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Post operative monitoring of microvascular breast reconstructions using the implantable Cook–Swartz doppler system: A study of 145 probes & technical discussion

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KEYWORDS
Free flap;
Monitoring;
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Summary *Introduction:* Accurate post operative assessment of free tissue transfers is challenging despite all the subjective and objective techniques available today. In our continual search to optimise patient outcomes, we introduced the Cook-Swartz probe into our clinical practice in May 2006.
Methods: We present our single centre experience in 103 patients undergoing 121 microvascular breast reconstructions and monitored using implantable Cook-Swartz venous dopplers between May 2006 and January 2008.
Results: In total, we used 145 probes on 121 microvascular breast reconstructions (DIEP = 102, SIEP = 15, SGAP = 4) in 103 female patients. The mean operative time was 4 h and 55 min ($\mu = 295$; range 117–630; ó ± 101 min) and we suffered 2 complete flap losses. A problem with the audible signal was noted in 15 patients (4 intra-operatively). We revised 14 of the 15. All fourteen had compromised anastomoses. In the remaining case, the patient was not returned to theatre as the primary surgeon was confident there were no other signs of vascular compromise. Overall, when using the venous doppler probe we found a false positive rate of 6.7% and 0% false negatives.
Discussion: We advocate the use of a Cook–Swartz probe which has been well received by both surgeons, nursing staff and patients, as an adjunct to traditional clinical monitoring techniques. We also include a comprehensive experience based technical discussion concerning its application, attachment, use and post-operative removal.
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Accurate assessment of the perfusion of free tissue transfers has always been a challenge for surgeons undertaking microvascular reconstructive procedures, and there are

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a range of contemporary techniques in clinical use, and currently in development.[1] Routine monitoring of free flaps is increasingly being undertaken by nursing staff on the ward, and often junior medical staff covering the ward have little experience of such monitoring and are not assigned specifically to the operating surgeons team. It is well recognised that surgical experience is an important predictor for flap survival[2] and recent advances in technology and improvements in surgical technique have led to reported success rates between 95 and 98%.[2] This success has been achieved in conjunction with improved monitoring of flap circulation post-operatively. Considering free tissue transfers are time consuming and complex procedures with inherent risks, we are always looking for devices that have the potential to minimise patient morbidity.

In our continual search to optimise patient outcomes, we introduced the Cook-Swartz probe (Cook Medical®, Cook Ireland Ltd, Limerick, Ireland) into our clinical practice in May 2006. The Cook–Swartz venous Doppler system is a technique for monitoring venous flow in free tissue transfer consisting of an implantable 20 MHz ultrasonic probe around the venous pedicle and a battery operated portable monitor. Although it was developed in the USA some time ago, and has been available for clinical use in the USA for several years,[3–5] it has only gained the CE mark and been distributed in Europe since 2006. Only a handful of small preliminary reports have been described in Europe and Australasia over the last 2 years,[6,7] with promising results. We present our experiences, on 103 patients with the device and advocate the use of a Cook–Swartz probe as an adjunct to traditional clinical monitoring techniques. We also include an experience based technical discussion concerning its application, attachment, use and post-operative removal.

The Cook–Swartz Doppler monitoring system

The Cook–Swartz venous Doppler monitoring system is a technique for monitoring blood flow following free tissue transfer. It consists of an implantable probe with a removable, 20 MHz ultrasonic Doppler crystal and a silicone cuff to secure it around the vessel adventitia of the venous pedicle, and a battery operated or line powered portable monitor. The cuff consists of a small $8 \times 5\ mm^2$ thin silicone sheet which is wrapped around the vessel and the overlying ends secured. The probe's proximal end exits as a thin wire through the wound and is connected to an intermediate extension cable that is attached to the patient through the use of specially designed retention tabs. The intermediate cable plugs into a transportable monitor at the patient bedside, which is battery or mains operated. The intermediate cable allows detachment of the probe whilst the patient mobilises post-operatively. The electrode slides free from the cuff when pulled externally at 5–10 days post-operatively depending on the length of monitoring required. The electrode is designed to separate from the cuff, when a tension of 50 grammes is applied. By 5 days the cuff is sufficiently adherent to the vessel and the vessel adherent to the surrounding tissue, allowing safe traction and removal of the electrode. The probe allows direct vessel monitoring of a microvascular anastomosis at a specific site along a designated vessel. It is possible to listen to the signal in the donor vessels whilst selecting a vessel for anastomosis. It is possible to use multiple probes if several venous anastomoses are carried out. Post-operatively, the surgeon, nursing staff and the patient are able to hear the audible venous signal. It potentially gives an early warning to flaps with compromised pedicles before clinical signs are apparent, allowing an earlier return to theatre (Figure 1).

