The use of neuromonitoring in descending and thoraco-abdominal aortic aneurysm surgery
Literature Review

Matthew Fok , Mohamad Bashir, Thomas Kennedy, Mark Field
Thoracic Aortic Aneurysm Service
Liverpool Heart and Chest Hospital
Liverpool
matthewfok@gmail.com

Alex Mason
The School of Built Environment
Liverpool John Moores University
Liverpool

Abstract— **Without surgical repair thoracic aortic aneurysms are a lethal disease with poor prognosis. An extensive major operation is required to correct an aneurysm that involves the descending or thoracoabdominal aorta. Particular considerations must be made to protection of all abdominal organs, the brain and the spinal cord which are all at risk. Consequently there is a risk that these patients post operatively wake up paraplegic from spinal cord ischaemia due to the nature of the surgery. Certain techniques have evolved that have considerably reduced this risk. Neuromonitoring is a technique that can provide an intraoperative assessment of the integrity of the spinal cord through stimulation of nervous pathways and detection in either peripheral muscles or the brain cortex. In theory this can alert the surgical team to impending spinal cord ischaemia and change the management of this patient to prevent paraplegia. However, there is much ambiguity surrounding its use, with no conclusive evidence to prove this technique effectively reduces the rates of paraplegia. This literature review will assess the current methods of neuromonitoring in thoracoabdominal aneurysm repair.**

Keywords-Thoracic aortic aneurysm, thoracoabdominal aneurysm, neuromonitoring, spinal cord ischaemia, biosensors

I. INTRODUCTION

The aorta is a complex living structure that is entrusted with the lifelong responsibility to transport oxygen rich blood ejected from the heart, to supply every organ of the human body. An aneurysm of the aorta, defined as a localised dilation of the vessel, carries a dismal prognosis and if left untreated is a lethal disease. Of particular attention, are aneurysms that involve the descending thoracic aorta and the thoraco-abdominal aorta (DTA and TAAAR) which pose unique operative challenges to the cardiothoracic surgeon. Considerations must be made to circulatory support with a heart lung machine, as well as further multiple adjunctive measures to combat ischemic injury of all abdominal organs, the brain, and the spinal cord are advocated.

Surgical repair remains the only option in these patients but still conveys a significant risk of mortality and morbidity, particularly that of paraplegia which can be as high as 2-20% [1-4]. Development of strategies for the prevention of paraplegia have considerably reduced this risk, these include; cerebrospinal fluid drainage, left heart bypass, distal aortic perfusion, re-implantation of intercostal arteries, and deep hypothermic circulatory arrest [5-7].

Recently, the technique of neuromonitoring has become an attractive option to provide real time intra-operative assessment of the integrity of the spinal cord through electrical stimulation of the primary motor or sensory cortex of the brain, and detection in peripheral muscles. Currently its use is employed as a guide to operative repair and serve as a tool to alert surgeons to the possibility of spinal cord ischaemia [8]. However, there exists a wide variety of intra-operative protocols for neuromonitoring in different centres. The most common method used currently is that of motor evoked potentials (MEPs), others include somatosensory evoked potentials (SSEPs) and near infrared spectroscopy (NIRS). This literature review will explore the current scope of techniques for neuromonitoring in DTA and TAAAR in the ever growing quest for prevention of neurological injury. Our further research in this area will be to develop novel biosensors to detect spinal cord ischaemia in the spinal cord.

II. MOTOR EVOKED POTENTIALS

To understand the theory underpinning the use and mechanism of MEPs, a crucial understanding of the blood supply to the spinal cord and its relation to the aorta is required. The anterior portion of the spinal cord is crucial for producing voluntary movements of the human body and carries the corticospinal tracts which serves as a pathway for upper motor neurones[9]. Blood supply to the anterior two thirds of the spinal cord is delivered through the single anterior spinal artery [10-11]. However, the anterior spinal artery is of small calibre, often appears discontinuous and hence requires re-enforcement from segmental arteries branching from the ascending cervical artery, deep cervical arteries, intercostal arteries, lumbar arteries and sacral arteries. During DTA and TAAAR it is the segmental arteries arising from the intercostals and lumbars that require careful attention and have the potential to cause spinal cord ischaemia [12].

