A Guide to Motor Nerve Monitoring

by Chris Hovey, BSc

This Guide is intended as background reading for medical staff in the theory and practical use of motor nerve monitoring during surgery. It focuses on the Neurosign 100 and Neurosign 800, although the theory and much of the practice is common to all devices used for monitoring.

It is not intended that this guide be read at one sitting! Use the Index and the Contents to pick out the information you need.

The information contained in this publication is offered only for guidance. At all times, it remains the responsibility of the operator to ensure that the equipment is being used appropriately and safely.

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About The Magstim Company

The Magstim Company designs and manufactures electronic equipment for the medical market from its plant in West Wales in the U.K. There are two broad product ranges; a number of magnetic stimulators which gave rise to the company’s name; and two motor nerve monitors.

The magnetic stimulators allow the peripheral and cortical motor nervous system to be stimulated in the clinical and intra-operative setting. Their main advantage is that the stimulus is painless; this allows the neurologist to conduct lengthy investigations with the minimum of discomfort for the patient.

The introduction of rapid rate magnetic stimulators has opened research into a number of new areas, including rehabilitation and psychiatry.

Please note that not all applications for magnetic stimulators are cleared by the FDA, and consequently readers in the USA should contact the Company for further information with regard to regulatory issues.

The motor nerve monitors which the Company manufactures form the basis for this Guide.

What is Motor Nerve Monitoring?

Monitoring motor nerves involves the collection and analysis of Compound Muscle Action Potentials (CMAP). The collection of CMAPs is usually achieved by inserting needle electrodes into the muscle innervated by the nerve at risk; the analysis of the data is the means by which the surgeon is given appropriate information.

An alternative to CMAPs is to collect Nerve Action Potentials (NAP) by placing electrodes directly onto the nerve itself, rather than the muscle it innervates. Whilst this is a useful technique and is referred to later in this Guide, the great majority of applications utilise CMAPs.

Why Perform Motor Nerve Monitoring?

Monitoring provides information for the surgeon. That information has to be balanced against the surgeon’s experience, the patient’s anatomical variance, and factors outside the direct area of surgery - artifacts and anaesthesia, for example.

Facial nerve monitoring has been performed for several years and has reached the status of ‘standard of care’ in many institutions. The Neurosign 100 is the Company’s facial nerve monitor, and is in widespread use throughout the world.

Monitoring has:

- helped to improve preservation rates in surgery involving the facial nerve, particularly where large cerebellopontine angle tumours are removed
- helped to improve patient outcome in terms of the quality of the nerve preserved
- provided a backup against anomalous nerves and variable anatomy in more routine surgeries
- reduced the risk of nerve injury in revision surgeries

However, there is no substitute for experience and skill, and no piece of monitoring hardware can be used as any form of replacement.

A Brief History

Facial nerve monitoring in some form has been practised for many years. The simplest form was to have someone watch the face and observe and report any twitches. A variance of this technique was to have the scrub nurse or assistant surgeon rest their fingers on the face to feel any movement. This basic technique suffers from several drawbacks. The face has to actually move, the assistant has to feel or observe that movement, and twitches may be missed or ignored.

An improvement on this technique was the hand-held, disposable stimulator. This was used to directly stimulate the nerve or suspect tissue, and if the nerve was stimulated, the face would twitch.

In 1979 Delgardo showed that EMG could be used to perform the same function but at a much more sensitive level. Various pieces of equipment were developed through the 1980’s, varying from simple EMG type machines to balloons inserted into the mouth to measure changes in pressure and piezo devices placed on the corner of the mouth.

In practice, the EMG type equipment has proved to be the most useful. Not only does it provide feedback if the surgeon uses the in-built stimulator, the machines also provide continuous monitoring so that any spontaneous responses, caused by mechanical disturbances of the nerve, will also be detected and relayed to the surgeon.

In 1987 the NIM-2 was launched, a 2 channel facial nerve monitor. It proved very successful, especially in the USA. In 1992 the Neurosign 100 was launched, a similar machine although engineered using different concepts. In 1997 the Neurosign 800, an 8 channel monitor, came to market, and has taken the idea of motor nerve monitoring to a new level.
The future of nerve monitoring is assured; the questions relate to its ease of use, reliability and new applications.

