Venodilation methods improving patient selection for arteriovenous fistula surgery: the quest to achieve gold standard in haemodialysis

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ABSTRACT

Autologous arteriovenous (AV) fistula is the gold standard for vascular access in haemodialysis. Vein suitability is determined by a patient's vein diameter and the vein's ability to dilate. This study aimed to determine which of the following was most efficient.

1) arm in a water bath,
2) Bair Hugger air jacket (providing patients with warm air),
3) handgrip exercise, was most efficient at dilating the cephalic vein, compared to venous tourniquet.

In this cross-over study 12 patients with chronic kidney disease had their vein diameter measured by ultrasound for each of the three venodilation techniques. Each venodilation technique was measured with and without tourniquet, and compared with control tourniquet. The water bath was the most efficient and effective method, causing 21 ± 15% ($p = 0.0010$) increase in vein diameter after 10 minutes and 34 ± 15% ($p < 0.0001$) after 40 minutes with 1 minute tourniquet. The Bair Hugger air jacket was comparable but significant dilation was only achieved after 40 minutes with 1 minute tourniquet, 26 ± 16% ($p < 0.0001$). These results suggest that use of a water bath for preoperative vein mapping may increase the number of patients eligible for AV fistula. Given that AV fistula has a lower rate of complications than other forms of vascular access in haemodialysis, use of the water bath may be beneficial.

INTRODUCTION

Autologous arteriovenous (AV) fistula, formed by connecting a vein to an artery, is the gold standard for achieving vascular access for haemodialysis of patients with kidney failure. It has low rates of complications including thrombosis and infection, allowing it to stay functional for longer.[1]

Adequate vein diameter is crucial for successful AV fistula formation. Patients with vein diameters of <2 mm are rarely considered for an AV fistula.[2] Evidence for this comes from a study by Mendes et al. which showed that in patients with a cephalic vein diameter of <2 mm a successful fistula maturation was achieved in only 16% of cases.[3] Lockhart et al. used a tourniquet in preoperative vein mapping in order to induce venodilation. They suggested the optimal diameter was >2.5 mm and showed that out of the patients who could reach this diameter after applying a tourniquet, 33% formed successful fistulae.[4] This was a similar success rate to those with adequate vein diameter before tourniquet. These studies suggest that vein diameter and its ability to dilate play an important role in successful AV fistula formation.

The protocol in the Vascular Laboratory Depatment of Surgery at Dunedin Hospital is to use a tourniquet to dilate the vein prior to assessment. There is some evidence however that techniques other than tourniquet may be more effective at venodilation. A study by van Bemmelen et al. looked at several potential interventions including gravity, heat, supine positions, and tourniquet. They showed that submersion of the arm in 44°C water for 2 minutes increased the diameter most effectively.[5]
Current research into the different ways of dilating veins is limited even though a successful intervention aiming to maximise venous diameter could help with preoperative vein mapping where a patient's suitability for fistula is assessed. If a more effective method of venodilation is found this could be added to the current practice, which would increase the proportion of patients getting AV fistulas and improve those patients' overall outcome. This study aimed to determine whether peripheral heat using 40°C water immersion, central heat via a Bair Hugger air jacket or handgrip exercise is most effective at dilating veins, in comparison to tourniquet as the current practice. A Bair Hugger air jacket is a temperature management unit which allows effective and safe warming of a patient's body using warm air. To our knowledge there have been no

previous studies looking at all three interventions against tourniquet. The rationale behind these techniques was that heat and exercise improves blood flow, and therefore, should dilate the vein, particularly when used in conjunction with venous tourniquet.

METHODS

Participants

Twelve patients with either stage 4 or stage 5 chronic kidney disease were recruited for the study through the Dialysis Unit of Dunedin Hospital, after gaining written consent. The participants were either pre-dialysis or currently receiving peritoneal dialysis. They came into the lab between November 4 and December 7, 2015 for vein diameter assessments on three separate days. The order of the three interventions over the three days was randomly assigned at the beginning of the study using a Latin Square Design. These interventions were

1) arm in a water bath,

2) Bair Hugger air jacket to provide central heating, and

3) handgrip exercise.