Materials and methods

The patients details of 103 patients undergoing 121 microvascular breast reconstructions (DIEP = 102 , SIEP = 15, SGAP = 4) and monitored using 145 implantable Cook-Swartz venous dopplers between May 2006 and January 2008 were retrieved. All patients were operated on in a single centre, with three senior plastic and reconstructive surgeons performing the operations. The age, sex, indication for surgery, type of flap, type of anastomosis, recipient vessels, ischemia time, anastomotic time, revisions and surgical outcomes were reviewed from our comprehensive database.

Results

Our study group included 121 microvascular breast reconstructions on 103 female patients with an age range of 22 to 67 years ($\mu = 50$; ó ± 9.5) All breast reconstructions were for oncological reasons; with 29 immediate breast reconstructions and 92 delayed reconstructions. The DIEP flap was the most often used flap (*n* = 102 breasts). SIEP (*n* = 15) and SGAP (*n* = 4) flaps were used less commonly. The internal mammary artery was the recipient site in the majority of cases (*n* = 113). The circumflex scapular artery was the recipient vessel in seven cases (*n* = 7) and the thoracodorsal artery once (*n* = 1). 117 (97%) of arterial anastomosis were end to end. The respective vein was used for the venous anastomosis. In 51 flaps, a second venous anastomosis was

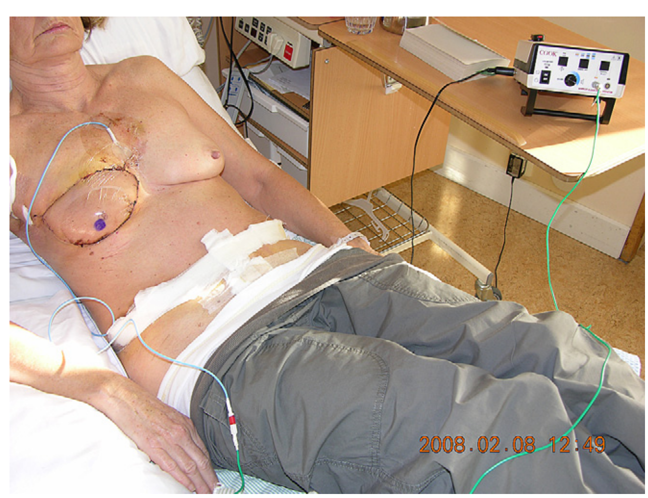

Figure 1 The Cook–Swartz venous Doppler monitoring system. The blue and green wires connect the probe with the white monitoring box.

