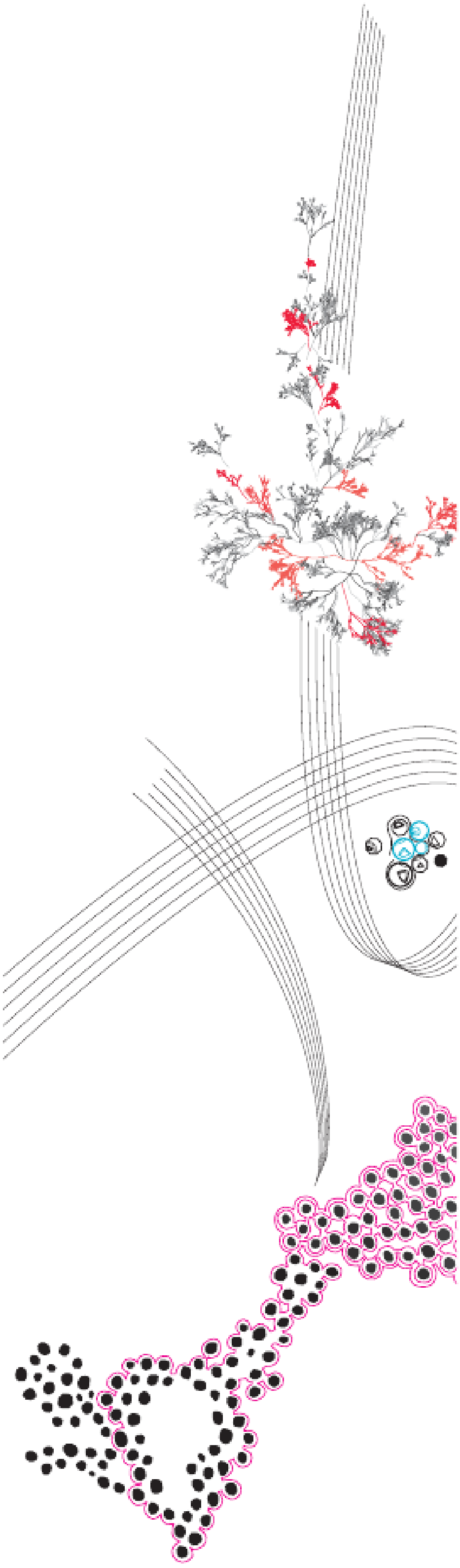

BSc Thesis Biomedical Technology

The effect of external compression on fainting incidents

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Abstract

Introductie: Het nadeel van de conventionele MRI is dat de processen waarbij informatie vanuit staande positie relevant is, niet geanalyseerd kunnen worden. Bij de kantelbare MRI kan er wel onder verschillende hoeken van het menselijk lichaam gemeten worden. Echter, doordat patiënten gedurende de scans stilstaan, kan het voorkomen dat er te weinig bloed vanuit de diepe aderen naar het hart terugstroomt met flauwvallen tot gevolg. Het flauwvallen zelf is niet per se schadelijk, maar de gevolgen van de val kunnen dat wel zijn. Vandaar dat er in dit onderzoek is gekeken naar een mogelijk oplossing voor een verbeterde veneuze stroming.

Methode: In dit onderzoek zijn er twee verschillende meetmethodes gebruikt om de oppervlakte en het debiet van de diepe aderen te bepalen. Aangezien debietmetingen niet op de kantelbare MRI kunnen worden uitgevoerd, is hiervoor de Siemens Area 1.5T scanner gebruikt. Er is in totaal op twee proefpersonen gescand waarbij metingen zijn uitgevoerd in zowel liggende als staande positie en zowel met als zonder toepassing van 40 mmHg externe druk.

Resultaten: Bij debiet- en snelheidsmetingen op de Siemens scanner, is in alle gevallen duidelijk zichtbaar dat deze grotere waardes kregen bij compressie. Uit het onderzoek is daarnaast gebleken dat een staande positie de oppervlakte van de femorale ader doet verwijden tot maximaal driemaal de grote van de dwarsdoorsnede in liggende positie. Echter, wanneer met en zonder compressie vergeleken wordt, zijn de metingen minder consistent.

Discussie: Doordat er is aangetoond dat in alle gevallen het debiet en de snelheid van het bloed toeneemt en in een deel van de metingen de dwarsdoorsnede afneemt. Duidt een combinatie van resultaten van beide scanners erop, dat er zich minder bloed in de benen zal ophopen wanneer een persoon met aanbrengen van compressie wordt gescand. In relatie met flauwvallen betekent dit dat de bloedsomloop verbetert waardoor de kans dat personen flauwvallen afneemt.

Keywords: weight-bearing MRI; calf compression; cross sectional area; blood flow; femoral vein

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Introduction

Magnetic Resonance Imaging is one of the many techniques for mapping (parts of) the human body. It is based on the principles of NMR, nuclear magnetic resonance, a technique used to obtain chemical and physical information about the structure of certain objects. During image acquisition of such objects, multiple radiofrequency (RF)(1) pulses are emitted and absorbed by the object. Due to the fact that it only operates in the RF range, it does not use harmful ionizing radiation like X-ray and computer tomography for example do. Another advantage of MRI is its excellent soft-tissue contrast(2), therefore the use of MRI is very suitable for scans related to the venous system which is interesting for this research.

Types of MRI

Various MRI machines can be used to image this venous system. These different types all have advantages and disadvantages. For example, the open MRIs are more suitable for patients with obesity or claustrophobic fears, while the closed systems are usually more useful where accurate diagnosis is needed. This closed scanner, with a field strength of 1.5T, is therefore most commonly used in the clinic(3). This magnet has a better resolution than the lower field strength magnets, but it also has drawbacks. This is for example developing claustrophobic fears by the patient and not being able to analyze physiological processes in which gravity plays a role.

For the claustrophobic fears, solutions such as closing eyes, paying attention to breathing, listening to music or ultimately medication can be a solution. However, processes that depend on gravity remain a problem. Consider for example the effect gravity has on venous return and pressures. In order to be able to make scans where standing information is relevant, a special MRI scanner has been designed: the weight-bearing MRI.

An example of a weight-bearing MRI scanner, the Esaote G-Scan Brio 0.25T, is visualized in Figure 1. When patients take place in this scanner, the table can be rotated to different positions with respect to the ground.

Although weight-bearing MRI has features that are not typically present in traditional magnetic resonance imaging, the device also has its drawbacks which will be explained in the next chapter.