A. History of motor evoked potentials

The first use of MEPs can be attributed to Patton and Amassian, who in 1954 found that applying electrical simulation to the motor cortex of monkeys and cats evoked several descending volleys in the corticospinal tract [13]. These initial experiments were thwart in such that the repetitive nature of the electrical simulation would cause epileptic seizures and not particular suited to human experimentation. It was not until the 1980's when Merton and Merton, from the Cambridge neurology group, who were the first to coin the name motor evoked potentials from their experiments, were able to refine this procedure [14]. They experimented with high voltage, low resistant transcranial electrical simulation to produce electromyographic twitches, on themselves. Still the ability to produce the EMG changes required uncomfortably high voltages and was poorly tolerated. Barker et al, again from the UK, are credited with the first published report of transcranial magnetic simulation in 1985 [15]. This technique used a brief yet strong magnetic field to induce an electrical current that could pass through the skull without the activation of nociceptors in the scalp thus reducing pain and discomfort. It is this technique that is now employed worldwide for motor evoked potentials.

B. Electrophysiology of motor evoked potentials

MEPs can be evoked through two methods, either transcranial magnetic stimulation (TMS) or transcranial electrical stimulation (TES). In TMS, stimulating coils are placed on the scalp in the position of the primary motor cortex[16]. A rapidly changing magnetic field is used to stimulate an electrical signal that travels from the motor cortex through the upper motor neurones in the anterior spinal cord and further on to the lower motor neurones to stimulate peripheral muscles. The speed of change of the magnetic field is related to the strength of electrical signal. TES require cutaneous electrodes placed to transmit the electrical stimulus of constant current, high-voltage pulses of brief duration. MEPs are then recorded in targeted muscle groups with surface electrodes, or coaxial bipolar needle electrodes.

MEPs produce characteristic waves that can be measured [18]. The initial resultant wave following simulation is names the direct wave (D wave). The D wave represents direct excitation of the corticospinal tract. Following a D wave several I waves follow, so named because they reflect indirect depolarization of the same axons via corticocortical connections. It is the summation of these waves in the anterior horn of the spinal that cause excitation of the lower motor neurones and these waves are measure to produced characteristic measurements to reflect the integrity of the spinal cord.

MEP threshold is a term used to describe the level of stimulation that is needed to obtain reliable MEPs over 50 microvolts in about 50% of 5-10 stimulations [18]. This term is important during intra-operative management as it reflects one of the measurements used to determine spinal cord compromise. The amplitude is also measured and is best expressed in terms of the percentage of the muscle response amplitude evoked by supramaximal peripheral nerve stimulation of the target muscle.

C. Use of motor evoked potentials

Historically, its use as tool for intraoperative monitoring resided initially in neurosurgery. It has diagnostic and prognostic uses in cerebrovascular accidents, multiple sclerosis, epilepsy, movement disorders, and motor neurone disease [19-22]. Intraoperative monitoring has now been used in brain tumour operations, spinal operations, cerebrovascular disease operations including carotid endarterectomy, and microvascular decompression.

Recent evidence have pointed towards it effectiveness in DTA and TAAAR. The current 2010 American College of Cardiology Foundation/American Heart Association Aortic guidelines state that MEPs may be considered as a strategy to detect spinal cord ischaemia and to guide re-implantation of intercostal arteries and/or heamodynamic optimisation to treat spinal cord ischaemia (level of evidence2) [23]. This strategy is now employed and promoted by many centers worldwide in DTA and TAAAR surgery.

However, its use remains ambiguous as MEPs vary greatly dependant on MEP protocol and surgical procedure, operative variables including temperature, CSF drainage, neuromuscular blockade, blood pressure and electrolytes. Critically, although the theory underpinning the use of MEPs as a neuromonitoring tool to prevent paraplegia is clinically sound, conclusive evidence to show its use is beneficial does not exist.

