Setting up and utilizing a service for measuring perioperative transcranial motor evoked potentials during thoracoabdominal aortic surgery and thoracic endovascular repair

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Abstract

OBJECTIVES: Paraplegia is a complication that may occur following surgery or endovascular stenting of thoracic and thoracoabdominal aortic pathology. Measuring transcranial motor evoked potentials (tcMEPs) has been shown to provide a reliable measure of spinal cord function during such procedures allowing interventions to protect cord function. In the spirit of sharing experience and eliminating the learning curve for others, this manuscript describes our experience of setting up a service for tcMEP monitoring as well as the documents and algorithms for measuring, recording and acting on the patient data, the so-called ‘MEP Pathway’.

METHODS: Recording and interpretation of tcMEP during thoracoabdominal aortic intervention requires training of staff and close team working in the operating theatre and postoperative intensive care unit. Providing consistent, reliable, specific and sensitive information on spinal cord function and its safe and effective use to alter patient outcomes requires a protocol. The MEP pathway was developed by medical and paramedical staff at our institution based on clinical experience and literature reviews over a 1-year period (2012–2013).

RESULTS: The tcMEP pathway comprises six documents that guide staff in: (a) assessing suitability of patients, (b) setting up hardware, (c) preparing algorithms for management, (d) documenting intervention (left heart bypass, cardiopulmonary bypass or endovascular stenting) as well as (e) documenting postoperative intensive care processes.

CONCLUSIONS: The tcMEP pathway acts as a guide for safe introduction and use of tcMEPs in thoracoabdominal aortic interventions. tcMEP-led guidance of intraoperative and postoperative management in thoracic aortic surgery is an important adjunct in caring for this patient group.

Keywords: Motor evoked potential • Neuro-monitoring • Thoracoabdominal surgery • Paraplegia

INTRODUCTION

Paraplegia is associated with intervention on the descending thoracic aorta and thoracoabdominal aorta. This complication is a consequence of interruption of blood flow to the spinal cord network following coverage or oversewing of intercostal and lumbar arteries. The risk of paraplegia has persisted in most published series [1, 2] despite adjuncts such as sequential clamping, left heart bypass, deep hypothermic circulatory arrest (DHCA), intercostal artery reattachment and cerebrospinal fluid drainage (CSFD). Intraoperative monitoring of spinal cord function has been adopted by several groups internationally to guide the conduct of the operation in this patient group [3–5]. Two approaches are available: transcranial motor evoked potential (tcMEP) and/or somatosensory evoked potentials (SSEP). Our group has concentrated on using a tcMEP system as in the absence of neurophysiology input tcMEPs are easier to set up and interpret. Spinal cord monitoring has been delivered with input from neurophysiologists and the debate in the literature has centred around the relative merits of SSEPs versus MEPs [4, 6]. Little if any information exists on the practical issues of setting up such a service, managing patients safely using this technology and informing potential users of pitfalls and safeguards. The Thoracic Aortic Aneurysm Service at Liverpool Heart and Chest Hospital has been developing a programme for intervention on the descending thoracic aorta over the last decade. As part of the introduction of a number of measures to prevent intraoperative paraplegia, we introduced tcMEP monitoring. Our previous observations suggest that a significant proportion of the episodes of paraplegia were not acquired intraoperatively but were delayed (Days 1–3) and were often related to deviation from agreed postoperative instructions for management of spinal cord perfusion pressure. We therefore extended our use of tcMEP monitoring to the postoperative period on intensive care. This manuscript documents our institutional processes and protocols for setting up and managing perioperative tcMEP monitoring, in the form of a pathway.

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METHODS

Service summary

The motor evoked potential monitoring service was established at the Liverpool Heart and Chest Hospital in April 2012. This is a 365-day-per-year 24-h service that was established as part of the multidisciplinary team to provide quick and reliable motor function assessments in anaesthetized patients. The principal technical delivery of the service is provided by an individual with a degree in life sciences trained by clinical staff and the company providing the hardware. Currently, the same individual runs tcMEP intraoperatively and then stays with the patient through the night in Intensive Care, intermittently taking measurements through the night. Throughout the 24 h the Technician is supported by clinical staff. On-going initiatives to mitigate this commitment, while keeping costs low, are to introduce remote monitoring and nurse-led bedside monitoring.