To standardise participants' status prior to each assessment, participants were instructed to be well-hydrated. Specifically, they were asked to drink at least one litre of fluid the day before each session and to avoid tea and coffee that morning. They were also tested at the same time of day for each of their three assessments to help reduce possible diurnal variation. Height and weight was measured at the beginning of the first visit, and information was gained on age, co-morbidities and medications. Hospital records were used to confirm any co-morbidities and to gain results of current creatinine and eGFR levels.

INTERVENTIONS

On arrival, the patient rested supine in a warm room (~22-24°C) for 15 minutes before the first baseline measurement, which measured vein diameter without tourniquet or interventions. A temperature data logger (Squirrel SQ2010, Grant Instruments, Cambridge, UK) recorded skin temperature over time using probes applied to the forearm and shoulder on the same side as the intervention to measure its effects, and ear on the opposite side of the intervention, for accessibility. The cephalic vein was measured in transverse section using a high-resolution ultrasound transducer (12 MHz), from inner wall to inner wall in the proximal, mid, and distal forearm. The locations were marked on the skin and recorded as a distance from the elbow crease, in case re-measurement was required, to ensure consistent measurements within subjects each time they were assessed. The sonographer was unable to be blinded from the interventions, however there was blinding of the analysis to minimize observer bias.

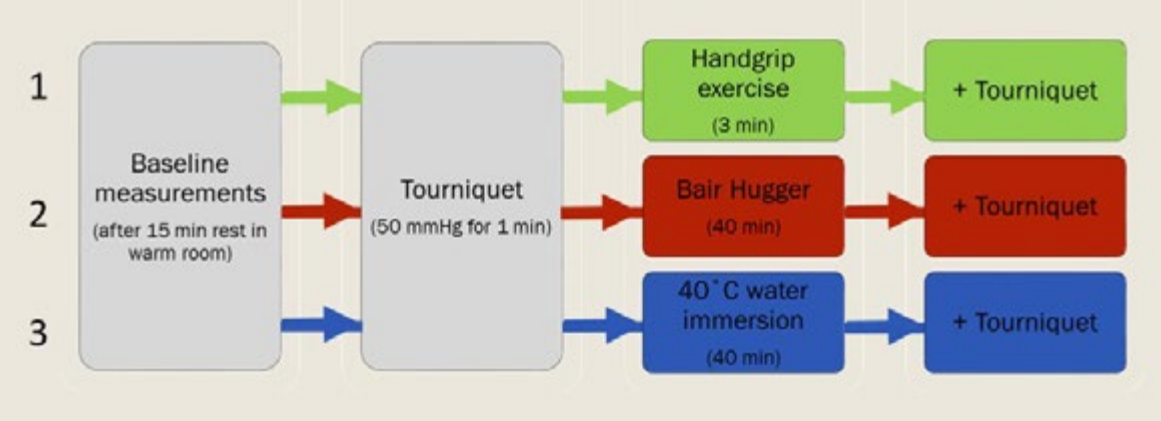

Figure 1. Study protocol for each of the three interventions, 1) arm in a water bath, 2) Bair Hugger air jacket, and 3) handgrip exercise

After doing baseline measurements, venous occlusion by tourniquet (standard protocol) was carried out as a control (Fig. 1). This involved inflating a blood pressure cuff around the upper arm to 50 mmHg for 1 minute prior to ultrasound measurement. Nelson et al. showed no difference in vein diameter when using BP cuff compared with tourniquet, and it is easier to be consistent between participants when using the BP cuff as 50 mmHg pressure can be maintained, which is why it was chosen.[6]

Next, one of the three interventions were conducted as follows. The water bath intervention consisted of placing the participants' forearm in a bath of 40°C water for 40 minutes, measuring vein diameter every 10 minutes while the arm was in the water. After this a tourniquet was applied for an additional minute with the arm remaining in the water, followed by a final measurement.