**The Neurosign 100 Nerve Monitor**

The Neurosign 100 was designed in 1991 and was launched commercially in 1992. The design was undertaken with the co-operation of ENT and Neurosurgery Consultants at Guy’s and The Maudsley Hospital, London. The unit is a self-contained Nerve Stimulator and Monitor. It provides two independent channels for monitoring which may both be used to monitor the VIIth nerve or may be split between, for example, the VIIth and Xth nerves. The machine has been designed to help the surgeon, but it does not in any way reduce the need for a high degree of surgical skill, nor a sound knowledge of the anatomic structures involved. When used in routine procedures, the machine gives both a sense of comfort and can help to speed surgical decisions.

The Neurosign 100 consists of three major parts, all of which must be connected to complete the system. The first part is the main unit, which contains the power supply, stimulator, isolation electronics, signal conditioning and audio electronics. The second is the Pre-Amplifier Pod, which provides the amplification of the signals and to which the sensing electrodes are connected. The third part consists of the Stimulator Pod and the associated Probes, which the surgeon uses to identify or confirm the integrity of the nerve.

The Neurosign 100 uses the mains supply to power the unit rather than batteries. The reason for this is primarily one of convenience. It is undeniably an extra chore to remove and recharge batteries and to keep a backup available which is in good condition. The Neurosign 100 is fully patient isolated and was designed to comply with international safety standards, including IEC 601 and UL 544. Because of these standards, it was unnecessary to use batteries which serve only to reduce the scope of the respective Standards.

The mains supply is converted to an electronics supply voltage using a transformer with 4kV isolation. This low voltage power supply provides power for the display and audio side of the electronics, and is also used to generate the isolated power supply. This has an isolation of 1.5kV - that is, you can place 1500Vac on the inputs of the pre-amplifier pod - the patient connections - and the leakage current from the pod via the Neurosign 100 to earth must be less than 50µA. In fact, it is less than 10µA. The low voltage power supply also provides power for an isolated supply for the stimulator section. This is a separate isolated supply to that of the pre-amplifier pod and has the same standard of isolation. By having a quite separate supply for the stimulator, the possibility of artifact from the stimulator being detected by the pre-amplifier electronics is minimised.

**Stimulator**

The stimulator provides a negative going output pulse of 200µs duration with a constant current set by the control knob on the front panel. There has been quite a debate as to the merits of constant current over constant voltage, with some nerve monitors providing the choice of either. Both methods have their advantages and disadvantages, but it is impractical to switch between one and the other during an operation. Constant voltage sources may exceed the advisable current limits when stimulating; constant current sources may stimulate ineffectively under certain circumstances; but it is best to stay with one form of stimulation. The Neurosign 100 uses constant current stimulation, and it is our experience that the design of the probes is the more important factor in the effectiveness of stimulation.

The stimulator provides an output range of 50µA (0.05mA) to 5mA. The lowest settings are suitable for use at or near the brainstem where the nerve is unmyelinated. Please note that no machine currently on the market has a setting lower than 50µA. Although some may claim to reach 0.00mA on the display, an inspection of the technical data reveals that they retain a residual current of 50µA below this setting. This point has led to considerable confusion, especially when the surgeon can apparently stimulate the nerve successfully even though the display shows that no stimulating current is available!

The 5mA setting is intended for stimulating through bone. The stimulator can be used to provide a subjective assessment of the depth of bone when drilling near the nerve. Very approximately, 1mA of current equates to 1mm of bone. The bipolar probe must be used for this type of stimulation.

More usually, the stimulator would be set to 0.2mA, this level being adequate to stimulate the facial nerve under most conditions. At the brainstem 50µA may prove to be sufficient current; where the nerve has its protective sheath, the current required may increase to 0.5mA or more. When using the Neurosign 100 to monitor the recurrent laryngeal nerve, we have found that a higher current, in excess of 0.5mA, may be necessary, and the nerve itself appears to have a threshold below which stimulation is ineffective. This differs from the facial nerve in that we have not detected a threshold value of stimulation for

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this nerve in that as the stimulation is decreased, so the response decreases. With the recurrent laryngeal nerve, it appears that the threshold is very much like a switch - there comes a point where, quite suddenly, the response disappears.