Figure 1: Weight-bearing MRI: Esaote G-Scan Brio 0.25T (20)

Upright imaging

While adjusting the position of patients, gravity can have other (stronger) effects on the body in those angles. One of these (adverse) effects is on the circulation of the blood, because the blood has to flow almost vertically from the bottom of the toes towards the heart. Normally this is not an issue, as the body has a natural mechanism to keep the blood flowing even in upright position. The so-called "Lower extremity vein pump system"(4) reduces distal venous pressure at upright or seated position. This system consists of 3 parts, namely:

- the muscle pumps
- the distal calf ("piston") pump
- the foot pump

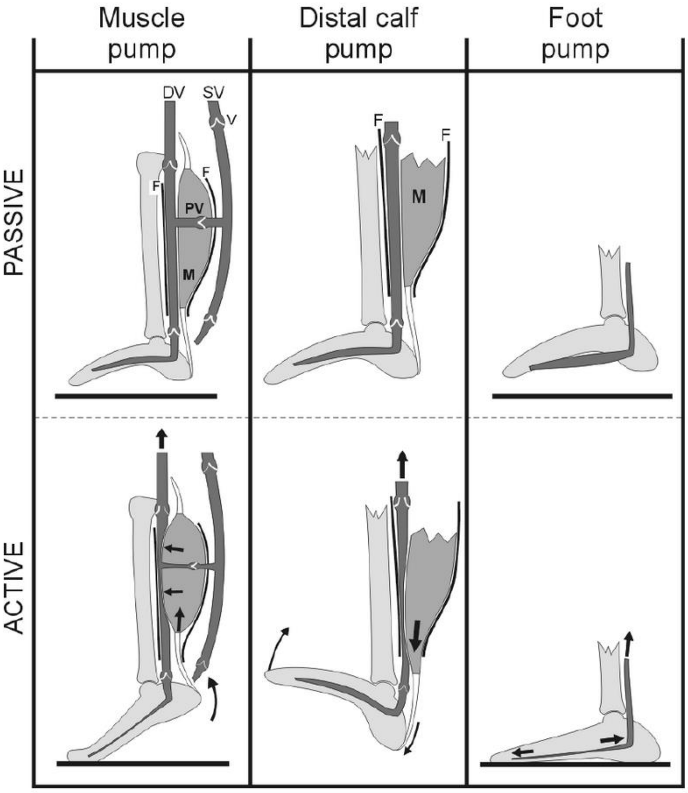

Figure 2: Visualization of the lower extremity vein pump system(4)

The muscle pump, the most left column of Figure 2, consists of muscles (M) sheathed by a common fascia (F) and veins. During relaxation, blood flows from the superficial veins (SV) into the deep veins (DV) in combination with arterial inflow. Then, during contraction of the calf muscles, for example when people walk, the pressure in the veins increases and the blood will flow from this high pressure to the lower pressure in the popliteal vein, which is located posterior of the knee joint(5). Due to the valves in the veins, as discussed earlier, the blood won’t flow back and the cycle will start again. The third column of Figure 2, the foot pump is visualized. The plantar veins in the foot are connected like a bow-string, during weight-bearing this bow-string is flattened and therefore veins are stretched, which leads to the ejection of their blood content.

The only problem with this natural mechanism is the fact that it only reduces distal venous pressure when the muscles are activated. While during the upright imaging, patients have to stand still so none of the leg muscles are active. This in combination with the aforementioned gravity that the blood has to overcome, can lead to fainting. Simply put, patients get too little return of blood to the heart and the cardiac output is therefore reduced, resulting in reduced blood flow to the brain(6). This fainting is not harmful in itself, but if patients fall the consequences can be severe.

Compression stockings

Thus, to prevent patients from fainting during weight-bearing MRI, the flow of blood to the heart must be promoted. Hansen et al. (7) used a pneumatic compression system, see Figure 3, which was originally made to prevent deep vein thrombosis (DVP). This device applies periodically external pneumatic pressure to the legs which increases the blood velocity in the deep veins. They set an inflation time of 12 seconds and deflation time of 48 seconds and a maximum pressure at 55 mmHg. They showed that 16 out of 86 patients fainted (19%) as a control group, i.e. without any medical aids. In this, fainting may mean losing consciousness completely or causing a patient to become light-headed or dizzy. In the experimental group, who were wearing a pneumatic compression device, only 1 out of 63 patients (2%) fainted. In addition, they found that the patients who had fainted were eight females and nine males with an average age of 39.6 ± 11.2 years and that 76% of those people fainted between 7 and 13 minutes.

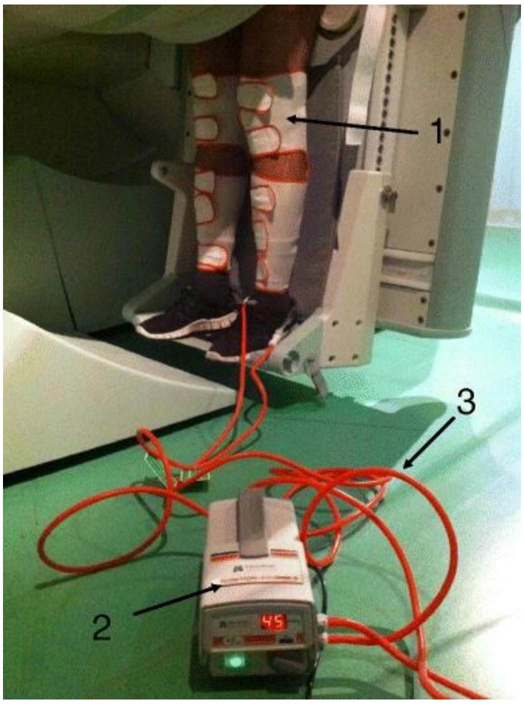

Figure 3: Compression cuff around the legs (1) connected to pneumatic compression system (2) via extension tubes (3) by Hansen et al. (7)

Another option is the use of a constant compression stocking, which as the name suggest, delivers a constant pressure to the leg. Due to this constant pressure the veins inside the leg must have smaller cross sectional areas and therefore the blood flow has to increase which is necessary to prevent fainting. To make sure the blood flow is in the right direction, the compression stocking is tighter around the ankle of the patient than around the knee, because of this difference there will be a pressure gradient and blood will flow from the high pressure side (ankle) upwards to the low pressure side (knee). This tightness is also directly the problem that comes with this solution, because applying these tight compression stockings is not easy, especially for people with strong legs.

Lyons et al. (8) made use of a compression stocking with a compression at the ankle between 25.2-33.3 mmHg and with a compression at the knee of 70 percent of that at the ankle. In addition to using this compression stocking, they also used a neuromuscular electrical stimulator. This device constantly delivers electrical pulses via electrodes to the muscles in the leg. Those pulses stimulate the muscles and therefore create an artificial control of the leg muscles and walking. They found that a combination of this compression stocking with a neuromuscular electrical stimulation device led to a maximum 538% increase of the peak venous flow.

Objective

Although all of the options discussed earlier seem to have a positive impact on the probability of fainting, there has not been looked at both vein cross sectional area and vein flow, which are important parameters for fainting. In addition, there has not been looked at time-efficiency of the possible solutions, while keeping in mind that MRI is an expensive method to use. Hansen et al. found a decrease in the number of patients who fainted but also included patients in the results who they themselves perceived to be near fainting. This means that the researchers did not measure physiological parameters before drawing conclusions, which can be more accurate. In contrast, Lyons et al. looked at a one physiological parameter which contributes to fainting, but this was only the maximum vein velocity. Therefore, no conclusion can be drawn for the minimum vein velocities while it is precisely these low velocities that cause problems. They also did not use MRI to map the fainting, but instead they used Ultrasound. Which applicability to especially the smaller deep veins in the leg is worse, due to the presence of bones, muscles and soft-tissues which affect the quality of US signals(9). And perhaps most importantly: all solutions that have been found, are not easy to apply to the patient and therefore often cost extra (expensive) time before scanning can take place.