For the Bair Hugger air jacket intervention, the participants' body (including arms) was placed into a Bair Hugger air jacket. The participants wore the Bair Hugger air jacket for 40 minutes and with measurements every 10 minutes followed by 1 minute of using a tourniquet in conjunction with the Bair Hugger air jacket. The participants arm was removed from the Bair Hugger jacket for measurement (approximately 30 seconds).

In the handgrip intervention, the patients performed a handgrip exercise of continuous contractions for 3 minutes without tourniquet followed by another 3 minute hand grip exercise with tourniquet. Vein diameter was measured after both exercises.

Ethical approval was obtained by the University of Otago Human Ethics Committee for this research.

STATISTICAL ANALYSIS

The percentage increase in vein diameter was calculated from baseline for each measurement. Repeated measures two-way ANOVA was used to compare the three measurement sites and showed no statistical significance, so all measurement sites for each intervention was averaged. Repeated measures two-way ANOVA was used to compare the interventions and the dilation within each phase of the study (control tourniquet, intervention, and intervention with tourniquet), and a Sidak correction for controlling for multiple comparisons was used.[7] 3 minutes of handgrip exercise was compared to 40 minutes of Bair Hugger air jacket and water bath. Data were analysed using GraphPad Prism version 6.0 for Windows (GraphPad Software, La Jolla California USA). Data are given as mean ± 95% CI, unless otherwise stated.

To determine if the interventions were effective in the group with smaller vein diameters the subjects were also split into two groups for analysis: those with a distal cephalic vein diameter after tourniquet of <3 mm and those with >3 mm diameter. One participant was excluded due to only having a vein of <3 mm for 2 of the 3 days after the control tourniquet measurement. The two groups, those with <3 mm and >3 mm veins, were compared using two-way ANOVA.

RESULTS

Table 1 Demographic and clinical data.

Characteristic	< 3 mm group, n (%) or mean ± SD	> 3 mm group, n (%) or mean ± SD	Total, n (%) or mean ± SD
Total patients in analysis	4 (100)	8 (100)	12 (100)
Age (y)	61 ± 11	62 ± 11	62 ± 11
Gender			
Male	1 (25)	8 (100)	9 (75)
Female	3 (75)	-	3 (25)
BMI			
Normal <24.9 kg/m^2	3 (75)	3 (37.5)	6 (50)
Overweight 25-29.9 kg/m^2	0 (0)	2 (25)	3 (25)
Obese >30 kg/m^2	1 (25)	3 (37.5)	4 (33)
Co-morbidities			
Type II diabetes	1 (25)	3 (37.5)	4 (33)
Hypertension	4 (100)	8 (100)	12 (100)
Hyperlipidaemia	1 (25)	5 (71.4)	6 (50)
Cardiac problems	2 (50)	3 (37.5)	5 (42)
Peripheral vascular disease	1 (25)	1 (12.5)	2 (17)
Ex-tobacco use*	2 (50)	4 (50)	6 (50)
Chronic kidney disease			
Stage 4	-	2 (25)	2 (17)
Stage 5	4 (100)	6 (75)	10 (83)
Creatinine (umol/L)	438 ± 108	442 ± 132	440 ± 119
eGFR (mL/min/1.73m2 L)	10 ± 3	12 ± 4	11 ± 4

Abbreviations are: BMI, Body Mass Index; eGFR, estimated glomerular filtration rate

* no current smokers

In short, 12 participants (75% male, age mean ± SD: 62 ± 11 years) came into the vascular laboratory on three separate occasions to see the effect of hand exercise, water bath and Bair Hugger air jacket on participants' venous diameter. The majority of these participants (83%) had stage 5 CKD, while the rest had stage 4 (Table 1).

The effect of interventions on all participant's cephalic vein diameter.