Governance

The Aortic Team (comprising surgeons, anaesthetists and a technician) is responsible for monitoring and audit of clinical practice to ensure that the tcMEP pathway is performed in a safe and appropriate manner.

Roles and responsibilities

While the technician has the specific responsibility of setting-up equipment for routine cases, it is the responsibility of each member of the aortic team to understand and apply this protocol. The interpretation of results is aided considerably by an intimate knowledge of what is happening clinically at each stage of the procedure, hence the need for close teamwork in our tcMEP monitoring. This protocol is intended to be used alongside our pre-existing protocol for the management of spinal drains and paraplegia/paraparesis. All medical staff who are responsible for acquiring and interpreting tcMEP signals receive appropriate training.

Transcranial motor evoked potential hardware

Commercial system. TcMEPs are performed using the SD NIM-ECLIPSE® system (Medtronic, Tolochenaz, Switzerland).

Electrode placement. Following skin cleaning, needle electrodes typically inserted into the tibialis anterior, abductor hallucis and abductor digitii minimi/abductor pollicis brevis muscles and fixed with Tegaderm (Video 1). If any lower limb deformities hinder the application of any electrodes, then a decision is made to apply electrodes into the vastus lateralis. This muscle is usually not preferred due to thick adipose tissue hindering the reach of the needle electrode to muscle. The needle electrodes are applied with care in order to avoid needle snapping; an angle of \( \approx 45^\circ \) between the needle and the skin is sought so that any observable stress on the needle electrodes is avoided.

Figure 1: Front page documentation of the pathway.

Head measurements and markings are made using the international 10–20 system of electrode placement. Four positions (two sets) are marked for stimulating electrodes 1 cm more anterior and 1 cm more lateral than C1 and C2 and also 1 cm more posterior than C1 and C2 as advised by Dr Colette Boëx (Geneva) (Video 2). One set of positions is utilized with the option to swap if the first position fails to provide a good trace with the amplitude at 650 V.

Settings used for transcranial motor evoked potential. Transcranial electric stimulation (7 single pulses, 333 Hz, 60 µs pulse duration, 200–700 V) is applied at the positions described above using corkscrew subdermal electrodes. The intensities used for electrical stimulations are adjusted so that adequate MEP trace amplitudes from all limbs are recorded, hence between 200 V and 700 V (try to avoid exceeding 600 V). The peripheral needle
Assessment

Contraindications & PMH

| Procedure: | ........................................................................................................... |
| Name of neuro-monitoring technician: | ........................................................................................................... |

Does the patient present with any of the following (tick as appropriate):

- Cochlear implant  
  - Yes ☐  No ☐
- Metal in head/shunts  
  - Yes ☐  No ☐
- Skull defects  
  - Yes ☐  No ☐
- Large bone fractures  
  - Yes ☐  No ☐

If the answer to any of the above is Yes, then MEP monitoring is contraindicated for the patient.

Does the patient present with any of the following (tick as appropriate):

- Cardiac pacemaker  
  - Yes ☐  No ☐
- Epilepsy  
  - Yes ☐  No ☐

If the answer to any of the above is Yes, then MEP monitoring is contraindicated although it may still be performed by collective agreement between the surgeon and anaesthetist.

I hereby confirm that the benefits/risks of the procedure have been carefully considered and agree to initiate/not initiate (delete as appropriate) MEP monitoring.

| Anaesthetist Name | ............................................................... | Signature: ............................................................... |
| Surgeon Name: | ............................................................... | Signature: ............................................................... |

Past medical history:

Figure 2: Assessment of suitability for MEP monitoring; series of questions to assure monitoring not conducted in patients contraindicated for tcMEP monitoring. tcMEP: transcranial motor evoked potential.

electrodes are applied before the initiation of surgery but after intubation of the patient. This allows baseline measurements of the MEPs to be taken once the effect of the initial dose of muscle relaxant has disappeared.

**Baselines and measuring change.** The first requirement is to establish good baseline readings in all four limbs and then subsequently to detect spinal cord impairment. Risk to the spinal cord is indicated by a 50% decrease in amplitude of only the lower
limb signals, when compared with baseline. The simultaneous use of upper limb electrodes represents an important internal control.

