Tomographic three-dimensional ultrasound imaging improves spatial visualization and management of varicose veins

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ABSTRACT

Tomographic three-dimensional ultrasound using handsfree electromagnetic tracking is an important adjunct to traditional two-dimensional duplex ultrasound examination. This technique allows vascular surgeons to better orientate and visualize the often complex anatomy along the entire length of the target vein. This paper reports a novel technique in preoperative and postoperative acquisition of superficial incompetent veins, thereby providing a comprehensive three-dimensional orientation of different pathological patterns of incompetence. (J Vasc Surg Cases Innov Tech 2024;10:101542.)

Keywords: Three-dimensional tomographic ultrasound imaging; Image rendering; Measurements; Varicose veins; Venous anatomy

Duplex ultrasound examination demonstrating both anatomical and functional information is an essential assessment modality for patients with varicose veins. It is noninvasive and can demonstrate venous anatomy of tortuosity, thrombosis, and obstruction, with concomitant venous haemodynamics.[1] Although there are international guidelines as to the use of venous duplex examination,[2] it remains operator dependent and may not represent an overview of the varicose vein systems. In particular, the evaluation of significant perforators, or at rare sites of reflux such as the Giacomini vein, or sites of recurrence after primary treatment, is difficult and time consuming, and duplex ultrasound examination may miss an important perforating vein associated with insufficiency, which may lead to recurrence after varicose veins intervention.

Tomographic three-dimensional (3D) ultrasound examination, using handsfree electromagnetic tracking, is an important adjunct to traditional two-dimensional (2D) duplex ultrasound imaging, to allow vascular surgeons to view 3D images of the entire length of the target vein. This can be an important adjunct to 2D ultrasonic images in selective patients. The purpose of this study is to report our technique in preoperative and postoperative acquisition of varicose veins images, and in providing comprehensive 3D images of different patterns of incompetence.

TECHNIQUE

Techniques of image acquisition for GSV have been reported previously in the assessment of arteries, arteriovenous fistula, and potential autologous bypass grafts,[3-5] but the technique in the examination of varicose veins has not been reported previously. As per usual, the viewing of superficial venous system does not require the use of sulphur hexafluoride ultrasound contrast. Tomographic 3D ultrasound is a handsfree, high-resolution, electromagnetically tracked 3D ultrasound system that can demonstrate clear 3D images of the entire target vein.

Specific patients with varicose veins attending our vascular laboratory underwent traditional 2D venous duplex ultrasound examination and 3D tomographic ultrasound examination. The 2D ultrasound examination looked at specific sites of reflux, and the 3D images were complimentary in providing venous anatomy and offered additional easily interpretable information to help vascular specialists for clinical management decisions. The use of 2D and 3D ultrasound examinations on vascular patient has local institutional review board approval (IRB reference number 2020-0737). All the duplex ultrasound scans were performed by certified experienced vascular ultrasound sonographers or physicians using the Philips Affinity 70G (Philips Healthcare Solutions, WA, USA) with a high-definition linear 9-MHz transducer and venous preset. Images were acquired with the patient standing up to maximize venous filling, with their legs slightly turned outward for best exposure of the great saphenous veins (GSVs). An electromagnetic tracking sensor was attached to the same ultrasound

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Fig 1. The sensor is attached to the probe (**A**). The information generated by moving the sensor in the magnetic field allows the source of all ultrasound reflections to be interpreted by the computer using tomographic ultrasound software (Piur imaging GmbH, Wien, Austria). (**B**) Acquisition of images in patient with lower limb venous disease using the sensor and the probe (*hollow arrow*), with the magnetic field transmitter mounted on a support stand next to the patient (*solid arrow*).

probe (Fig 1, *A*). The tracking system is small and lightweight and, when affixed to the ultrasound probe, does not interfere with the grip and maneuverability of the probe and the additional weight is negligible. Because the electromagnetic tracking system is an external device, it does not interfere with the 2D imaging, and there have been no long-term issues with the ultrasound probes. The GSVs including the saphenofemoral junctions were imaged from the groin to knee or upper calf with the probe swept down the GSV in an axial orientation.

The information generated by moving the sensor in the magnetic field allows the source of all ultrasound reflections to be interpreted by the computer using tomographic Ultrasound software (Piur imaging GmbH, Wien, Austria) (Fig 1, *B*). Multiplanar reconstructions and a volumetric image are then computed from the ultrasound frames using these positional data (Fig 2). With the information of all the ultrasound reflections gathered and interpreted by the computer forming multiplanar reconstructions and volumetric imaging, the diameter of the vein, distance from the saphenofemoral junction, and tortuosity information could be calculated. The tomographic scanning would usually take an additional 2 to 3 minutes, involving the setup of the electromagnetic system and the attachment of the electromagnetic sensor to the ultrasound probe. Postprocessing of images may take up to 10 to 20 minutes, but this process will become quicker with experience and familiarity of the system. The still images and clips of the 3D rendering view can be exported as PNG and mp4 files. As yet, this system does not allow dynamic or functional images; therefore, only static images are obtained. The 2D ultrasound scan can be performed by the vascular sonographer or the physician and, after appropriate training, both can use the processed data to create the 3D images. Therefore, this technique is not strictly technician dependent and limited to the person doing the scan.