A comparison of results of all three interventions and their effect on the vein diameter is represented in Figures 2, 3 and 4. Handgrip exercise was carried out for 3 minutes without tourniquet followed by 3 minutes with tourniquet, with vein diameters taken after each. After 3 minutes of handgrip exercise the vein diameter reduced 7 ± 21 % ($p = 0.93$) and increased with tourniquet by 13 ± 21 % ($p = 0.41$) compared with the control measurement, neither of which were statistically significant (Fig. 2).

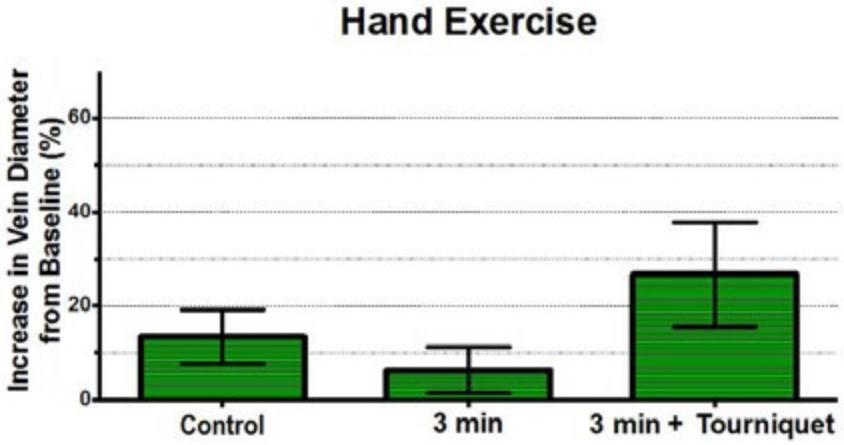

Figure 2. Average percentage increase in cephalic vein diameter in response to hand exercise. The error bars indicate the SEM.

The Bair Hugger air jacket was applied for 40 minutes, with the addition of 1 minute of tourniquet at the end, with measurements being taken every 10 minutes to see its effect on vein diameter. The Bair Hugger air jacket caused a statistically significant increase in vein diameter from control measurement of 26 ± 16% ($p < 0.0001$) only after 40 minutes of Bair Hugger air jacket with 1 minute tourniquet (Fig. 3). However, no significant increase was seen with any other time interval of applying the Bair Hugger air jacket. The right arm needed to be taken out of the Bair Hugger air jacket to be measured, which also caused a drop-in arm temperature of 0.5-2.0 °C, recorded by the temperature data logger. The shoulder temperature did not drop however, but gradually increased 4-5 °C over the 40 minutes

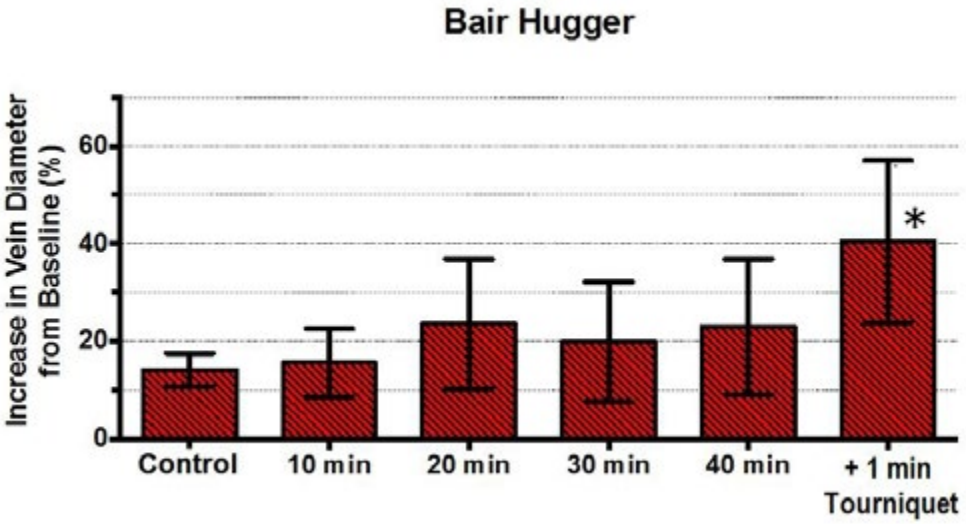

*Figure 3. Average percentage increase in cephalic vein diameter in response to Bair Hugger air jacket. The error bars indicate the SEM. * indicates a significant difference from the control measurement.*