The aim of this research is therefore to analyze how calf compression affects the physiological of the blood flow in relation with fainting. For achieving this goal, multiple sub questions have to be answered, namely:

- How are vein cross sectional areas affected by application of calf compression?
- How does the vein cross sectional areas differ under supine and upright imaging?
- How is the blood velocity affected by application of calf compression in supine position?
- How is the blood flow affected by application of calf compression in supine position?

Hypothesis

Based on what is now known in the literature, it is expected that external pressure exerted on the leg causes a smaller cross sectional area of the blood vessel and therefore a greater flow and speed, which relates to a decrease on the number of fainting incidents.

Methods and Materials

For this examination, the veins in the leg are looked at. To be specific: the deep veins(10), as the blood flows from the superficial veins through the perforating veins to the deep veins and then flows back to the heart. Thus, it is precisely the blood flow in these deep veins that will be resisted the most by gravity and by the non-contraction of the leg muscles.

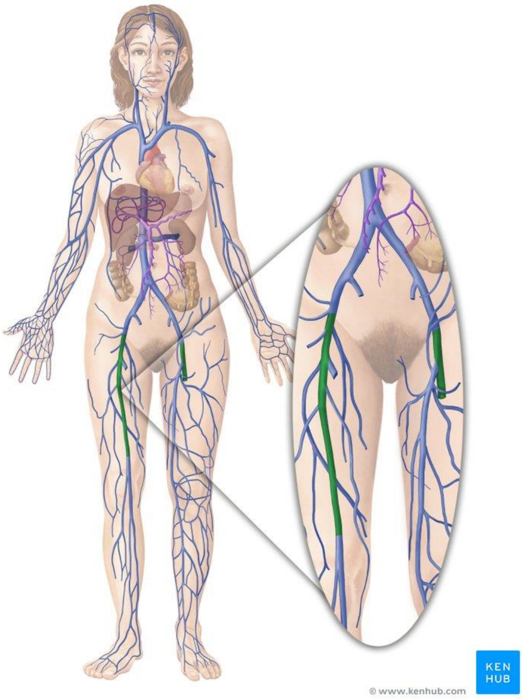

Figure 4: Location of the femoral vein (FV) in the human body(21)

In order to determine which deep vein has to be examined, the application region of the compression was considered. Because the calf compressor, as the name suggests, simulates calf compression. This is both the (superficial) femoral vein, see Figure 4 & 5, and the popliteal vein(11). The superficial femoral vein or subsartorial vein is clinically seen a deep vein, although the term suggests it is a superficial vein(12).

To make a good choice of the blood vessel to be imaged, the location where the structure of the blood vessel can be clearly distinguished from the rest of the tissue for both the sagittal and transverse planes was examined. This appeared to be the femoral vein which is located proximal to the knee joint and is a continuation of the popliteal vein (13). In addition, it is important that the blood vessel runs reasonably vertically so that there are few bi- and trifurcations and that the slice thickness can be increased for a better signal-to-noise ratio (SNR).

As indicated earlier in the introduction, the aim of this study is to measure both the flow in the blood vessel and the cross sectional area. It is therefore important to be able to compare information from both parameters and to know their relationship. In equation 1 this relationship is given.

$$Q = v * A \tag{1}$$

Where Q is the flow rate of the blood, i.e. the volume of blood that moves per time unit [mL/s]. v is the blood velocity, i.e. the distance the blood moves per unit of time [cm/s]. A is the cross-sectional area of the blood vessel [cm^2].

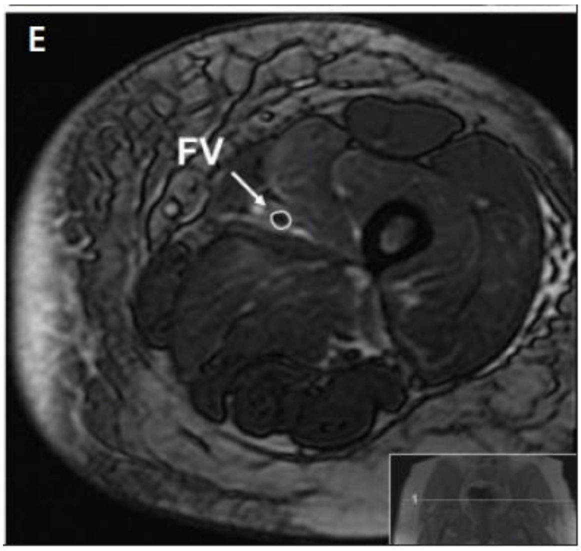

Figure 5: MRI scan with the femoral vein (FV) visible(22)

Protocol

A protocol was then set up in which the experiments were divided into 2 groups: one for blood flow and the other for vessel cross sectional area acquisition both performed in the right upper leg. The measurements for cross sectional area were performed on the Esaote 0.25T scanner (G-scan Brio, Esaote SpA, Genoa, Italy) with a multi-channel spine coil, as this scanner allows data acquisition under different angles of the body. Unfortunately this scanner does not allow quantitative blood flow measurements, therefore also the Siemens 1.5T MRI scanner (Magnetom Aera, Siemens Healthineers, Germany) was used. On both of the scanners, the femoral vein in the right upper leg was examined. In the next sections the different experiments will be discussed in detail.

There were two subjects scanned with inclusion criterion that they should be healthy, for example no varicose veins and that they are not at risk to MRI according to the MRI safety checklist. Since the purpose of this study was not to cause subjects to faint, the experiments were stopped at any indication of near-fainting (e.g. dizziness, nausea and sweaty palms).

Measurement 1: Cross sectional area

For determining the vessel cross sectional area there were transverse scans made at one height of the leg with the Esaote 0.25T MRI. The measurements were done at the mid-thigh where the femoral vein is well visible. If the scans were exactly placed on a bi- or trifurcation, the ROI was a bit shifted proximal or distal.

The experiment started with a five minutes sitting to correct for the influence of walking on blood flow and to accommodate them to the temperature in the room. After this break they were scanned in upright position, 81 degrees to minimize motion artefacts(14). This scan took about one minute and was performed with application of the Arjo Huntleigh Flowtron DVT garment, which was applied in the preceding pause, without any further applications. After this measurement, the table was turned to horizontal position, 0 degrees, to take the second measurement with calf compression. This Flowtron DVT garment was set at a pressure

Figure 6: Flowtron DVT garment with hand pump

of 40 mmHg(15) for all scans with the use of a hand pump and was placed as can be seen in Figure 6. In contrast to the Arjo Huntleigh Flowtron ACS900 device, which inflates and releases periodically, in this research only a constant pressure of 40 mmHg on the leg was considered which corresponds to that of the Flowtron ACS900.

After the few minutes it took to remove the Flowtron DVT garment and prepare the subject for the next measurements, a scan in supine position first, followed by upright position was performed. Those measurements were done without any further applications.

For the scans in upright position, the subjects were scanned with their shoes on to increase comfort. In addition, the subjects were also attached with a strap around their chests, so that they were better secured when tilting.

Various sequences were used for the data acquisition, from which a gradient echo was ultimately chosen. The other sequences had too little signal to determine the surface of the blood vessel accurately or even at all. This will be explained further in the next sections. The parameters corresponding to the different sequences, can be found in Table 1.