The stimulator has two frequencies, 3Hz and 30Hz, which are designed to meet varying anaesthetic protocols. Under normal circumstances, where no neuromuscular block has been used, the Neurosign 100 is set to 30Hz. This gives an immediate response, which is easily recognised by theatre staff. If the nerve apparently tires after a few moments of stimulation, or if the anaesthetist has needed to introduce some neuromuscular block during the procedure, then the stimulator should be set to 3Hz. The facial nerve takes about a quarter of a second to recover from a single pulse of stimulation when neuromuscular block has been used; by using a frequency of 3Hz, sufficient time is being given to the nerve axon to recover before firing again. However, because of the relatively low frequency and consequently the extra time taken for the response to be noted by the theatre staff, the Neurosign 100 should routinely be set to 30Hz. The 3Hz setting is not a guarantee that the neuromuscular block will be overcome, and if any block is used there will be no responses from manipulation or mechanical distortion of the nerve. Therefore this setting is provided only for those instances where the patient has had to be paralysed during the procedure for the sake of safety and to enable some monitoring to continue.

**Signal Conditioning**

All nerve monitors translate the EMG signal into a usable form, whether this be an oscilloscope trace, a bargraph indicating amplitude, an audible tone or raw EMG sound. In the case of the Neurosign 100, the EMG is turned into an audio signal and has bargraphs indicating amplitude. The machine has a Channel Identity feature which colours the tone of each channel and enables the user to differentiate between the channels without having to look at the display. Therefore, for example, the upper and lower branches of the facial nerve can be identified without the surgeon having to look up from the microscope.

**Pre-Amplifier Pod**

The voltages which are produced during muscle contractions are very small - in the order of millions to a few thousandths of a volt - and are very susceptible to interference from other sources within and outside the body when being measured. In order to turn these small signals into useful data, a very carefully designed pre-amplifier pod is employed. By keeping this as close as possible to the patient, a minimum of noise is amplified and the electronics has the best chance of rejecting artifact. Artifact, for the purposes of the pre-amplifier pod, can be defined as an equal signal which appears on both the active electrodes. By comparing this signal with a reference electrode, it can be determined whether the input is genuine signal to be amplified or common artifact which is to be rejected. By using a differential input amplifier with a reference away from the two sensing electrodes, it is possible to reject much of the artifact created by bipolar electrocautery, metal to metal contact etc. To improve matters still further, the Neurosign 100 has separate reference electrodes for each channel. The Neurosign 100 is unique in having this arrangement, and we believe that this is the reason for its exceptionally good artifact rejection. It allows bipolar diathermy to be used with little or no audible interference. This can be important when working close to a nerve as the surgeon will not be aware of the thermal effects, or indeed even of the proximity of the bipolar coagulating forces to the nerve, if the signal is muted.

**Electrodes**

The starting point for any nerve monitoring system is the electrode used to detect the body signal. Various electrodes have been tried, including balloons to measure pressure changes, piezoelectric sensors, surface electrodes, hooked wire electrodes, and needle electrodes of one type or another. Unlike a neurophysiological examination, where a specific MAP or small group of MAPs may need to be measured, and consequently a needle with only a very small uninsulated portion is used, we want to detect voltages within a large area of the muscle. By using uninsulated needles of 20mm length, the Neurosign 100 ensures that it samples the muscle thoroughly and also ensures a low enough electrode impedance to allow for good artifact rejection. The needle electrodes supplied by the Magstim Company are designed to have a long life; they can be autoclaved and are plaited together in order to reduce noise and to minimise electrical pick-up and movement artifacts in the wires themselves.

Needle electrodes will not always be the most suitable type of electrode for a given nerve monitoring situation. In some short procedures, where no great accuracy of electrode placement is required, surface electrodes can be used quite successfully. For monitoring the laryngeal muscles in either thyroid or skull base surgery needles can be inserted in the thyroarytenoid muscles or vocal cords, but these are difficult to place and may be the cause of infection post-operatively. The Magstim Company has
developed an electrode which attaches to the endotracheal tube and monitors both the vocal cords. This non-invasive technique has proved very simple to locate correctly and is effective in defining the recurrent laryngeal nerve. In skull base surgery it is helpful in locating the IXth and Xth nerves.