**Tailoring anaesthetic techniques**

It is helpful to maximize the baseline traces in order to identify a more than 50% reduction in the lower limb signals. For this reason, we avoid factors known to diminish the tcMEP traces. Volatile gases are known to attenuate the tcMEP amplitudes, while muscle relaxants obliterate the signals altogether. The use of muscle relaxants is unavoidable at the start of anaesthesia to allow placement of a double lumen endobronchial tube, and inevitably obliterates the tcMEP tracings for a period. Thereafter, we use the total intravenous anaesthetic technique. Following double lumen tube placement, line placement, spinal drain insertion and attachment of the neuromonitoring electrodes, the initial dose of muscle relaxant should be eliminated, allowing detection of tcMEP traces by the time of commencement of surgery. The traces should be of good amplitude well before cross clamping the aorta. We utilize a total intravenous anaesthetic technique with fentanyl and propofol; however, other combinations such as remifentanil and propofol would be equally appropriate.

**Interventional approach and motor evoked potential protocols.** The MEP pathway is used to guide and record each step of the neuromonitoring period dependent on operative approach. Thoracoabdominal aortic intervention is either through an endovascular approach, open surgery or both. Open surgery is performed using left-heart bypass and relative normothermia or using cardiopulmonary bypass and DHCA. In procedures that require DHCA, intraoperative tcMEP monitoring is rendered useless. This is because the low body temperature slows stimulus transmission. Therefore, in cases requiring circulatory arrest, the tcMEP monitoring is set up at the start of the case for future baseline comparison. Usually, MEP monitoring is paused during DHCA and recommenced once the patient is adequately rewarmed. This is continued postoperatively until the patient is able to emerge from anaesthesia and move limbs to command.

**The tcMEP pathway**

**Page 1–3: preoperative documentation.** Page 1 (Fig 1) is a ‘front page’. Prior to anaesthetizing the patient, a checklist is completed to avoid tcMEP monitoring in patients in whom tcMEP stimulations are contraindicated (Fig. 2).

Page 2 (Fig 2) clearly lists the contraindicated parameters. TcMEP monitoring cannot be performed in patients with cochlear implants, metal/shunts in the head, skull defects and large bone fractures. It is also relatively contraindicated in epileptic and patients fitted with cardiac pacemakers, although we have decided to commence monitoring in such patients if joint agreement is reached by the responsible anaesthetist and surgeon after considering the risks and benefits. In practice, the contraindications are relatively rare.

It also allows text entry of past medical history that may be useful in determining irregularities in tcMEP traces.

**Page 3: electrode placement.** Page 3 (Fig 3) allows documentation of electrode placement (it includes a series of tick boxes next to the relevant muscle recording site). This acts as a recording sheet for selected peripheral muscle electrode positions. For simplicity, the head measurements and markings are performed prior to anaesthetizing the patient. If this is not possible, head measurements/markings are then performed after intubation while applying the needle electrodes. Subsequently after insertion of the lumbar spinal drain, the head corkscrew electrodes are applied and the rest of the peripheral electrodes inserted and secured using 3M TEGADERM™ FILM (Fig. 3).

A soft bite block is placed in between the teeth to protect the tongue from lacerations, and neuromonitoring is initiated. The voltage intensity is adjusted to the intensity (V) that gives good MEP amplitudes in all limbs and this intensity is continued throughout the intraoperative period.

**Points to be aware of**

(i) Wipe skin with disinfecting wipes prior to needle electrode placement.
(ii) Wear gloves for insertion of needle electrodes.
(iii) Ensure that wires are not around surgical site.
(iv) Any loose wires (trip hazard) should be secured to bed.
(v) Do not use diathermy when stimulating (affects MEP readings).
(vi) For transfer to critical care area, remove electrodes from recording box, and using tape secure onto skin for ease of patient manoeuvring.

Immediately after evoked potential stimulation, the simultaneous cerebrospinal fluid pressure (CSFP), mean arterial pressure (MAP), cord perfusion pressure (CPP = MAP – CSFP), nasopharyngeal temperature bladder/rectal temperature and any accompanying notes are recorded. This helps with MEP trace interpretation.