Table 1: Used sequences for data acquisition

	Gradient Echo	STIR	FSE-T2	XBONE	2D HYCE
Repetition time(ms)	90	1660	3810	500	10
Echo time (ms)	10	25	100	28	5
Slice thickness (mm)	4	4	4	5	5
FOV (mm)	260 * 260	210 * 210	200 * 200	180 * 180	200 * 200
Image size	256 * 256	512 * 512	512 * 512	512 * 512	512 * 512
Flip angle (degrees)	75	90	90	90	80
Acquisition type	2D	2D	2D	2D	2D

Measurement 2: Blood flow

The Siemens Magnetom Area 1.5T MRI scanner was used for the examination of blood flow in the femoral vein, in combination with a suitable coil (body 18 coil) to collect the signal. For this analysis the subjects were studied only in supine position with their feet first positioned in the scanner. The subjects were examined in rest with and without the application of the Arjo Huntleigh Flowtron DVT garment at a pressure of 40 mmHg. Before the first measurement, the sitting break was again applied to let the blood flow restore. In addition, there was scanned at the same height of the scans performed on the Esaote 0.25T scanner (at the mid-thigh), which is approximately 15 cm proximal of the knee joint.

A technique called "phase-contrast imaging" was used for the quantification of the blood flow. This is a simple and non-invasive method to use, based on the principle that magnetic field gradients introduce a phase shift in the MRI signal arising from the flowing spins that is proportional to blood flow velocity(16). Therefore construction of velocity maps is possible which in turn can be used to calculate the volume of the flow due to integrating the velocity over the surface of the vessel.

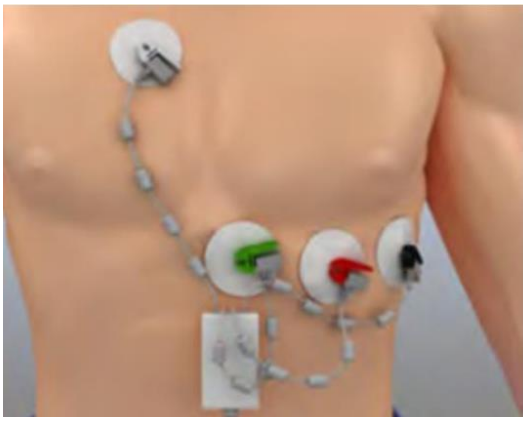

Figure 7: ECG electrodes positioning (23)

A quantitative flow analysis with the following parameters was used: repetition time of 63 ms, echo time of 5.7 ms, flip angle of 20 degrees, field of view of 340 * 233.75 mm, slice thickness of 6.00 mm and an acquisition matrix of 192 × 119. Furthermore, there were 15 heart phases recorded.

Since almost no information could be found in the literature about the velocity encoding parameter corresponding to the femoral vein, it was decided to perform a VENC scout. This showed that a VENC of 10 cm/s was the most suitable for making the scans.

The scanner was equipped with a vector ECG system for triggering acquisition of the images. The location for applying the ECG electrodes can be found in Figure 7.

From the phase-contrast flow volume images and the magnitude data, the volume of flow (in milliliters per minute) was calculated for each time frame by integrating the velocity data over a region of interest exactly containing the entire vessel lumen.

Analysis

After the experiments had been performed, the obtained scans were analyzed. For analysis, the trial period of 30 days from Inobitec Dicom Viewer Pro 2.7.0. was used(17). With the help of this program the cross sectional area of the femoral vein in the different scans, was determined by drawing a polygon along the edges of the ROI. After finishing the last dot of the polygon, the program calculated the cross sectional area. Since the ROI had to be drawn manually on the scans, an average of values measured by 3 different people was taken to minimize a potential bias. Although the screen used had a higher resolution, the accuracy of the measurement is limited by the 1 mm pixel size from the acquisition.

In addition, the software has an function for determining flow that can be used for the analysis of measurement 2. To do this, both suitable magnitude MRI (MAG MRI) series and the respective phase-contrast MRI (PC MRI) series must be opened in the flat image viewer window. Then "Flow Analysis" can be selected, which opens a screen with parameters. The VENC value and the number of beats per minute must be entered here. In addition, you can optionally enter how many blood vessels (maximum) should be automatically detected. When these choices have been made, you can press "OK" to determine the graphs.

By comparing these cross sectional areas in the different situations (supine/upright and with/without compression), conclusions can be drawn with regard to the sub questions. The combination of results from both scanners will ultimately enable that conclusions can be drawn about the sub-questions.

Results

After running the protocol on both scanners, data was collected on the cross sectional area of the vessel as well as the flow. In this chapter, results of both scanners will be discussed divided into the headings of "Cross sectional area" and "Blood flow".

Cross sectional area

After applying the external compression, a noticeable difference can be observed directly on the scans. This can be seen from the transverse section of the whole upper leg, as well as the blood vessel of interest. Figure 8 shows two scans, one with compression and one scan without, both in supine position. Due to the pressure of the MRI table where the subject is laying on, it is easy to see that the leg is flattening on the dorsal side. However, when calf compression is applied, it is visible that the leg is again in a more round shape. The same phenomenon is visible for the femoral vein (red arrow), that without application of external compression it is flatter. However, with an application of 40 mmHg pressure, the blood vessel becomes rounder again. In addition, closely looked, a difference in the shape of a superficial blood vessel (blue arrow) can also be observed. The external pressure has more effect on this, because the distance between the blood vessel and the surface of the skin, where the pressure is applied, is smaller.

Another important observation that must be made is the difference between upright and supine position. This remarkable difference is both discernible in the situation where calf compression is applied as without external pressure. In Figure 9, two scans are visible, both without external pressure. What is striking is that the femoral vein in a standing position is much rounder/larger than in a lying position, which means that it contains more blood.

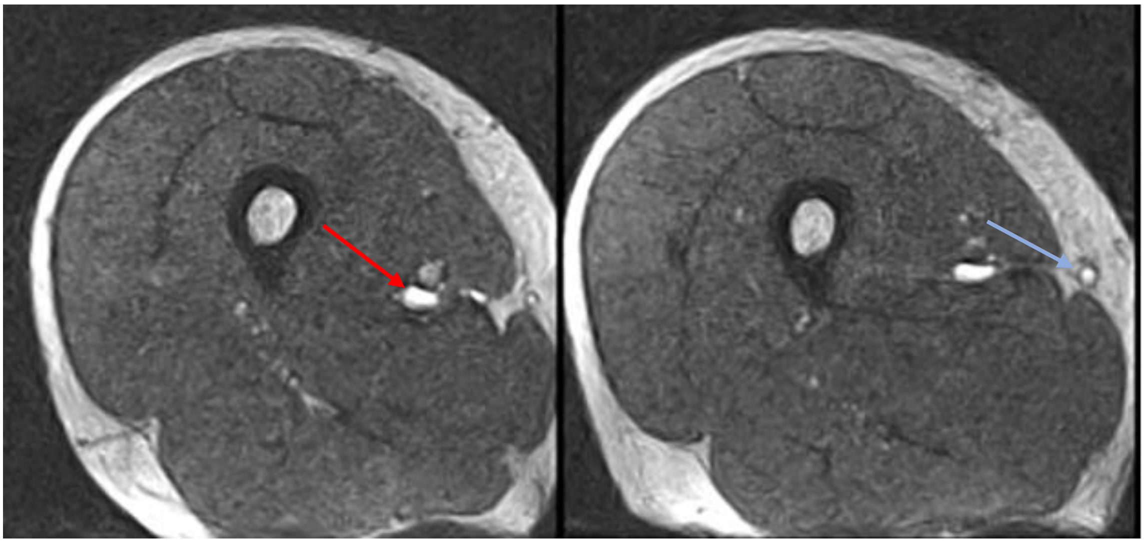

Figure 8: Transversal scan of the upper leg in supine position with compression (left) and without compression (right), subject 1