Further specialist electrodes are in development and the Company is always keen to develop a surgeon’s ideas where practical.

The Neurosign 800 Nerve Monitor

The Neurosign 800 has 8 channels, as opposed to the 2 of the Neurosign 100. In addition, the Neurosign 800 can be used as either a bargraph machine, or to display waveforms. It also provides for much greater control over many of the default parameters of the machine - for example, a constant current or a constant voltage source can be set for the stimulator, whereas the Neurosign 100 can only be used as a constant current source. A limited number of waveforms can be stored, recalled, evaluated and printed, or a printer can be used to dump screens immediately.

The Neurosign 800 therefore gives much greater flexibility, and permits much more extensive monitoring to be undertaken.

Many of the accessories and component parts are identical to both machines. All stimulating probes, the stimulator pod and mute sensor are interchangeable, the main difference between the machines lying in their electrodes.

Neurosign 800 electrodes

Because of the number of electrodes involved, only a single reference electrode is required for all 8 channels. Electrodes are therefore manufactured as pairs, the cores twisted together to reduce noise. However, to reduce noise further, it is strongly recommended that once inserted, the electrode wires should be collected together and taped to form a neat bundle. This reduces the risk of individual needles being pulled out, but also helps to cancel out any noise detected in a single electrode pair, since the reference will also be in the bundle. Where this is not practical, electrode wires should be collected together and placed in a small pile to achieve a similar result.

Common Features

Nerve Stimulation

A neuron has a resting potential in the range of -40mV to -90mV, typically -70mV, on the inside of the cell membrane. Therefore the outside of the neuron is positive with respect to the inside, and in order to depolarise the neuron a negative pulse is applied to the nerve. The Neurosign 100 supplies a 200µs pulse at a current set by the user. This current, passing through tissue, sets up a negative going voltage according to ohms law, and this voltage depolarises the nerve.

As can be seen from the diagrams which show the importance of the cathode in stimulating the nerve, this use of current to depolarise the nerve has certain implications in the use of stimulating probes.
The use of the concentric probe much reduces this effect, since the cathode is in the centre of the anode and therefore, if there is a response, it must be the nerve, and if there is no response, neither the cathode or the anode is touching the nerve.

The bipolar probe is excellent for accurate mapping of the nerve and for stimulating through bone. The facial nerve can be stimulated when drilling through the mastoid process or the internal auditory canal. As a very rough guide, 1mA of stimulating current equates to 1mm of bone; in any event, as the surgeon drills closer to the nerve, the response to stimulation will become greater.

When drilling, a high frequency whine or repetitive clicking is sometimes heard; this is the vibration from the drilling affecting the nerve. Occasionally this response will continue even after the drilling has ceased. This may be due to irritation of the nerve, or possibly the thermal effects of the drilling. In either case, it is wise to wait until the response has stopped.

The bipolar probe has some current spread because the electrode tips are 2mm apart. This allows the surgeon to stimulate the nerve through bone and tissue, or by careful control of the current, to accurately map the nerve. Depending on the stimulating current being used, the probe will be accurate to within about 1mm, and an indication of depth is given by the response rapidly diminishing. This allows the surgeon to know that the nerve is present although covered by a layer of tissue. If the surgeon needs to know if the nerve is within a certain area, for example to check that the nerve is not lying stretched over the surface of a tumour, then the stimulating current can be increased to 1mA and the probe used to confirm that the nerve is not present. This has been proved to be a very useful feature of nerve monitors in general, and the Neurosign 100 in particular. The bipolar probe is manufactured as a straight handled device for ENT use.

The concentric probe is a different design such that the cathode is surrounded by the anode; this probe allows the surgeon to discriminate accurately between the finest of structures since the stimulating electrodes are separated by only 0.25mm. This gives the surgeon great flexibility and confidence in the interpretation of the sounds heard from the Neurosign 100 or 800. The concentric probe is particularly useful when the microscope is in use as it has a diameter of only 1mm, or when great accuracy is required. With this probe there is virtually no current spread, which is useful where nerves are close together. There are two types of concentric probe available, suitable for ENT and Neurosurgical use.

