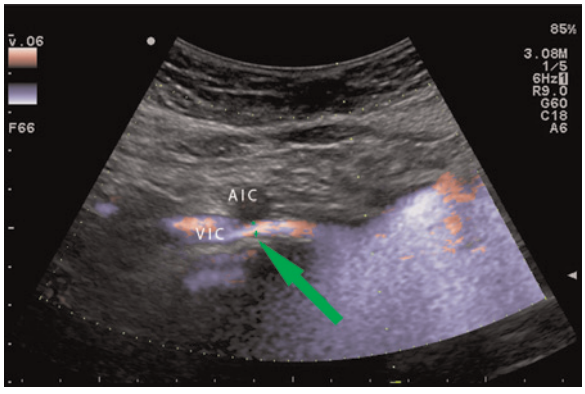


Figure 4 Example of May-Thurner visualized with duplex ultrasound. AIC marks the common iliac artery and VIC marks the (compressed) common iliac vein

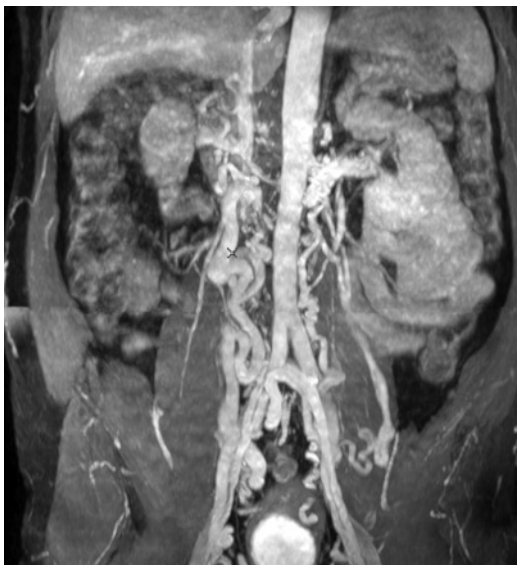


Figure 5 Atresia of the vena cava inferior (VCI) visualized with magnetic resonance venography (MRV). Maximum intensity projection (MIP) reconstruction of MRV in the coronal pane; the image shows multiple collaterals in the trajectory of the VCI (para-aortal) but no actual VCI

via the (left) ovarian vein was seen in three cases, and azygos collaterals in both cases of atresia of the IVC. All these collateral pathways were identified in patients suspected of chronic venous disease; no true collateral pathways were identified in the acute DVT cases. On MRV, the average residual lumen in vessel segments suspected of having been affected by DVT was 71% (SD 37%) and on DUS 52% (SD 41%), both with large variations. With regard to trabeculation, MRV identified fibrotic strands in 75 segments and DUS in 43.

Obstruction of the (left) iliac outflow due to compression by the (right) iliac artery (May-Thurner) was identified by DUS in 12 cases and by MRV in 19 cases; in one case the compression was seen in the right iliac vein due to an anatomical variant. In two cases atresia of the IVC was seen on MRV, and in one case this was also identified with DUS. In four cases duplication of the superficial femoral vein was seen, and in one case duplication of the common iliac vein. In one case a renal vein entrapment was identified on both MRV and DUS; compression of the left renal vein between the abdominal aorta and superior mesenteric artery (also referred to as the nutcracker phenomenon).

Discussion

When systematically analysed using our standardized scoring system, in addition to the presence of thrombus, a lot more information about the deep venous system could be acquired using MRV and DUS. In the acute phase both the technician operating the DUS and the radiologist interpreting the MRV were confident they could determine the exact location and extent of the DVT using the segmentation of the scoring system. The only variation we identified between the two modalities was the exact cut-off point for certain segments. On MRV, being able to reconstruct the anatomical image in three dimensions, it is easy to exactly determine the anatomical boundaries of any segment. With DUS this can definitely be more challenging, which might explain the differences in identifying thrombosed segments. Identifying the thrombus signal as homogeneous or heterogeneous varied a lot between the two techniques, which could have been caused by lack of experience with interpreting the signal or the fact that many of the interpretations of the DUS had to be done at a later time than the examination, forcing the interpreter to

Patient: **Patient nr.:** **Date of examination:**

		Acute					*Chronic*	
Segment:	**Diagnostic quality**	**Trombus**	**Obstruction**	**Recanalization**	**Collaterals**	**Cause of obstruction**	**(Residual) Lumen**	**Trabeculation**
IVC supra-renal								
IVC infra-renal								
CIV								
EIV								
CFV								
PFV								
FV – prox								
FV – distal								
PV								
	Good (3) Limited (2) Bad (1) Not evaluable (0)	Yes (2) No (1) N/A (0)	90-100% obstruction 50-90% obstruction 10-50% obstruction 0-10% obstruction	Yes (2) No (1) N/A (0)	Azygos vein Hemi-azygos vein Ovarian vein Epigastrica inferior vein Pundendal / dePalma vein Circumflex vein Greater saphenous vein Ischiadic vein Giacomini anastomosis	Compression: - May-Thurner Mass - tumor - hematoma Iatrogenic - Central line / CVC - Other	0-10% near occlusion 10-50% severe 50-90% mild 90-100% no occlusion	Yes (2) No (1) N/A (0)

Diagnostic quality:
Good: no artefacts, no limitations in evaluation
Limited: evaluable with a few (minor) artefacts
Bad: partially not evaluable
Not evaluable