Our pilot study included patients with primary varicose veins who had incompetence in their saphenofemoral junction and GSVs. More than 30 cases have been performed, and the 3D images were able to demonstrate diameter of the vein, distance from the saphenofemoral junction, and tortuosity information. Specific characteristics such as local tortuosity, bulges of the vein and post-procedure venous recanalization can be shown. Fig 3 gives examples of theses tomographic images. As a case example of this new technique, we have measured that diameters of the GSV along its length (Fig 4, *A*). We have shown that, in the management of a patient of varicose veins with cyanoacrylate ablation of GSV, the diameter of the GSV preoperatively is important in predicting recanalization, and we have our modified extra-drop protocol, which improved the closure rates (Fig 4, *B*).[6]

DISCUSSION

To our knowledge, this report is the first to evaluate varicose veins using tomographic ultrasound examination perioperatively, which provides a comprehensive 3D image. This is important in the preoperative evaluation of and planning for the venous procedure, as well as in explaining the venous anatomy to the patient in the preprocedural consent process. This technique is useful in examining the diameter and tortuosity of the GSVs, in defining anatomical variations such as duplication of the saphenous systems, and also in showing the diameter of the GSVs, which may affect subsequent management.[6] This tomographic 3D ultrasound technique is an adjunct to, and does not replace, the conventional 2D ultrasound examination; the 3D images improve spatial venous interpretation and may be more reproducible over conventional 2D ultrasound examination.

Tomographic 3D ultrasound is a high-resolution, tracked, handsfree 3D ultrasound system that works by frame grabbing the images from a standard duplex ultrasound system. This tomographic ultrasound imaging with computerized software (Piur imaging GmbH, Vienna, Austria) was developed for vascular use, looking at the aorta and other peripheral vascular systems such as the carotid, lower limb, and arteriovenous fistula. It has been shown that the acquisition of the 3D-tomographic ultrasound images was quicker than standard duplex imaging technique and required less operator skill, making it more cost effective.[5] When the Piur Imaging system including the electromagnetic sensor set and the probe attachment set was purchased, the cost was

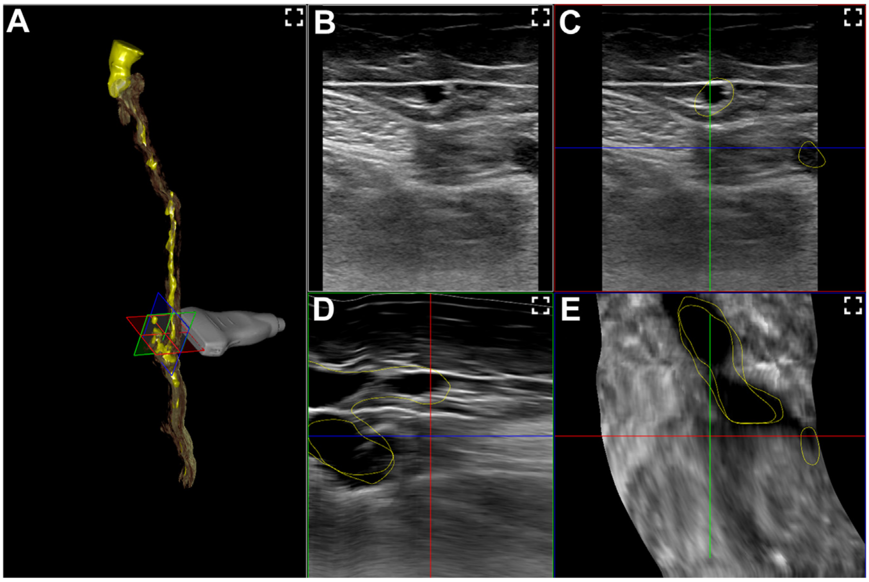

Fig 2. Multiplanar reconstructions and a volumetric image are then computed from the ultrasound frames using these positional data. (**A**) Three-dimensional (3D) reconstruction. (**B**) Original two-dimensional (2D) image. (**C**) Multiplanar reconstruction of the transverse plane. (**D**) Multiplanar reconstruction of the sagittal plane. (**E**) Multiplanar reconstruction of the frontal plane.