**Figure 2: Concentric Probe end view**

For surgeons who prefer them, we supply forceps which are wired as stimulators. Two types are available; a 150mm straight pair for ENT use; and a 250mm bayonet pair for Neurosurgical use. This allows the surgeon to use the forceps as normal instruments, reducing the number of times it is necessary to withdraw instruments and introduce the probe. The forceps cannot, of course, be used as diathermy instruments.

Surgical instruments can also be adapted for use with the Neurosign 100 and 800. This allows the surgeon to stimulate tissue continuously whilst removing pieces of tumour from the nerve. Probe design is always under review, and the Company will look at any suggestions with interest.

**Stimulator Pod**

All the probes designed for the Neurosign 100 and 800 have safety connectors so that they will fit the Stimulator Pod. This is designed to allow two Probes to be connected to the Neurosign 100 or 800 at the same time. There is no switching involved - both probes remain active at all times. Warning is given that a probe is passing current by the CURRENT CONFIRM indicator on the front panel of both the Neurosigns. If this remains on after stimulation, then the tip is probably covered in blood or tissue and needs to be wiped clean. However, we have not found this to be a problem, and most surgeons find it very useful not to need to use a switch to change from one probe to another. The Pod has a clip so that it will fit on the side of the Operating Table; together with the Pre-Amplifier Pod, it is out of the way during the surgery.

**Anaesthesia**

In all nerve monitoring, this is the one aspect which can destroy any attempt to detect responses. It is vital that, where possible, no muscle relaxants are used. In the case of acoustic neuroma procedures, where it may take one to two hours to reach
the tumour, muscle relaxant can be used during intubation and then removed so that it has worn off by the time the surgeon has gained access through the skull. However, in the case of shorter procedures, and particularly where the surgeon wishes to monitor the nerve at an early stage, any muscle relaxant at all will affect the quality and amplitude of the responses obtained. In particular, a parotid or thyroid procedure will mean that the surgeon will be needing to monitor the respective nerve within minutes rather than hours, and in our experience the conventional train of four is a poor indicator of the responsiveness of the nerve. The train of four stimulator is designed to induce a supra maximal response, whilst the Neurosign 100 is trying to detect signals well below the threshold of visible movement. Great care needs to be taken when choosing a suitable anaesthetic protocol which will allow for intubation, the safe maintenance of the patient, and full nerve monitoring. Neuromuscular blockers used during intubation should be as short-acting as possible. Please refer to the Reference Papers for further information.

The Facial Nerve

The basic anatomy of the facial nerve is shown in figure 3. In addition, the muscles relevant to facial nerve monitoring are shown. The facial nerve exits the brain stem, travels a short distance - about 17mm - to enter the internal auditory meatus where it runs together with the VIIIth nerve until it reaches the end of the internal auditory canal (about 10mm). From here it travels inside a boney canal, close to the inner ear, through the mastoid bone and emerges at the stylomastoid foramen. The nerve is a single trunk, containing about 30,000 fibres. Damage at this stage can result in total paralysis of the face.

Once the nerve emerges from the foramen, it passes into the parotid gland; here it divides in a variable manner, with the four main branches leading to the larger areas of the face, as indicated in figure 3. Small twiglets pass between the main branches and provide innervation to small muscles, to individual motor units, or provide links between the branches that can lead to reinnervation of the face should these smaller branches be damaged. The cervical branch actually runs underneath the angle of the jaw, and innervates the skin and a thin layer of muscle known as the platysma on the neck. This branch is often damaged or sacrificed, leading to some deterioration in skin tone around the neck. Another branch, the posterior auricular, innervates the ear lobe and muscles on the back of the skull; this branch is usually cut since it is of little importance to those who cannot wiggle their ears and it gets in the way of the dissection. The strongest branch, in relation to nerve activity during monitoring, is usually the mandibular branch, perhaps not surprising given its role in speech and eating.