The right arm was immersed in the water bath 40 minutes, with the addition of 1 minute of tourniquet at the end, with measurements being taken every 10 minutes to see its effect on vein diameter. Incubation in the water bath caused a statistically significant increase in vein diameter compared with the control measurement for all lengths of incubation tested in the study.

The 10 minute incubation resulted in increase of vein diameter by 21 ± 15% ($p = 0.0010$), whilst 40 minutes incubation led to an increase by 28 ± 15% ($p < 0.0001$). When used in conjunction with tourniquet, the water bath caused a mean increase of 34 ± 15% ($p < 0.0001$) compared with the control measurement (Fig. 4).

The degree of venodilation caused by the water bath was significantly greater than that of the Bair Hugger air jacket after 10 - 40 minutes ($p < 0.0001$ after 10, 30 and 40 minutes, $p = 0.0006$ after 20 minutes). However, after the use of 1 minute tourniquet directly after 40 minutes of the intervention there was no significant difference between the water bath and Bair Hugger air jacket groups (9 ± 13% ($p = 0.30$)).

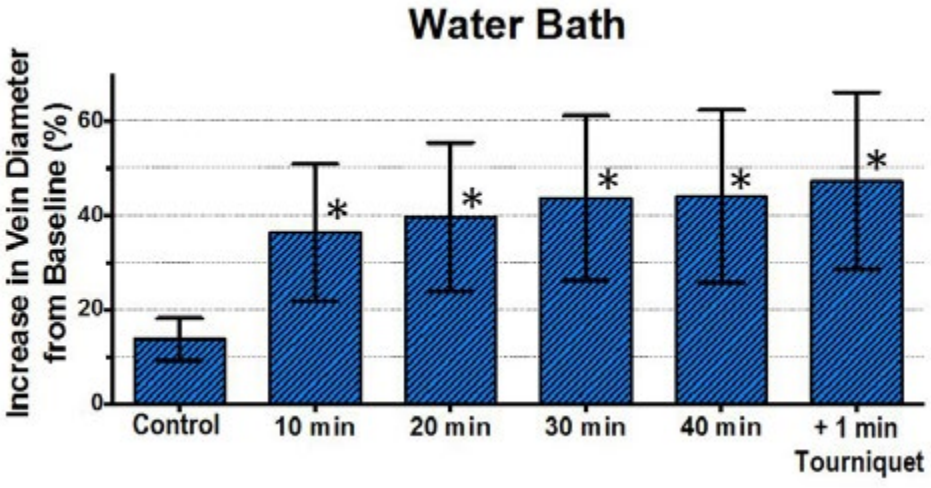

*Figure 4. Average percentage increase in cephalic vein diameter in response to water bath. The error bars indicate the SEM. * indicates a significant difference from control measurement.*