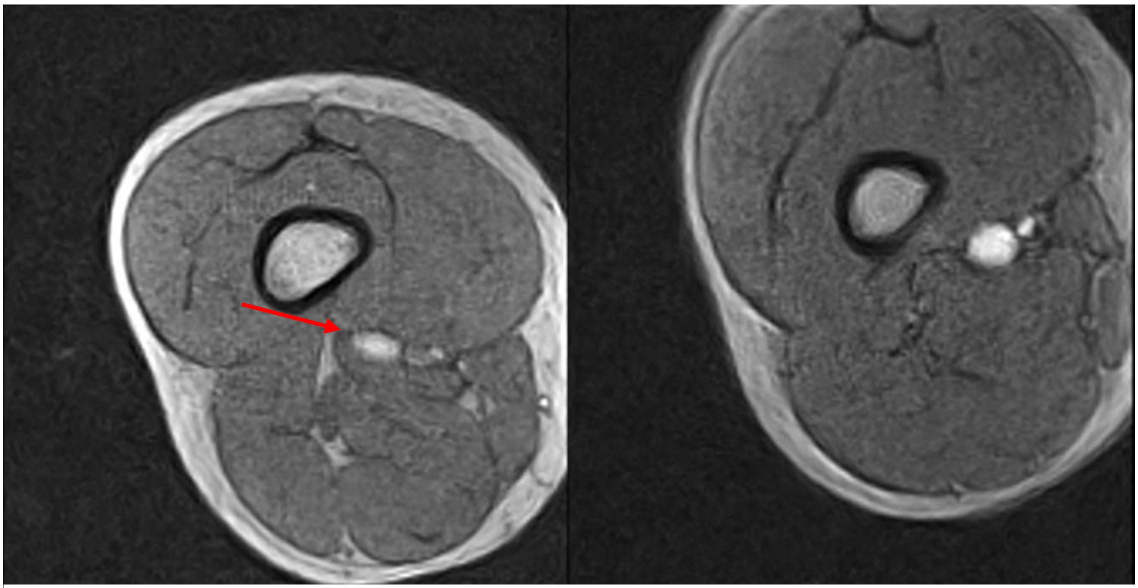

Figure 9: Transversal scan of the upper leg without compression in supine position (left) and upright position (right), subject 2

Also after data analysis of the scans, it appears that the femoral vein in upright position has a considerably larger cross sectional area compared to the supine position. This ratio, as shown in the Table below, ranges from 1.7 to 3.0. However, in all cases the ratio is greater than 1 which means that the cross sectional area in upright position is in all measurements greater than those in the supine position.

The differences between the vein cross sectional area at 0 mmHg and at 40 mmHg is less consistent. If compression and no compression are compared, the ratio varies between 0.8 to 1.5. This means that in some cases no compression results in a larger cross sectional area. While in other cases a larger cross sectional area has been observed with 40 mmHg compression. Table 2 shows that in half of the cases the ratio (no compression: 40 mmHg) is greater than 1, in a quarter of the cases it is equal to 1 and in a quarter of the cases it is less than 1.

Table 2: Cross sectional areas (mm^2) of femoral vein under different circumstances.

Subject		Supine (0 degrees)	Upright (81 degrees)	**Ratio (upright : supine)**
1	Without compression	45 ± 8	137 ± 2	**3.0**
	40 mmHg calf compression	61 ± 1	119 ± 4	**2.0**
	Ratio (no compression: 40 mmHg)	**0.74**	**1.15**	
2	Without compression	104 ± 10	174 ± 6	**1.7**
	40 mmHg calf compression	70 ± 1	169 ± 2	**2.4**
	Ratio (no compression: 40 mmHg)	**1.49**	**1.03**	

In addition to the above results obtained with the Gradient Echo of Table 1, there are also results obtained with the other sequences of Table 1. In Figure 10 the XBONE and 2D HYCE scans are visible.

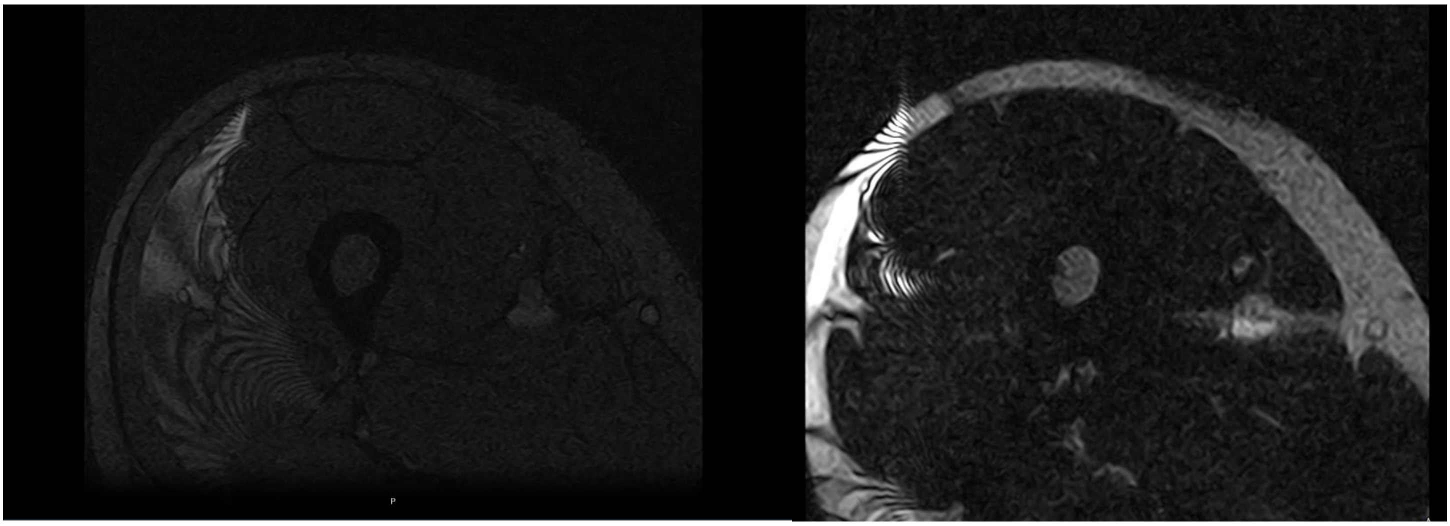

Figure 10: Transversal image upper leg with XBONE (left) and 2D HYCE (right) sequence from Table 1

What has to be remarked is that aliasing is present on both scans and that the structures of the upper leg are difficult to recognize, especially at the 2D HYCE image.

Unfortunately, the FSE-T2 and the STIR sequences gave an even worse SNR, as can be seen in Figure 11. Only the femur can be recognized in these scans. Possible explanations for this and a comparison with the results from other studies, are discussed in the next section.