D. Safety

The technique of measuring MEPs remains with little complication to the patient. Pain and discomfort can be experience with transcranial electrical simulation [24]. TMS coils used to produce an electrical signal can very quickly heat up and may potential be a source of harm. However, this is avoided with temperature monitors and automatic shutdown of the coils. These methods have been known to produce seizures and for the most part a bite block is placed in the mouth during surgery to protect the airway from this complication.

III. SOMATSENSORY EVOKED POTENTIALS

SSEPs have been used in a variety of surgeries and have recently been used in aortic aneurysm surgery. Much like MEPs the key to understanding SSEPs is a good basing in spinal cord blood supply anatomy. SSEPs enjoy dual blood supply from a paired posterior spinal arteries [10]. The posterior spinal arteries arise from either the vertebral arteries or the posterior inferior cerebellar arteries and run caudally on the posterolateral surface of the cord. Furthermore, the metabolic demands of the upper motor neurones in the posterior cord are not as demanding as the motor neurones. When coupled with the fact that the posterior cord does not reply as heavily on collaterals from the aorta it subsequently means that in comparison to the anterior spinal cord, the posterior pathways are much less susceptible to spinal cord ischaemia following DTA and TAAAR [24].

A. *Electrophysiology of somatosensory evoked potentials*

Typically an electrical impulse delivered through a needle electrode to stimulate a peripheral nerve [25]. Commonly the median nerve, common perineal nerve and posterior tibialis nerve as used to stimulate. Signal averaging is used to extract the SSEP from other signals by standard EEG electrodes.
Much like MEPs SSEPs can measure amplitude, latency and also waveform morphology. Peak latencies are consistent across subjects, whereas amplitudes show large intersubject variability

B. *Use of somatosensory evoked potentials*

SSEPs have been used in a wide variety of situations other than intraoperative monitoring of the posterior aspect of the spinal cord. These include; evaluation of the peripheral nervous system and the large-fiber sensory tracts in the CNS, localization of the anatomic site of somatosensory pathway lesions, Identification of impaired conduction caused by axonal loss or demyelination, confirmation of a nonorganic cause of sensory loss [25]. It is less commonly used in aortic surgery because of it reduced susceptibility to ischaemia.

C. *Safety*

Currently SSEPs very rarely cause any significant harm to the patient and is consistent to the safety profile of MEPs (see above).

IV. NEAR INFRARED SPECTROSCOPY

NIRS is a technique that has only currently being developed as a technique to assess the collateral paraspinous collateral network to predict pending spinal cord ischaemia intraoperatively. However, currently this technique is still in its infancy and experimental stage meaning there is very little in the way of research as to the benefits of this method. There are currently no studies comparing the efficacy of NIRS to MEPs or SSEPs. NIRS offers the advantage of using optodes rather than electrodes, which patients find less discomforting and less pain full. Furthermore, it produces real time measurements intraoperatively.

Etz et al theorise that NIRS takes advantage of the extensive collateral network surrounding the spinal cord and that this network that provides blood in chronic ischaemia and in the acute situation of segmental artery ligation. It is this theory they are currently researching as a method to detect impending spinal cord ischaemia intra-operatively.

A. *History of near infrared spectroscopy*

NIRS was initially discovered in the 19th century by the British astronomer Willian Herschel [27]. It has not seen much development into the medical community and its use mainly resides in assessing cerebral perfusion during cardiac surgery. However, its development of use into aortic surgery has own recently been suggested and investigated. LeMaire et al were the first group to show that in pigs NIRS was able to show regional decreases in oxygen saturations following sequential ligation of segmental arteries [28]. It is now gaining more popularity within the aortic world as subsequent case reports and studies are beginning to appear.

B. *Technical specification*

NIRS takes advantage of the natural visible colour change seen in oxygenated and deoxygenated blood. It primarily detects three different parameters; oxyhaemoglobin, deoxyhaemoglobin, and the oxidised form of cytochrome aa_3 [29]. Cytochrone aa_3 found in the mitochrondria wall of all eukaryotic cells and represents the terminal enzyme within the electron transfer chain process. An applied beam is shone through the skin and is absorbed following interaction with optimal pigments including haemoglobin and myoglobin which will change the resultant spectrum produced in varies with the degree of oxygenation [30]. Detection is made through the reflection of the light produced by dectectors in the NIRS probe.