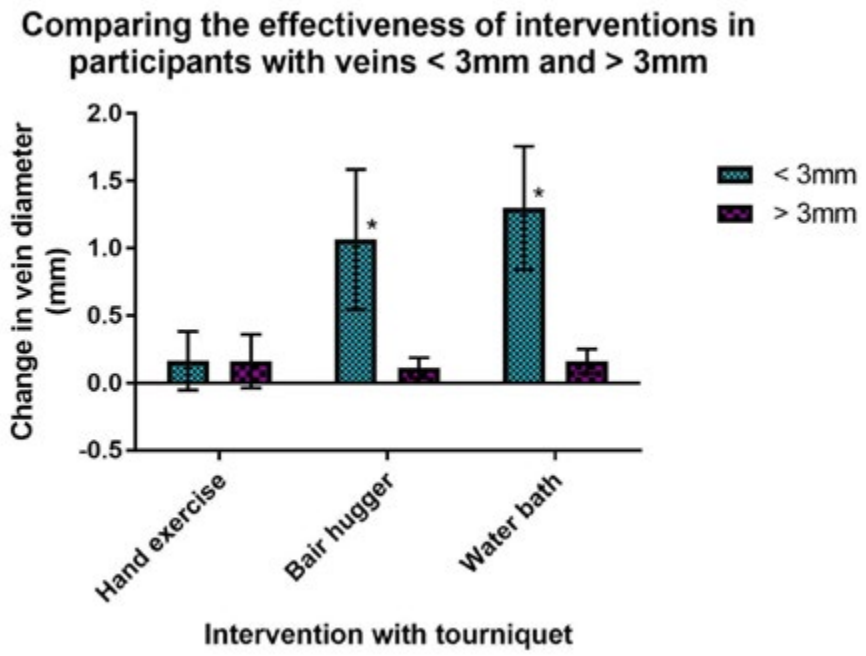

*Figure 5 Comparing the effect of the three interventions on veins of <3 mm or >3 mm. The change in diameter from the control measurement to 40 min of the intervention with tourniquet is shown.The error bars indicate the mean with SEM. * indicates a significant difference between <3 mm group and <3 mm group.*

If used in practice, the intervention would be most needed in those patients which do not reach eligibility criteria for AV fistula, which are those with <3 mm veins, therefore it is important these interventions work effectively in this group of people. To assess this the participants were split into two groups, those with <3 mm and >3 mm veins, and their results are shown in Figure 5. In participants that already had a vein diameter of >3 mm after the control measurement, the benefit from the three interventions was not statistically significant (hand exercise p = 0.63, Bair Hugger air jacket p = 0.84, water bath p = 0.63). There was a large increase in vein diameter in participants with veins <3 mm after water bath of 1.30 ± 0.30 mm (p = 0.038) compared with the control measurement. Bair Hugger air jacket caused an increase in vein diameter of 1.01 ± 0.30 mm compared with control measurement in those with <3 mm veins, although this was not statistically significant (p = 0.0718) (Fig. 5). The Bair Hugger air jacket had a significantly larger effect on vein diameter in the <3 mm vein group with a difference of 0.95 ± 0.83 (p = 0.0198), as did the water bath with a difference of 1.14 ± 0.83 (p = 0.0048). This means the interventions appear to be more effective in those participants with <3 mm veins.

The effect of interventions on <3 mm vein diameter group

Table 2 Total Number of Participants reaching 3 mm vein diameter (no. #)

	Bair Hugger	Water bath
Control	9	8
10 min	9	10
20 min	9	10
30 min	9	10
40 min	10	11
40 min + 1 min tourniquet	11	10

The number of participants reaching the criteria for AV fistula of 3 mm cephalic vein was determined to see if the effect of the interventions differs from current protocol with regards to patients reaching eligibility criteria. After 10 minutes of water bath two additional participants reached criteria (3 mm), followed by another one after 40 minutes of water bath (11/12 participants). Bair Hugger air jacket caused one participant to reach the criteria after 40 minutes, and another one with tourniquet (11/12 participants). One participant did not reach the criteria regardless of the intervention.

DISCUSSION

Results showed that the water bath was the most efficient and effective mechanism for dilating the cephalic vein, taking the least time to reach a significant dilation (10 minutes) of 21 ± 15% (p = 0.0010), and achieving the largest vein dilation of 34 ± 15% (p < 0.0001). This is beneficial as there is a limited amount of time with each patient when they come in for preoperative vein mapping, making the efficiency of the venodilation process advantageous.

In the participants with vein diameter of <3 mm the greatest results were seen using the Bair Hugger air jacket and water bath interventions. This is promising as this is the cohort which would not be put forward for the AV fistula application under the current protocol. There was no effect from the handgrip exercise seen in this group of participants, which suggests it is not a good method for dilating veins.