**Electrode positions selected**

**Electrode placement**

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![Figure 3: This page allows documentation of electrode positioning.](https://academic.oup.com/icvts/article/18/6/748/646795)
Intraoperative algorithm

Intraoperative neuromonitoring overview:

**Establish baseline**
- Maximise MEP signals (TIVA technique)
- Establish internal controls (use of upper limb electrodes and if necessary train of four)

**Open surgery**
- Test around procedures that may alter cord perfusion
  - Aortic cross clamp
  - Stopping distal aortic perfusion
  - Sacrifice of intercostals

**TEVAR/stent**
- Test around procedures that may alter cord perfusion
  - Occlusion of intercostals by inflation of balloon
  - Stent deployment

**How do we decide on a bad result and communicate it**
- Agreement of technician and Anaesthetist before informing surgeon
- Internal controls: upper limb signals OK
- Lower limb MEP signal amplitude decrease by 50% or more
- Increase in latency observed
- If above apply then communicate to surgical/endovascular team that we have an impending paraplegia/paraparesis

**What do we do to improve signals (specific to open surgery)**
- Establish distal perfusion if not already
- Or improve distal perfusion pressure
- Reimplant intercostals

**What do we do to improve signals (applicable in open or endovascular)**
- Lower CSF pressure by draining CSF
- Increase Mean Arterial pressure
- Correct anaemia

**What do we do to improve signals (specific to endovascular treatment)**
- ? Create a temporary endoleak (for days to weeks)

Figure 4: Intraoperative algorithm; guideline for monitoring motor evoked potentials in open and endovascular procedures.

**Page 4–6: intraoperative algorithm and associated documentation**

Open thoracoabdominal aortic surgery with left heart bypass. Throughout the process of exposing the aorta and establishing left heart bypass, tcMEP signals are recorded. When the cross clamp is positioned on the aorta, a 5-min pause is taken, after which tcMEP stimulation is performed. This should be adequate time to indicate interrupted perfusion to the anterior spinal cord and therefore demonstrate a rapid decrease in lower limb trace amplitude. This step is designed to distinguish the segments of the aorta containing side branches of importance to spinal cord perfusion. If at this point a rapid decrease (>50% of baseline) in tcMEP signals in the lower limbs is observed, then the clamp is removed and an alternative approach is considered (Figs 4–6).

If during the conduct of the operation a visually significant drop (>50% of baseline) in lower limb tcMEP amplitude is detected, the anaesthetist is alerted. The technician and anaesthetist will ascertain whether the change is significant by excluding false positives and repeating testing. If there is agreement that there is a significant drop in the tcMEP amplitude, this is conveyed to the surgical team. To determine whether the change is anaesthesia related, the MAP and/or the distal aortic pressure should be raised, and if the lower limb amplitudes continued to be <50% of baseline, this is indicative of the need for
surgical intervention. It is important to note that lower limb tcMEP signals can also be diminished by inadequate distal aortic perfusion. Figure 4 is the algorithm-driven conduct for open surgery using left heart bypass, cardiopulmonary bypass, DHCA and thoracic endovascular aortic repair (TEVAR). It guides and ensures that baseline measurements are made at the start of surgery. A second acquisition is then required following exposure of the aorta. A final acquisition is then required following left heart bypass.

If the MEP signal does not decrease <50%, the aorta is opened and surgery proceeds. If the signal does deteriorate, then a series of steps are considered to maintain spinal perfusion pressure and/or an alternative surgical strategy is considered including prioritizing intercostal vessel reimplantation. The protocol then provides a free text box to document the myriad of sequential clamping options during the conduct of the operation (Pages 5–6, Figs 5 and 6). The end of surgery is then punctuated by documenting MEP signals prior to administration of muscle relaxant for change of double to single lumen tube. Lack of satisfactory signals mandates medical optimization of cord perfusion.

**Intraoperative documentation**

<table>
<thead>
<tr>
<th>Intraoperative notes:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature all TcMEPs disappear (amplitude &lt; 10 mV)</td>
</tr>
<tr>
<td>Temperature first TcMEPs appear (amplitude &gt; 10 mV)</td>
</tr>
</tbody>
</table>

Figure 5: Intraoperative documentation text entry to allow detail.