Trombus:
Homogenous: mostly low intensity (fresh) thrombus material (A)
Heterogenous: various intensities (old) thrombus material (B)
Dilatation: venous dilatation due to thrombus burden (C)

Figure 6 The lower extremitity venous pathology scoring system (LOVE score)

rely on the stored images and his recollection of the examination, rather than the realtime ultrasound image. It is also possible that the signal of thrombus is affected by different factors for DUS and MRV, which could mean that it has different characteristics over time for different modalities, which could be investigated separately. Both imaging modalities were in agreement with regard to the presence of obstruction, but quantification of obstruction seemed difficult, as was also seen with the chronic cases with regard to the residual lumen. We think that the technique applied to score obstruction, identifying the vessel boundary which is used to calculate the volume of the vein in relation to the volume of thrombus or trabeculations at that level, can be misinterpreted easily accounting for a wide variety in volume measurements. Additionally, inhomogeneous luminal filling adds another dimension, complicating accurate volume measurement of thrombus. Recanalization was mostly seen in acute DVT cases where the obstruction was limited to only a few segments still with some degree of (out)flow. This might be an indication that identifying recanalization might be a positive predictor with regard to the ability to dissolve the thrombus and restore outflow. In chronic cases (residual) changes could be visualized by both DUS and MRV with only slight variations between DUS and MRV in the pelvic and upper leg segments. We had expected that DUS would report a lower diagnostic image quality in the pelvic region, but in the hand of our dedicated technician it did not, and additionally he was capable of visualizing the lumen of stented segments, which MRV could not. But in those patients where there were anatomical variations in the pelvic region or those with atresia of the VCI, it was difficult for DUS to identify the 'true' iliac veins between collaterals, and in one case abdominal extensions of the (hemi-)azygos vein were mistaken for the IVC, which was actually absent. Additionally, in a few cases with chronic venous disease, where the residual lumen in the upper leg and pelvis was very small (<5 mm), MRV was able to identify changes within the vein segments that could not be identified with DUS. Furthermore, MRV identified a lot of post-thrombotic fibrotic strands, regardless of the location in the deep venous system, which seemed more difficult to assess with DUS. Unfortunately, it is not possible to conclude whether or not MRV was more accurate with regard to interpreting these changes in the veins specifically, nor was this study designed to do so. There still might be a slight benefit for MRV with regard to imaging the abdominal and pelvic region, in particular since this technique allows you to image the whole body, displaying not only the deep venous axis in high detail but also its tributaries and surrounding anatomy. While the limitations of DUS in patients presenting with recurrent and chronic DVT are well known, there is still an important diagnostic tool which currently only DUS has available. DUS is currently superior to MRV (and any other non-invasive imaging modality) in dynamically assessing the venous system. Only during DUS examination is it possible to dynamically adjust the positioning of the patient from supine to upright and back. This allows for haemodynamic evaluation of the deep venous system, observing variations with high and low flow in the venous system and identifying reflux or valve insufficiency, which other imaging modalities cannot do, or not as easily. This might also explain why DUS detected almost twice as many collateral pathways compared with MRV. On MRV it was not too difficult to identify potential collateral pathways anatomically, but their (clinical) significance was sometimes hard to establish without being able to evaluate flow within these veins (especially when not obviously dilated at the time of the examination). Additionally, on MRV more May-Thurners were reported than with DUS. Most of these could be proven non-existent by haemodynamic evaluation using DUS.

There are a few important limitations to our study. The sample size of our study is a major limitation which allowed us to only identify abnormalities visualized, without having a sample size big enough to be able to accurately compare the ability of either imaging modality to visualize them. Second, while we think that we have included the most important vein segments and abnormalities in our scoring system, due to limitations in our current scan volume we have not yet included the calf veins routinely in our examinations, nor did we evaluate them using our scoring system.[15] Furthermore, we are aware of abnormalities reported by other groups, for example vein wall edema and other changes in vein wall thickness due to thrombosis.[16] If either prove to have an impact on the management of venous pathology in the future, they might need to be added to the LOVE score.

With regard to the imaging modalities, we would like to say that in our clinical setting they are used as complementary imaging tools to get a complete overview. We are aware that in general MRV is less accessible than DUS, which is widely available. However, both techniques require dedicated equipment and technicians to get the most out of either examination. A less experienced sonographer might

not be able to produce such an extensive overview of the venous system as we require for the LOVE score. An advantage for MRV is that the images can be interpreted by different radiologists. In general, it is considered a pre-requisite to perform the DUS examination to be able to accurately interpret the study. This also makes it easier to compare different MRV studies. With regard to the haemodynamic information DUS can supply, this might make it superior to other non-invasive imaging tools in cases where reflux and valve insufficiency need to be evaluated. In the pelvic and abdominal regions there are no valves and there, detailed anatomical information and obstruction are more important than hemodynamic information, which suggests that the best anatomical imaging tool is most likely superior there. Unfortunately, this study does not allow us to conclude either way, and thus we are currently conducting a larger study comparing these techniques in greater detail.

Conclusion

We think that the LOVE score can be used effectively to get an overview in patients with venous disease in order to decide on a treatment plan (for example, in combination with the LET classification in cases of thrombosis) as well as for documentation purposes in clinical trials.

Disclosure statement: CHAW and CWKPA: no relevant relationships.

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