Facial Nerve Monitoring

The facial nerve is at risk in a number of surgical procedures, and its injury is of particular concern to the patient because of the wide range of expression used by humans in communication, and because of the perceived disfigurement left by facial nerve injuries. In the great majority of surgeries which may involve the facial nerve, the patient has normal nerve function before the surgery; one of the surgeon’s aims is therefore to preserve that nerve function without any impairment.

The following sections deal with individual surgeries and recommends the techniques with which to provide comprehensive monitoring.

How Does Monitoring Affect the Surgeon?

For monitoring to be effective, several factors have to be considered:

- information has to be given to the surgeon immediately
- ‘false’ information (artifacts) has to be identified and relayed to the surgeon
- the equipment must be reliable
- the whole operating team must be involved

Both the Neurosigns have powerful audio amplifiers, so that basic information is relayed instantly to the surgeon. A gentle stroking of the nerve results in a quiet rustling sound; a tug on the nerve results
in a loud neurotonic discharge. Artifacts can be identified because of the harshness of the sound; in addition, the Neurosign 800 has a waveform display so that artifacts can be seen.

An important factor which is easy to overlook is that many people will be involved in providing a monitoring service. The anaesthetist in particular is important, as the patient should not be relaxed. Someone must look after the equipment, arranging for sterilising electrodes and probes, connecting the equipment etc. Many of these ancillary functions need to be doubled, since staff or rotas may change.

In brief, the surgeon will hear any response caused by mechanical or electrical stimulation of the nerve, and can modify the surgery appropriately; however, for reliable monitoring to be carried out, the surgeon requires the co-operation of a number of other professionals in the Operating Theatre.

**Removal of a parotid tumour**

Because of the branching of the facial nerve at the *pes anserinus*, the fine filaments of nerve fibre leading to the facial muscles, and the need to mobilise the nerve in deep lobe parotidectomies, it can be very helpful and timesaving to use either the Neurosign 100 or 800. Fibres can be quickly identified as nerve tissue, and the initial location of the nerve can be made with confidence.

In particularly difficult cases which involve scar tissue, the surgeon may find it helpful to be able to monitor more than two parts of the face. If the electrodes are inserted according to the diagram for monitoring the facial nerve during an acoustic neuroma excision it is possible that the middle part of the face may be left with insufficient monitoring. This can be partially addressed by changing the montage so that an active electrode lies above and below the mouth and the eye, as shown in the figure 4. This will improve the ability of the monitor to detect responses, but at the expense of artifact rejection and selectivity.

For more precise identification of fibres and greater confidence in coverage the Dual Pod Switch will enable the upper and lower branches of the facial nerve to be treated independently. Electrodes inserted above and below the eye would be connected to Pod A, and electrodes inserted above and below the mouth would be connected to Pod B.

The spacing between the needles could be increased to 10mm. In this way the zygomatic and buccal branches of the facial nerve can be monitored; selectivity will be maintained whilst a greater area of the face is monitored. Remember that for Pod B no reference electrodes should be used; the sockets on the Pod are left unconnected. Until the surgeon has located the *pes anserinus*, the Dual Pod Switch will be set to monitor Both Pods. As soon as the junction has been identified, the Dual Pod Switch can be set to monitor whichever branch is relevant. This system will give the surgeon greater flexibility and confidence when using the Neurosign 100 to monitor the facial nerve.

This is the most common use of facial nerve monitoring for the ENT surgeon. There is, in the literature, an argument made that no monitoring is required for parotidectomy if normal anatomical dissection techniques are employed. I would emphasise that a nerve monitor *is an aid, another tool*, and as such it is an extremely cheap and valuable tool to employ. Whilst many superficial parotidectomies do prove to be straightforward, some are not and it is difficult to be omniscient before the operation!

There is little doubt that the use of a monitor during a deep-lobe or revision parotidectomy is of considerable help to the surgeon. It can not only warn of potential injury, but also help in the decision-making process, speeding up the operation and providing a large degree of comfort and confidence to the surgeon.

The parotid gland produces saliva, and benign (usually) tumours grow within it. The facial nerve emerges from the stylomastoid foramen as one trunk, and divides within the parotid gland into five branches. One of these branches, the posterior auricular (which innervates the ear lobe) is usually
sacrificed as it gets in the way of the dissection, and is not considered important. The other four branches divide somewhere within the parotid gland, but the exact division is variable, and in some individuals some divisions may even be missing. The branches further subdivide, and as many of these branches may need to be sacrificed in order to remove the gland, it is useful to be able to stimulate these fibres to see which are the most significant.