C. *Use of near infrared spectroscopy*

NIRS has been used in a variety of situations. It is currently employed as a technique in cardiac surgery to measure cerebral oxygenation [31-32]. Its use however, has not gained as much publicity. There are isolated reports of NIRS being used in abdominal surgery or vascular surgery, particularly in carotid endarterectomy, and for trauma patients. However, routine use of NIRS is very small and secluded to cardiac surgery. It use to detect impending signs of spinal cord ischaemia is not yet conclusively proven and there remains a lack of high level evidence available.

To our knowledge, only 5 papers exist on the use of NIRS for monitoring spinal cord perfusion [33-37]. There does not exist comparative studies as to the best method of neuromonitoring in DTA and TAAAR. Etz et al in 2013 reported the use of NIRS to monitor the oxygenation of the paraspinous collateral network [38]. They demonstrated that the use of NIRS may potentially have a use in the future of neuromonitoring in this type of surgery considering the NIRS levels were directly proportional to the compromise of aortic blood circulation. Other case studies and small case series in endovascular repair and type b dissection have found good associations between oxygenation of tissues and predict an impending ischaemic event in the spinal cord. This indirect method still required a wealth of clinical studies to show the correlation between NIRS and paraplegia and to assess its efficacy.

D. *Safety*

This technique has not yet been reported to have any adverse effects to the patient following placement of optodes.

V. SUMMARY

This literature review assessed the current techniques that are employed worldwide in an effort to reduce spinal cord ischaemia following DTA and TAAAR. Patients undergoing DTA and TAAAR are susceptible to a risk of paraplegia that is quoted as high as 20% [23]. This life changing complication has led to a concerted effort to reduce its risk. There is high quality evidence to advocate the use of cerebral spinal fluid

drainage to reduce intracranial pressure, and has been demonstrated in randomised controlled trials and systematic review to statistically reduce the incidence of paraplegia. Good evidence is available for hypothermia to reduce metabolic demand, and this is also the case for other adjuncts including re-implantantation of segmental arteries during thoracoabdominal repair.

Neuromonitoring is an attractive option to assess the integrity of the spinal cord during surgical repair of the aorta. It primarily relies on electrical stimulation of the motor or sensory cortex with detection of a signal that has travelled through the spinal cord to peripheral muscles. This is able to give an indirect view of the functionality of the spinal cord intra-operatively and any deviation of this is used as a marker to reflect subclinical spinal cord ischaemia. In turn, intraoperative detection of decreased motor evoked alert the surgical team to possible impending spinal cord ischaemia and allows them to change operative strategy in an effort to regain the motor evoked potentials. The concurrent measurements of SSEPs mean that both the anterior and posterior portion of the spinal cord is monitored. However, its use is under much debate. Currently, there exists a wide variety of intraoperative monitoring protocols. There is no consensus as to what threshold to intervene, some centres do not routinely measure SSEPs. Furthermore, MEPs and SSEPs are susceptible to change with neuromuscular blockade and anaesthesia. This further increases the complexity of interpretation of MEPs, and in consideration that many centre use different types of anaesthesia, international comparison of results become more difficult. Due to the nature of clinical research it has not yet conclusively been proven that changing operative strategy during surgery actually effects the outcome.

NIRS is a novel method that uses near infrared spectroscopy that monitors tissue oxygenation of the thoracic and lumbar paraspinous muscles hence the par-aspinous CNdto provide real-time, non-invasive spinal cord monitoring, potentially indicating pending spinal cord ischemia. This new method has shown some promise as a novel method to detect pending spinal cord ischaemia and has shown some promise as a new monitoring tool. However, it is still in the experiment stage and requires further experimentation before its use can be advocate in this situation.

Our further experimentation will focus on novel neuromonitoring techniques that incorporate novel biosensors that can look into quick, cheap and easy, real time monitoring.

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