**Postoperative monitoring**

Postoperative neuromonitoring overview

Every hour monitoring, muscle relaxant clearance dependant on patient physiology, can sometimes take over 3–4 h after surgery to clear.

If unexplained significant decrease in lower limb MEP signals present while upper limb MEP signals unchanged, then institute COPS protocol.

<table>
<thead>
<tr>
<th>Postoperative notes:</th>
</tr>
</thead>
</table>

Figure 6: Postoperative monitoring text entry to allow detail.

Open thoracoabdominal aortic surgery with cardiopulmonary bypass and deep hypothermic circulatory arrest. The protocol for patients undergoing DHCA starts in a path similar to that of left heart bypass with baseline tcMEP measurements at start of surgery. Monitoring continues throughout bypass recording the temperature at which signals disappear and reappear during rewarming (Figs 4 and 5). Our practice is to maintain strict adherence to measures that maintain cord perfusion during this period of cooling. Typically intercostal arteries are routinely reimplemented. It is our experience that following this form of intervention, signals disappear at an average bladder temperature of 21.8 ± 2.1°C (n = 7) and they may reappear at 21.4 ± 1.8°C (n = 7) but to an adequate level as late as 3 h following return to our intensive treatment unit.

Thoracic endovascular stent grafting. Monitoring of MEPs in TEVAR was introduced latterly in our practice and follows a unique pathway due to the nature of the intervention. As with our other protocols, baseline signals are acquired. Signal amplitude is confirmed just prior to and following stent deployment, and prior to stent deployment tcMEPs are rechecked and set as baseline. A drop-off of signal mandates correction of any variables to maintain cord perfusion. Should these measures not improve signal amplitude there are limited options available. Creating an endoleak in an attempt to reperfuse intercostal arteries is possible but the decision requires balancing the risks of the endoleak against the risks of paraplegia in the individual patient. At the end of surgery prior to leaving theatre, the progress of the tcMEPs throughout surgery is summarized briefly in the care pathway (Figs 4 and 5).

**Leaving theatre with no MEP signals.** Lack of tcMEP signals on leaving theatre and when there is an absence of muscle relaxant is an ominous sign for the risk of paraplegia. All conceivable troubleshooting measures should have been addressed. Strict adherence to the medical management of optimizing spinal cord perfusion should be ensured. This should include implementation of the ‘CSF drain status/Oxygen delivery/Patient Status (COPS) protocol’ [7, 8]. Our experience suggests that tcMEP signals may recover during the first 3 h postoperatively. In our institution, this
scenario is an absolute indication for continued intensive treatment unit-based tc MEP monitoring. Prior to continued MEP monitoring, an early ‘sedation holiday’ was essential to clinically assess spinal cord function.

Page 7: Postoperative management

During postoperative tcMEP monitoring when the patient is sedated (dexmedetomidine infusion with intrathecal diamorphine for pain relief), tcMEP monitoring is performed as required (approximately hourly) until the patient is ready to have sedation discontinued and be weaned from the ventilator. After this point, neurological examination should be feasible and MEPs no longer required. Postoperative tcMEP monitoring is performed in order to detect delayed paraplegia for those who leave theatre with appropriate signals and to monitor for a return of signals in those patients who leave theatre without signals. If a situation of significant lower limb MEP signal amplitude reduction arises, then the Aortic Team is alerted and the ‘COPS protocol’ is initiated [7, 8]. TcMEP trace amplitude values are noted simultaneous to the CSFP, MAP and CPP. This ensures that the amplitudes correspond to these recordings. Any issues can be commented upon in the notes section (Fig. 6).

Our postoperative protocols [8] mandate optimization of MAP and CPP in order to ensure spinal cord perfusion. In the sedated patient often vasopressors are required to maintain MAP. Since the introduction of MEP measurements, we have been more permissive of lower MAP providing MEP signals are maintained. This approach has reduced our vasopressor utilization.

Trouble shooting

Signal interference

(i) The cause is usually electrical interference from other devices, in our experience often electrically operated beds.
(ii) Check electrode position and connections.