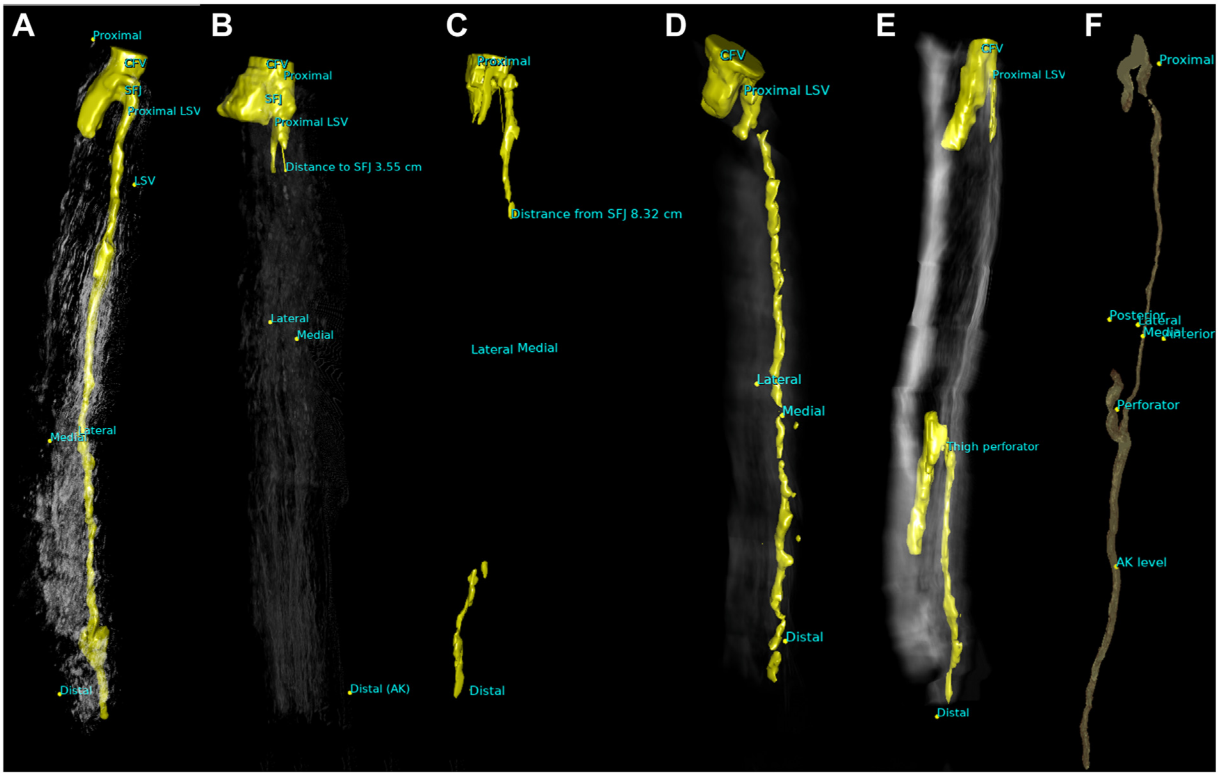

Fig 3. Examples of three-dimensional (3D) tomographic venous images. (**A**) Preprocedure incompetent great saphenous vein (GSVs). (**B**) Postprocedure with complete obliteration of the GSV, and the distance from the saphenofemoral junction can be measured. (**C**) Partial recanalization of the GSV from the saphenofemoral junction (*SFJ*) downward, after endovenous cyanoacrylate treatment. (**D**) Complete recanalization of the GSV from the SFJ downward, after endovenous cyanoacrylate treatment. (**E**) Neovascularization at the groin level reconnecting to the GSV. The position of vein perforators could be seen on this scan. (**F**) Incompetent GSV due to incompetent lower thigh perforator.