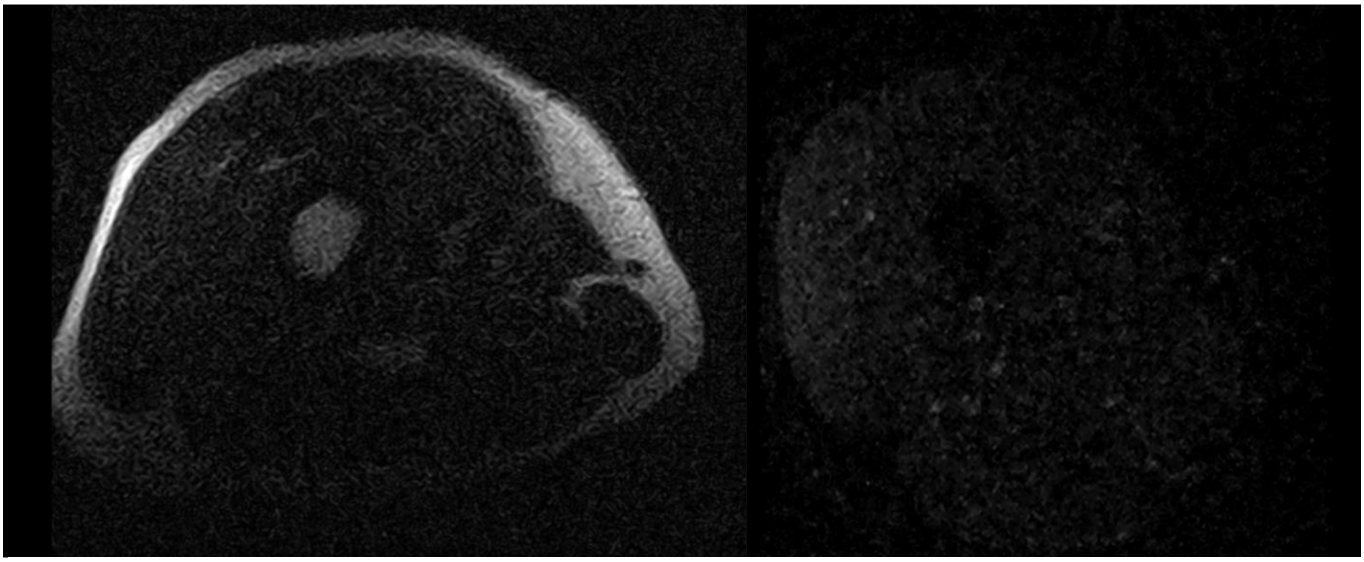

Figure 11: Transversal image upper leg with FSE-T2 (left) and STIR (right) sequence from Table 1

Blood flow

After performing the quantitative flow experiment, phase and magnitude scans were obtained, see Figure 12 for an example. From this single scan it is immediately apparent that the artery (red arrow), which is on the image to the right of the femoral vein (blue arrow), is creating a higher signal than the signal from the vein. This is also confirmed by the fact that an aliasing artifact (black dot) occurs in the artery, meaning that the velocity in the blood vessel exceeds the VENC value.

Several methods have been used to solve this problem. For example, a saturation slab in the proximal direction was used. Because arterial blood flows away from the heart and thus flows in a distal direction, it should be saturated before entering the ROI. In addition, a saturation slab between the vein and artery was used too, however, as can be seen in Figure 13, the femoral vein was as well partially saturated there. The last option that was tried, was a low VENC of only 5 to 8 cm/s, but this disrupted the ECG signal so that triggered recording was no longer possible.

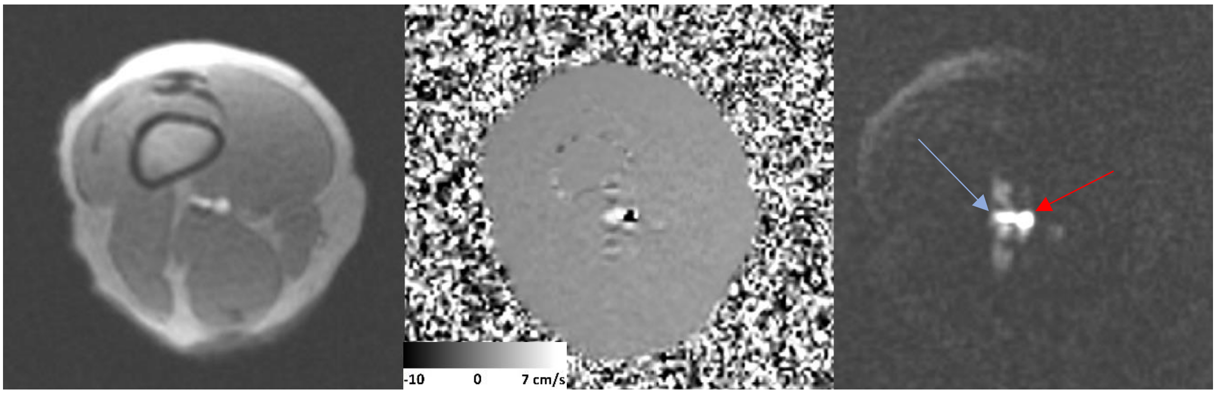

Figure 12: Quantitative flow data from subject 2 with calf compression including magnitude and phase scans, the red arrow indicates the femoral artery

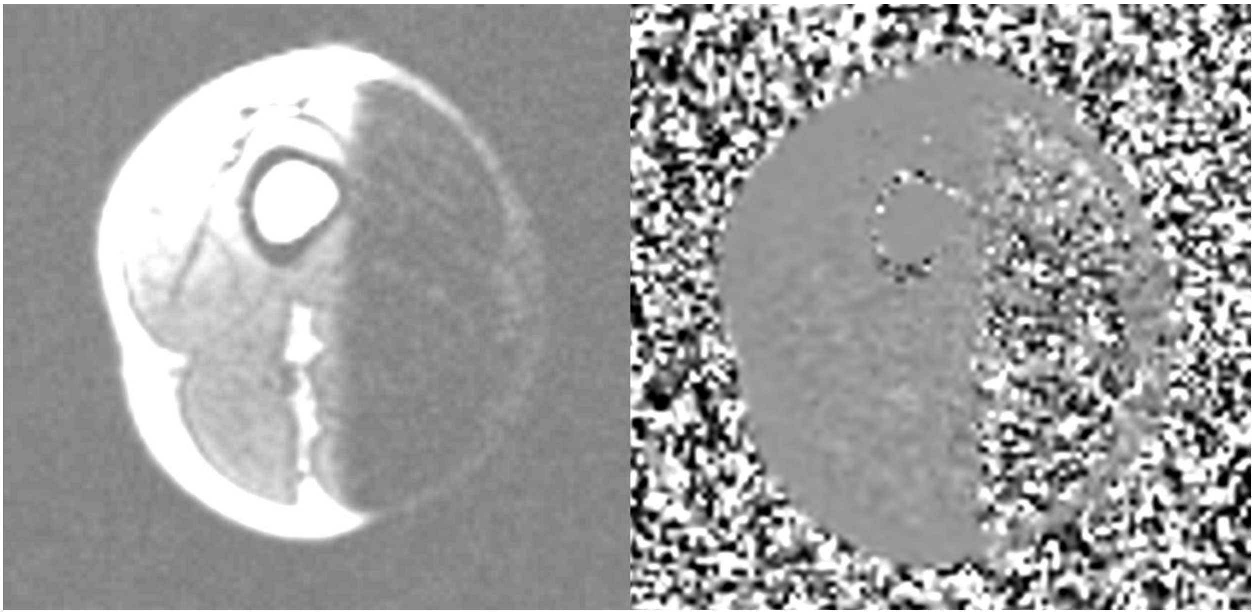

Figure 13: Quantitative flow data from subject 1 without compression including saturation slab

Using the software of Inobitec DICOM Viewer Professional, magnitude and phase scans were used to obtain information about blood flow and blood velocity of both subjects' femoral vein. An example graph can be found in Figure 14, where on the y-axis the velocity is displayed and on the x-axis the time. It is noticeable that at the beginning of the series, when the pressure is increased rapidly to 40 mmHg, the speed increases considerably, while precisely at later times the maximum speed decreases rapidly. In addition, it is visible in the results that veins have a very irregular pattern in blood flow.