performed as the flap subjectively appeared engorged following successful primary venous anastomosis. The cephalic vein was most commonly used as the recipient vessel for the secondary anastomosis ($n = 36$). The internal mammary ($n = 8$), circumflex scapula ($n = 4$) and thoracodorsal ($n = 3$) were also used. 170 (99%) of venous anastomoses were performed in an end to end fashion, the rest were preformed end to side. The mean ischemia time was one hour ($\mu = 60$; range 20–155; ó $\pm$ 24 min). The mean anastomotic time was 14 min ($\mu = 14$; range 4–38; ó $\pm$ 5 min) and 9 min ($\mu = 9$; 1–35; ó $\pm$ 6 min) for the artery and vein, respectively. The mean operative time was 4 h and 55 min ($\mu = 295$; range 117–630; ó $\pm$ 101 min). There were 2 complete flap losses and one case of partial necrosis (overall success rate 98%). Overall we used 145 implantable probes in 121 cases. A problem with the audible signal was noted in 15 patients. A poor audible flow signifying flap compromise was picked up intra-operatively in four cases. There were problems with the artery in three cases (two arterial thrombosis, one arterial spasm), and one problem with the vein (one venous pedicle was kinked). In 10 of the remaining 11 cases, a salvage procedure was performed. The mean time to re-operation was 35 h and 52 min (μ = 35h52; range 1h01–80h00; ó $\pm$ 29h07). The most common intra-operative finding were an arterial thrombosis ($n = 4$) and a venous thrombosis ($n = 4$). A haematoma causing venous compression was seen in two cases. In the remaining case, the patient was not returned to theatre as the primary surgeon was confident there were no other signs of vascular compromise. The two flap failures were due to 1 arterial, and 1 venous thrombosis. See Table 1. Overall, when using the venous doppler probe we found a false positive rate of 6.7% and 0% false negatives.

Discussion

In many cases, the complexities of flap microcirculation are difficult to assess despite all the subjective and objective examination techniques available today.[1,2,8–15] Efficacious post-operative monitoring of free tissue transfers in mandatory in order to detect vascular occlusion at an early enough stage to allow re-exploration and ultimately improve the chances of flap salvage.[16,17] Of the techniques currently available to monitor free flaps post-operatively, clinical assessment is the most commonly used,[11,18] however there is a need for experienced interpretation and such tests are often unreliable.[11,19] Clinical changes may be subtle initially and by the time they are clinically apparent, salvage of the flap may be impossible due to irreversible tissue damage. Notwithstanding this, some authors still believe clinical observation to be the 'gold standard'.[20] It is clear there is a wide variation in the post-operative monitoring of free tissue transfers, in the UK at least.[10,18,21] Flap perfusion has been investigated using a myriad of techniques using: sodium fluorescein,[22–26] indocyancine green,[27–30] radioactive isotopes (technitium 99 m,[31,32] xenon 133,[33] sodium 22[34]), hydrogen gas clearance,[35,36] microdialysis,[37–39]tissue pH,[40–43] pO_2,[44–54] surface temperature,[55,56] near infra-red spectroscopy,[57–61] hand held doppler,[62] lazer doppler[57,63–66] and photoplethysmography.[67–69] It is an indictment of all the techniques available that most surgeons still rely on their own clinical observation. However, with the routine monitoring of free flaps on the ward often being undertaken by junior ward nurses, and inexperienced junior doctors on rotation, it is incumbent on us as senior medical practitioners to strive to optimize patients outcomes following microsurgery and lead us towards the ideal method of monitoring flap viability proposed by Creech and Miller (1975).[70] Over time, flap salvage rates decline significantly and the ideal time to detect a flap with inflow or outflow compromise is before the patient leaves the operating theatre. Implantable probes such as the Cook-Swartz dopper system offer this exciting opportunity. Initial experimental work with the implantable Doppler probes showed that there were un-necessary re-explorations (false positives 3%) and venous thrombosis that were not detected (false negative 5%) when the probe was placed only on the arterial pedicle. Significant delay of up to 5 h was found between a problem with venous outflow to loss of the arterial signal in large muscle flaps.[3] These findings were corroborated by Swartz[4,5] when he found that arterial probes immediately detected an arterial occlusion but continued to record pulsation for up to 6 h after venous occlusion. Venous probes detected a venous problem immediately and an arterial problem on average 6 min after arterial occlusion. A recent small study ($n = 24$) in the United States has described promising results for the implantable venous doppler in head and neck surgery[71] with increased success and operative salvage rates. Two other recent studies, one in the UK[7] ($n = 24$) and one in New Zealand[6] ($n = 4$) have also advocated the probe's use. This device has only recently become available for general use in the UK and mainland Europe, and we have been using it since the release date. Since May 2006, we have performed 121 microvascular breast reconstructions (29 immediate and 92 delayed) on 103 female patients. The majority of our cases were DIEP flaps using the internal mammary vessels as the recipient site. We performed a second venous anastomosis to augment venous outflow in 51 flaps, most commonly using the cephalic vein as the recipient vessel. Overall, our success rate of 98% is comparable with other published studies.[72–74] From the 145 implantable probes used in 121 cases, a problem with the audible signal was noted in 15 patients. A poor audible flow signifying flap compromise was picked up intra-operatively in four cases. There were problems with the artery in two cases (one arterial thrombosis, one arterial spasm), and two problems with the vein (one venous thrombosis and one venous pedicle was kinked). In the remaining 11 cases the change in signal was picked up on the ward and in 10 a salvage procedure was performed. The mean time to re-operation was 35 h and 52 min (μ = 35h52; range 1h01–80h00; ó $\pm$ 29h07). Eight of the ten flaps returned to theatre were salvaged successfully. It is of note that in one case, even though there was a change in Doppler signal, the decision was made not to return the patient to theatre. Upon complete clinical examination of the patient and flap, there was no indication that flap viability was threatened. Overall, when using the venous doppler probe we found a false positive rate of 6.7% and a false negative rate of 0%. We routinely remove the probe at seven days post-operatively. As a surgical team, we have very positive experiences with the application and use of the Doppler probe and would advocate its use as an adjunct to clinical monitoring techniques. Since introduction into our