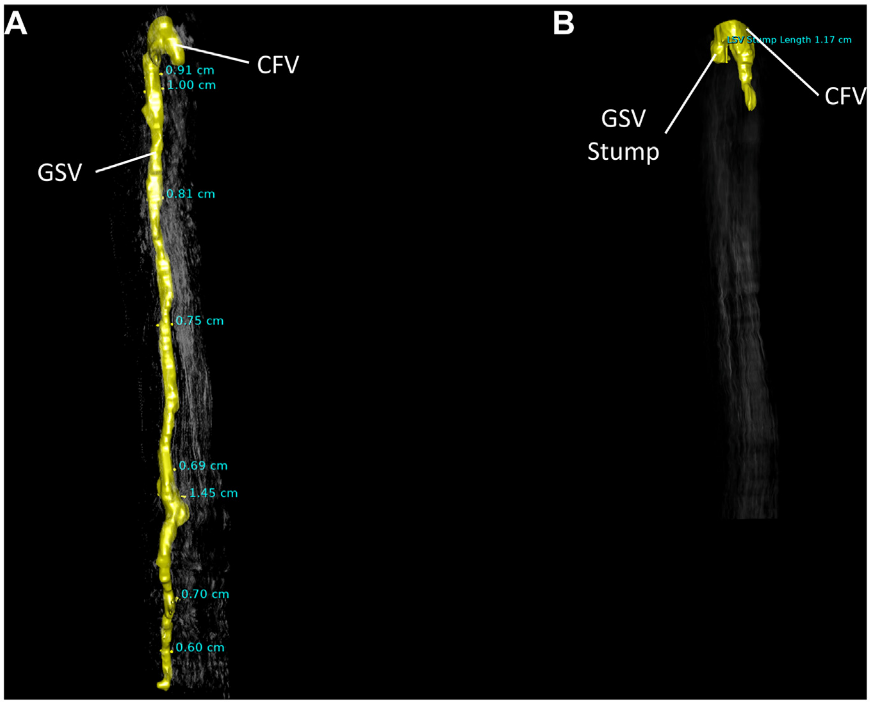

Fig 4. Example of this new technique, of preprocedure (**A**) and postprocedure (**B**) images. *CFV*, common femoral vein; *GSV*, great saphenous vein.

US$63,500. Although the 3D image quality depends on the resolution of the duplex instrument, acquisition of images is easy with vascular ultrasound technicians or physicians, and the software is user friendly.

As the management of varicose veins had become more minimally invasive and patient-oriented, preoperative imaging has also become more sophisticated. Two-dimensional venous duplex gives planar anatomical information and dynamic information with regards to patterns and amount of incompetence, but does not give a complete morphologically map of the venous system. White et al used 3D[7] reconstruction using a Philips Epiq 7 ultrasound system (Philips Ultrasound, Bothell, WA) with a linear transducer to examine complex neovascularization of the groin.

A computed tomography (CT) venogram gives an accurate technique for assessment of the venous anatomy to enable better surgical strategy, but it involves radiation exposure and depends on correct phase of contrast during image acquisition, as the flow between the GSV and in incompetent varicose veins may differ significantly.[8,9] Uhl[10] described the efficient use of spiral CT scan to investigate patients with complex or recurrent varicose veins, examples including those with neovascularization of the groin after GSV surgery, postoperative recurrence of the popliteal fossa, or varicose veins of the great saphenous territory fed by an ascending flux of the Giacomini vein via a saphenous popliteal reflux. The limitation of a CT venogram was that patients were exposed to radiation. The CT venogram did not offer any hemodynamic information, and the images were acquired with patients in the supine position. Magnetic resonance imaging, which is comparatively more expensive, can also be used to view lower limb system, and 3D images can be reconstructed without using a contrast medium.[11]

To summarize, to have 3D information of superficial venous anatomy, a CT scan requires ionizing radiation and magnetic resonance imaging is comparatively more expensive. Our novel technique of 3D tomographic ultrasound examination is inexpensive, noninvasive, and avoids radiation, with the ability to measure venous geometry easily. Images can be viewed and rotated, and measurements of venous diameters and lengths can be performed easily using the appropriate software, permitting perioperative data rendering and planning by the operating surgeon. The tomographic ultrasound is noninvasive, user-friendly, does not require specialist 3D matrix ultrasound transducers, and achieves good image resolution because it uses the same standard duplex ultrasound transducers. This novel system facilitates vessel lengths and diameter measurements, and is an important adjunct to the conventional 2D ultrasound images. The sensor-based tracking unit is lightweight, can be attached easily to an ultrasound probe, and transmits real-time 2D ultrasound images and information about transducer movement to the Piur Imaging system computerized database, which stores this information. The ultrasound acquisition is separate from the image analysis, which would not impinge on patient throughput in a busy vascular laboratory. The enhanced understanding of spatial relationships between varicose veins and surrounding tissues can ultimately provide patient-tailored treatment leading to more successful and individualized venous ablation and improvement in symptoms. Apart from examining varicose veins of the lower limb, this 3D technique may play a role in identifying venous communications between pelvic venous disease and lower extremity venous insufficiency. This novel technique of 3D tomographic ultrasound imaging may have a particular niche in specialist vascular centers, and it is anticipated that with, frequent use and familiarity, more compelling examples of its impact on patient care can be collected.

The use of 2D and 3D ultrasound on vascular patients has local IRB approval (IRB reference number 2020-0737). All our patients gave written consent for their venous ultrasound images to be published.

DISCLOSURES

None.

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