Bilateral loss of limb signals

(i) Check electrode position and connections.
(ii) Check whether muscle relaxant has been administered.
(iii) Check patient temperature.

Unilateral change of signals in lower limb

(i) Femoral cannulation is the most common cause of unilateral loss of signal. This is due to distal ischaemia following direct and occlusive cannulation and is reversible following decannulation.
(ii) Sheath insertion in TEVAR procedures often causes limb ischaemia and thus MEP signal attenuation/absence. This is reversible once the sheath is removed.
(iii) Check electrode position and function.

Clinical example

Representative screen shots of the MEP signals are shown in Fig. 7. Signals are seen from *abductor pollicis brevis* (top) and then descending order: *tibialis anterior* and *abductor hallucis*; on left and right side of body. Figure 7A shows baseline readings from all limbs; (Fig. 7B) shows application of a cross clamp and loss of lower limb signals left and right, and (Fig. 7C) reappearance of lower limb signals with distal perfusion.

Influence of MEP on conduct of interventions and postoperative management and outcomes

Intraoperative. Intraoperative measurement of MEP has transformed the conduct of our operations particularly those performed using left heart bypass or cardiopulmonary bypass without profound cooling. Loss of the MEP signal results in a series of problem-solving steps to optimize spinal cord perfusion. Our modified COPS

Figure 7: Representative signals from *abductor pollicis brevis* (top) and then descending order: *tibialis anterior* and *abductor hallucis*. (A) Baseline; (B) aortic cross clamp and (C) established distal perfusion.

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protocol [8] is instituted. The surgical approach is redirected to early perfusion of intercostal vessels typically through a parallel graft. The conduct of the operation is altered to re-establish flow in native vessels such as sequential clamping and early distal flow into iliac vessels.

Postoperative. Postoperative care has been significantly altered by the use of MEP. Previously, we chased the spinal CPP aggressively by draining CSF and driving up MAP with vasopressor drugs. Our impression was that excessive vasopressor support was adversely affecting other outcomes. With the advent of MEP on the intensive care we are now more relaxed about cerebrospinal perfusion pressure in the sedated patient when signals are present. We believe we are using less vasopressor support; however, this will be analysed in future studies. Our protocol now is to reinstitute MEP measurements in any patient reintubated in the early postoperative phase to ensure adequate cord perfusion.

Endovascular intervention. Our experience is at an early stage however tcMEP monitoring during stent deployment and in the early postoperative phase allows for the potential abandonment of a multidevice procedure when MEP signals are compromised or the creation of an endoleak to improve cord perfusion.

Early clinical outcomes

Because of our case load, it is likely to take up 2–3 years to accumulate sufficient number of patients to statistically prove the subtle changes to our practice described above. However, Table 1 outlines our limited experience to date. At the point of analysis, we had used MEP monitoring in 57 patients. Six were excluded from our analysis, 2 because of intraoperative death and 4 because we were unable to establish baseline signals. Forty-four cases involved open surgery and six endovascular methods. Of the surgical cases, 30 were performed using left heart bypass, 11 using cardiopulmonary bypass and DHCA and 3 cases using cardiopulmonary bypass without circulatory arrest. Of interest is that in 18 of the 51 cases, there was a loss of MEP signal considered ‘non-methodological’ (i.e. temperature related, drug related, cannula related etc.), resulting in a change in operative approach. Of these 18 cases, 15 were seen to generate subsequent MEP signals while 2 did not. These two suffered paraplegia. In addition, of those that suffered loss of MEP signals that responded to intervention (15), 3 suffered delayed or transient paraplegia/paraparesis. Our tentative clinical experience suggests that a lack of return of MEP signals with hours of postoperative period indicates that patients will suffer paraplegia, while those that have transient loss of MEP signals during the case may be susceptible to delayed spinal cord injury.

CONCLUSION

In conclusion, the tcMEP pathway acts as a guide for the safe introduction and utilization of tcMEP in thoracoabdominal aortic interventions. TcMEP-led guidance of intraoperative and postoperative management in thoracic aortic surgery is an important adjunct in managing this complex patient group.

ACKNOWLEDGEMENTS

We would like to thank Colette Boex and Simon Stacey for their assistance in setting up the service.
Conflict of interest: none declared.

REFERENCES