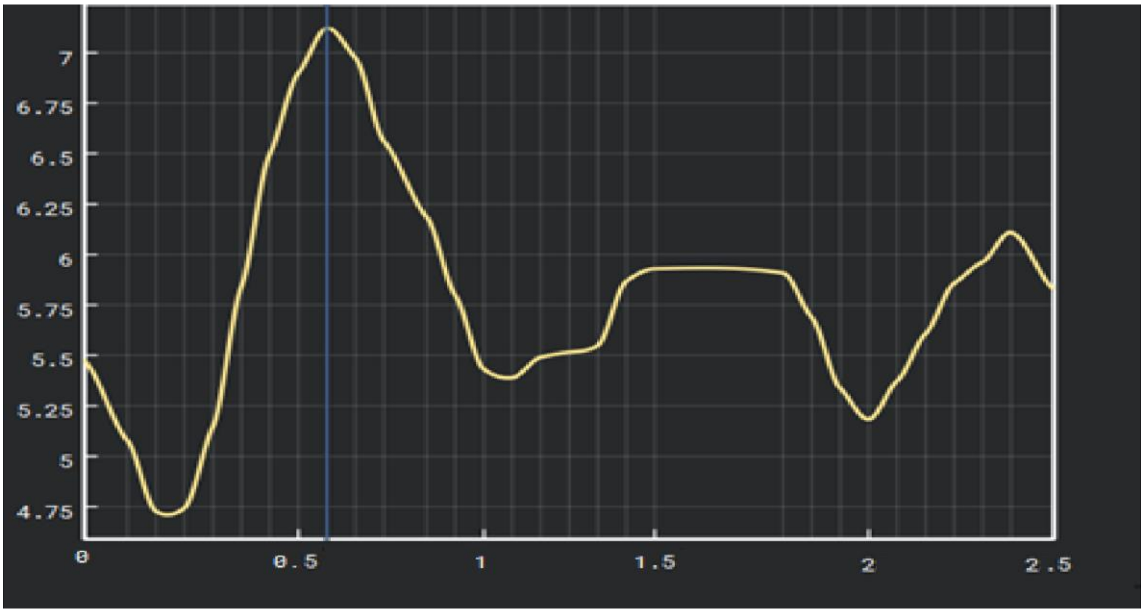

Figure 14: Example graph of subject 2 with calf compression with on the y-axis the blood velocity (cm/s) and on the x-axis the time (s)

After all scans on the Siemens Area 1.5T were analyzed, the obtained values for blood velocity and flow are plotted in Table 3. During the scanning, it was immediately apparent that subject 2 had much more signal coming from the femoral vein than subject 1. This was subsequently confirmed by the obtained values: in both of the measurements (with and without compression) subject 2 has higher values for both parameters than subject 1. It is also interesting to see that both subjects, while applying compression of 40 mmHg, always have a higher value than without calf compression. In addition, an outlier is observable in subject 2. Where the maximum speed of the blood during calf compression is considerably greater compared to the rest of the results, while the flow does not increase to the same extent.

Table 3: Maximum velocity and flow of femoral vein under different circumstances.

Subject	Supine (0 degrees)	Max. velocity (cm/s)	Flow (mL/s)
1	Without compression	1.4	0.8
	40 mmHg calf compression	2.1	1.3
	Ratio (no compression: 40 mmHg)	**0.67**	**0.6**
2	Without compression	1.8	1.7
	40 mmHg calf compression	7.1	2.0
	Ratio (no compression: 40 mmHg)	**0.25**	**0.85**

Discussion

The goal of this research was to analyse how calf compression affects the physiological of the blood flow and how this relates with reducing the fainting incidents that are occurring during weight-bearing MRI. To answer this question, several sub questions were formulated and the cross sectional areas of the femoral vein in the thigh were examined. The change in cross sectional area, in combination with blood flow data from the Siemens Aera 1.5T, has yielded several insights that will be discussed in the following sections.

Cross sectional area

It can clearly be concluded from Table 2 that a subject in an upright position has a larger cross sectional area of the femoral vein than a subject in the supine position. The ratios measured between supine and upright range from 1.7 to 3.0. This means that in the extreme case, the blood vessel in upright position had a cross sectional area of $137.38 \pm 2.42\ mm^2$ which is three times the cross sectional area compared to the same measurement in supine position with a cross sectional area of $45.38 \pm 8.44\ mm^2$.

In addition to the ratio between the different positions of the human body in the scanner, Table 2 also shows the relationship between applying calf compression or not. In this case it is not really possible to conclude anything about the relationship between no pressure and 40 mmHg as only four measurements have been made, one of which claims the opposite and in another measurement the two situations are equal. Therefore the hypothesis in which it was expected that a higher external pressure will lead to a reduction in the cross sectional area of the blood vessel, could not be confirmed at this moment.

The last point to mention is the striking value of the cross sectional area in subject 1, where in supine position the exerted pressure on the leg leads to an increase in cross sectional area. Because venous flow is much less constant than arterial flow, this deviation can be explained by, for example, movement. Performing this measurement several times will show whether the cross sectional area without compression is really smaller than with compression.

Protocol improvement

There is room for improvement for the measurements taken to determine the different cross sectional areas. First of all, more subjects and different deep veins will have to be scanned so that deviations between individuals are averaged out. In addition, in order to demonstrate significance, a METC approval is required to scan the amount of people needed.

Perhaps the most important point of attention is the use of suitable receiving coils. During this research, a multi-channel spine coil was used on the Esaote 0.25T. The advantage that the coil had was that the entire upper leg fitted in it, even with the other leg still there. However, this resulted in the received signal being much weaker than when a coil for the thigh only was used. Because the distance between the ROI and the receiving coil is increased, this causes the SNR to decrease. To overcome this problem, attempts were made to apply the Dual phased array (DPA) knee coil. Unfortunately, the thighs of both subjects were too large for this. In Figure 15, transversal images of the deep veins in the lower leg with the same sequences used in this study can be found, where the difference between both coils can be seen clearly and the importance of a suitable receiving coil for data acquisition is shown.

When the study is repeated, subjects with narrow thighs or a DPA cervical spine coil should be considered at in which the other leg can still be placed next to this receiving coil. The use of flex coils is not recommended, as image quality is reduced with those.