Table 1 Cases in which the medical staff were alerted to poor audible Doppler flow

Case	Age	Risc factors	Flap used	Immediate vs delayed reconstruction	Receptor vessels	Type of arterial anastomosis	Arterial anastomosis material	Type of venous anastomosis	Venous anastomosis material	Change in signal	Time t opera (hours
1	45	DM[a]	DIEP[c]	Delayed	internal mammary	end to end	suture	End to end	Clips	Stop	Ior[f]
2	52		SIEP[d]	Delayed	internal mammary	end to end	suture	End to end	Clips	Stop	Ior
3	56		DIEP	Delayed	internal mammary	end to end	suture	End to end	Unilink®	Pulsating	Ior
4	57		DIEP	Delayed	internal mammary	end to end	suture	End to end	Suture	Weak signal	Ior
5	59		DIEP	Delayed	internal mammary	end to end	suture	end to end	Clips	Stop	1
6	59	HT[b]	DIEP	Immediate	internal mammary	end to end	suture	End to end	Suture	Stop	4
7	35		SGAP[e]	Immediate	internal mammary	end to end	suture	End to end	Clips	Stop	11
8	53	HT	SGAP	Delayed	internal mammary	end to end	suture	End to end	Clips	Decrease	14
9	39		SGAP	Immediate	internal mammary	end to end	clips	End to end	Unilink®	Stop	22
10	39		DIEP	Delayed	internal mammary	end to end	suture	End to end	Unilink®	Stop	51
11	43		DIEP	Delayed	internal mammary	end to end	suture	End to end	Clips	Stop	51
12	38		DIEP	Delayed	internal mammary	end to end	suture	End to end	Unilink®	Stop	54
13	58		DIEP	Delayed	internal mammary	end to end	suture	End to end	Unilink®	Decrease	74
14	34		DIEP	Immediate	internal mammary	end to end	suture	End to end	Unilink®	Stop	80
15	60		DIEP	Immediate	internal mammary	end to end	suture	End to end	Clips	Stop	No sur perfor

[a] DM (diabetis melitus).
[b] HT (hypertension).
[c] DIEP (deep inferior epigastric perforator).
[d] SIEP (superficial inferior perforator).
[e] SGAP (superior glutal artery perforator).
[f] Ior (intra operative revision).

clinical practice, the Cook-Swartz probe has changed the way we monitor free flaps. Whereas previously we relied on the regular use of hand-held doppler probes and clinical tests, we now only use these methods if there is a clear change in audible doppler output. This makes the monitoring less labour intensive and cause less patient disruption, as we can often turn the monitor on quietly at night without waking the patient.