In this study, there were still several participants who managed to meet the criteria for AV fistula after using the water bath or Bair Hugger air jacket, who did not after control tourniquet which is the current protocol. The water bath allowed three of these participants to meet the criteria; two of them after only 10 minutes, one after 40 minutes. The Bair Hugger air jacket took 40 minutes with tourniquet to have a significant effect on vein diameter (26 16%, p < 0.0001) compared with 10 minutes for water bath (21 ± 15%, p = 0.0010), and also took 40 minutes to allow 1 participant to reach eligibility criteria for fistula formation compared with 10 minutes for water bath. The water bath is therefore a more efficient method of dilating veins which is supported by van Bemmelen et al. which showed that immersion of the arm in warm water (44 °C) for 2 minutes caused significant vein dilation. [5] The study by van Bemmelen only involved immersion for 2 minutes in warm water however this

study did it for a total of 40 minutes, measuring every 10 minutes.[5] This is because the interventions were used in test participants and the vein diameter continued to increase up to 40 minutes, for both water bath and Bair Hugger air jacket, so to get a full representation of the effect 40 minutes was chosen. There was quite a quick increase within the first 10 minutes for the water bath, but the vein diameter within this time was not recorded which is a potential limitation. However measurements were only done every 10 minutes as each measurement with the Bair Hugger air jacket is 30 seconds when the arm is not being heated, therefore affecting the vein dilation. To keep measurements consistent, both the Bair Hugger air jacket and water bath were measured every 10 minutes rather than at smaller intervals.

Other advantages to using a water bath for vein dilation were found in this study. During the water bath procedure, the ultrasound probe could be placed under the water in such a way that no direct pressure needed to be applied to the arm (act as a standoff) whereas above the water gel is required, which could have altered the vein diameter slightly. This meant that the probe would not cause any compression of the vein when below the water. An accurate measure of diameter could then be obtained. In addition, the temperature is more stable with the water bath as the arm can remain in the water during measurements, in contrast to the Bair Hugger air jacket which required the arm to be removed from the jacket and into cooler air to do the measurement. This may have reduced the dilation of the vein when using the Bair Hugger air jacket, but also demonstrates a benefit of the water bath. Most vascular labs would not have their own water bath or Bair Hugger air jacket system, therefore one would need to be purchased for the unit if it was used, which could be a barrier to its use for preoperative vein mapping. Once purchased however the water bath is very cost effective as only the water needs to be replaced, while the bath itself is re-used each time, unlike the Bair Hugger air jacket where each patient uses a new jacket for hygiene reasons.

Limitations of this study include the small sample size and possible gender bias. In addition, there was only 4 participants who had <3 mm veins, which is the group of people these results are most likely to affect as they would currently not be put forward for an AV fistula. Ideally the study would have more participants with <3 mm veins to ensure the intervention functions effectively in these individuals, so future studies should look specifically at this group. Measuring the participant's arm outside the Bair Hugger air jacket was also a limitation as this could have affected the vein dilation, however we were unable to find a solution for this as it is more a limitation of the Bair Hugger air jacket. Another limitation is the inability to blind the sonographer to the interventions, which could create observer bias.

This research will be continued by using a water bath on patients who come in to the Vascular Laboratory for preoperative vein mapping and have a vein diameter of <3 mm after tourniquet. The results will be prospectively audited to see if water bath increases the number of patients being put forward for AV fistula formation, compared with venous tourniquet alone and to determine if these patients go on to form successful AV fistulae.

CONCLUSION

Overall, the water bath was the most effective and efficient mechanism for dilating veins prior to using them to form the AV fistula. The methods used in this study were assessed in comparison with the use of venous tourniquet, a current standard practice. Although the study was conducted on a small number of participants, thanks to using the water bath, several participants met the criteria for the procedure of AV fistula. If used during preoperative vein mapping, water bath could improve the ability to assess each patient's vein diameter and increase the number of patients receiving AV fistula, which is the gold standard for haemodialysis.

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The author has no conflict of interest to declare.

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