In addition, to give subjects a more comfortable position for the scans taken in supine position, a supporting pillow under the knees that will be elevated approximately 15 cm from the horizontal table of the scanner could be used(18). As a result, they could lay as still as possible and the quality of the scans could improve. The pillows may exert light pressure on the blood vessels around the knee, but it is not expected that this affects the cross sectional area of the blood vessels proximal being analyzed.

Finally, subjects had five minutes sitting break only before the measurements started to allow their blood circulation to restore and to get used to the temperature of the room for this study. However, the results will be more reliable if a five minutes pause is inserted after each measurement to reset the blood flow. To further increase reliability, marking points will have to be applied. For example, a fish oil pill (with a high signal) can be attached to the leg at the height in which one is interested. By then looking on the scan where this pill is largest, each scan can be taken at exactly the same height, unlike this study where the surrounding tissue was looked at to obtain approximately the same height.

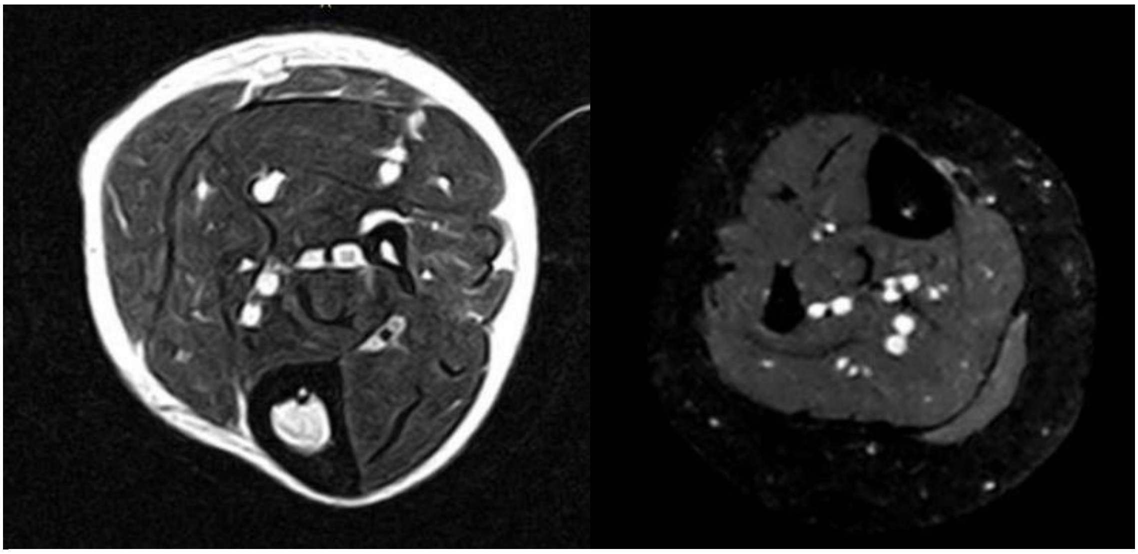

Figure 15: Transversal image lower leg with FSE-T2 (left) and STIR (right) sequence from Table 1 with use of knee coil (24)

Blood velocity

Table 3 shows that there is a relationship between flow/velocity and compression. As the pressure increases, an increase in both blood flow and velocity was observed in both subjects. This is at least a factor of 1.5 for the blood velocity and a factor of 1.6 for the flow. This is in line with the hypothesis that applying external pressure would cause a reduction in cross sectional area and thus an increase in velocity and flow. However, in subject 2 the maximum blood velocity has a deviating value. The velocity increases by a factor of 3.9 compared to no pressure, while the flow only increases by a factor of 1.2.

The relationship between blood flow, velocity and cross sectional area (see equation 1), makes it clear that a large increase in the velocity with a small increase in the flow indicates that the cross sectional area of the blood vessel must be small. This may be explained by the fact that venous flow does not depend directly on ventricular contraction, but rather on skeletal muscle action, respiratory movements, and constriction of smooth muscle in venous walls(19). It is therefore very irregular compared to arterial flow. Thus, it may be that a large amount of blood already passed this ROI before scanning and that at the time of recording only a small amount of blood was left which was displaced by the application of the pressure. Another possible solution is that the pressure, which was set manually, exceeded 40 mmHg and thereby greatly reduced the blood vessel in cross sectional area.

Protocol improvement

To improve the results of the blood flow measurements, the greatest improvement can be obtained by increasing the signal strength. To improve the SNR, the VENC could be lowered, but this disrupted the ECG signal, making triggered recordings no longer possible. In addition, the use of saturation slabs was tried, but this did not have the desired results because the veins are too close to each other. In order to get a better signal, for example contrast fluid could be used, which was not possible for this study.

Another important point is that the change in blood flow and velocity is now only measured in supine position. From this an assumption is made that the results will be comparable in upright position. However, this has not been proven in this study and a method will have to be devised to demonstrate this.

Further research

In addition to the improvements specific to the two types of measurements, there are also issues that still need to be answered in follow-up research.

First of all, as indicated in the method, the Arjo Huntleigh Flowtron ACS900 pneumatic compression device has not been used in this study. At the beginning of the study, an attempt was made to use this device as it has already been proven to be effective in patients with DVT. The device inflates to the same pressure as the hand pump was set to in this study, and then releases the pressure to inflate the other leg. However, due to the presence of a metal ring in the connection of the Flowtron DVT garment in combination with a sensor on the device, it could not be used within the magnetic field of the scanner. As a result, the device did not recognize the garment and therefore did not switch to inflating the garment. This was true for both the 1.5T Siemens scanner as the 0.25T scanner from Esaote. To avoid this problem, the air hoses of the Flowtron DVT garment should be extended or the connection should be bridged.

Another important consideration within MRI is time. Since one of the major drawbacks of MRI is the cost, it is important to look for solutions that are cost and time effective. Where sequences sometimes cannot be shortened or where the number of slices cannot be reduced, time can usually be saved on the issues involved in scanning. For patients who faint, this is for example the application of compression stockings or a pneumatic compression device. Compression stockings are often very tight and people with large thighs will hardly get them on. Fortunately, applying a Flowtron DVT garment is easier due to the Velcro, but here it too takes time to set up the device and connect the hoses. In order to reduce this, alternatives will have to be looked at. One possibility for this is to activate the venous pump, the same way as it functions in the human body. This can be done by having patients do heel raisings in a short period of time (40 raisings per minute) just before the examination, while the specialist is preparing the scan. Subsequently, these results should be compared with those of the Flowtron compression device to conclude whether the effect is the same.

Conclusion

The main question of this study was: "How calf compression affects the physiological of the blood flow and set this in relation with reducing the fainting incidents that are occurring during weight-bearing MRI ". From the results of the Esaote 0.25T scanner it could not be concluded that calf compression of 40 mmHg, does result in a reduction in femoral vein cross sectional area. However, the measurements on the Siemens scanner showed that the blood velocity and flow increased in all cases. Therefore, when the results of both scanners are combined, it can be carefully said that the venous return of the femoral vein improves with 40 mmHg external compression. This offers hopeful results for external pressure as a solution against patients who faint in weight-bearing MRI. However, broadening this study to the number of deep veins analyzed and the number of subjects studied, will have to prove this definitely.

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