The Cook implantable probe — technical aspects

Application and attachment

We manipulate the silicone cuff bi-manually with fine non toothed forceps. One side of the cuff is gently wrapped around the vein (distal to the anastomosis) and then the other side. Both ends of the cuff are gently gripped by the forceps, and micro-clips are used to secure the cuff in situ (Figure 2). It is important to get the tension correct as the doppler probe in the cuff must be securely in contact with the vein. If the cuff is too tightly secured, the potential for venous outflow obstruction exists. If the probe is not well approximated either no signal is produced, or it may rotate and induce vasospasm in the arterial wall if adjacent. Other possible methods to secure the cuff include fibrin glue[75] and sutures.[7] We prefer using microclips as we believe very accurate placement may be achieved, and adjustment is easy due to the atraumatic 'sliding' nature of application and removal. In our experience the use of this system adds less than five minutes to the procedure. Whilst with any procedure there is a learning curve, we have found it straightforward to use from the first case. It has been used by three surgeons in our unit during this study without technical difficulties with its application or use. The Cook—Swartz system can be used in conjunction with other monitoring techniques and the probe allows direct vessel monitoring of microvascular anastomoses at a specific site along a designated vessel. If two venous anastomoses are needed to augment high flow flaps, multiple doppler probes can be used as the monitor has two channels that can be used simultaneously.

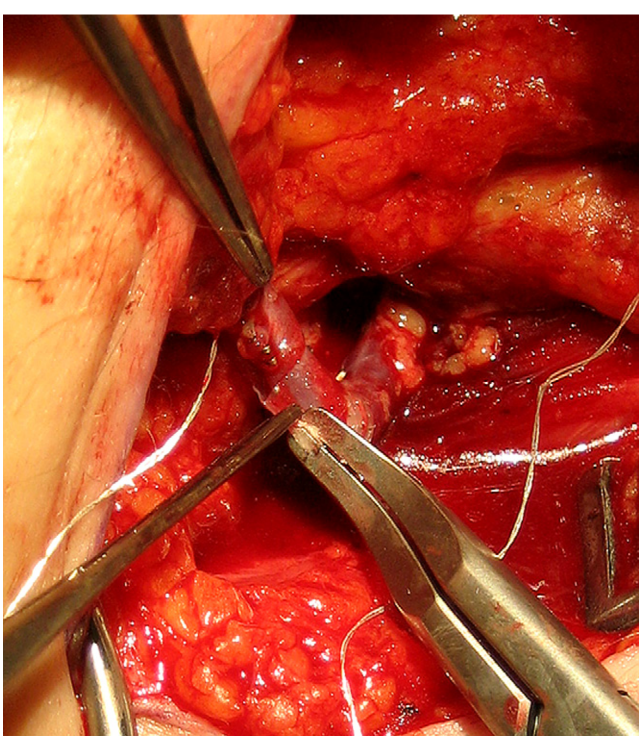

Figure 2 Attachment of the silicone cuff using micro-clips.

Post-operative removal

In our clinic the probes are removed the seventh day post surgery. The probes are removed by the responsible consultant. They are removed by using minimal traction on the wire where it exits the flap. Manufacturers specifications state that a force of only 50 grams needs to be applied. After removal the probe, we routinely perform a final check with the hand held doppler to ascertain anastomotic integrity. Of the 145 probes we have removed so far, we have encountered no complications.

Cost

Each disposable probe costs £270 and the monitoring box £1750. Considering the cost of return to theatre and revision, morbidity of flap loss and consequences for the patient, we believe that venous Doppler monitoring can be justified.

Conclusion

In our experience with 145 probes, we found a false positive rate of 6.7% and a false negative rate of 0%. We advocate the use of a Cook—Swartz probe which has been well received by both surgeons, nursing staff and patients, as an adjunct to traditional clinical monitoring techniques.

Conflict of interest

Cook® awarded a Microsurgery Travelling Fellowship to Mr Iain S Whitaker to support his work with Dr Rafael Acosta in Uppsala, however I can confirm that none of the authors of this manuscript have any financial or other interest in the techniques described or commercial sales of products investigated in this manuscript.

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