A tumour which lies on top of the nerve is known as a superficial parotidectomy, and one which lies underneath or on either side is known as a deep-lobed parotidectomy. The latter is more difficult and carries more risk to the facial nerve. Refer to figure 3 for the approximate anatomy of the facial nerve.

Figure 4 shows the electrode montage that should be used with the Neurosign 100. Because this is a 2 channel machine, and 4 branches have to be monitored, the electrodes need to be spread out as shown. If they are not, areas of the face will not be monitored, and if stimulated, will move even though there is no response from the monitor. However, this is clearly a compromise, because the best that can be determined is that any response is coming from the upper or lower part of the face.

To monitor each branch individually, which is particularly useful in revision parotidectomy, the Neurosign 800 is more helpful. Figure 6 shows the electrode placement when using the Neurosign 800. It can be a definite advantage to be able to discriminate between the four branches, as any anatomical variation can be quickly and definitively defined.

**Acoustic Neuroma**

To monitor the facial nerve, the Neurosign 100 is widely used when acoustic neuromas are being removed. The electrode montage is shown in figure 5 and shows a slightly different placement than for parotidectomy. The reason for using this montage is that the closer the electrodes are to each other, the better the amplifiers can function and so the less unwanted noise will be detected - the artifacts which can plague those trying to perform monitoring.

However, if MRI scans show that the tumour is large (>2.5cm), I would recommend that the electrodes are placed as for parotidectomy. This ensures that, if the nerve is compressed and thin on the posterior side of the tumour, any stimulation of the nerve will be detected - if the electrodes are positioned as for small acoustics, there is the risk that fibres which are not being monitored will be stimulated, and no response will be evident.

Using the Neurosign 800, it is possible to be much more thorough. The 4 main branches should be monitored separately, with the placement as shown in figure 6, but in addition other cranial nerves may be monitored. This depends on which approach is being used to excise the tumour. If a translabyrinthine approach is employed, only VII and V are likely to be encountered. V is easily monitored by placing electrodes in the masseter. Find the angle of the mandible and the electrodes should be inserted two fingers forward and straight upwards. If you clench your teeth you can feel the masseter - this is a little more difficult when the patient is asleep! It is important not to place the electrodes too high above the mandible, or you will detect facial nerve activity (as distinct from facial muscle activity). There are situations where it is only by looking at the latency of the response that it is possible to differentiate between V and VII.

If a sub-occipital or retro-sigmoid approach is used, V, VII, IX, X and XI can all be monitored.
The table below gives the electrode positions for these nerves.

**Table 1: electrode positions for V, VII, IX, X, XI**

<table>
<thead>
<tr>
<th>Cranial Nerve</th>
<th>Muscle</th>
</tr>
</thead>
<tbody>
<tr>
<td>V</td>
<td>Masseter</td>
</tr>
<tr>
<td>VII</td>
<td>Frontalis, zygomaticus, buccalis, mentalis</td>
</tr>
<tr>
<td>IX</td>
<td>Soft palate</td>
</tr>
<tr>
<td>X</td>
<td>Vocal cords</td>
</tr>
<tr>
<td>XI</td>
<td>Trapezius</td>
</tr>
</tbody>
</table>

**Using the Neurosign 100 during Acoustic Neuromas**

Figure 5 shows the electrode montage when using the Neurosign 100 during acoustic neuroma excision. This montage should only be used if the tumour size is less than 2.5cm as estimated on the MRI scan. For larger tumours, it is recommended that the electrode placement in Figure 4 is used, even though this placement is designed for parotidectomies. The reason is that, in larger tumours, there is a risk that the nerve may be stretched and compressed behind the tumour, so that when the nerve is stimulated using the probe it is possible that fibres will be stimulated which are not being monitored by the electrodes shown in Figure 5. However, using this montage will lead to more frequent artifacts since the needles are further apart, so it is recommended that the preferred montage is adhered to where possible.

The Neurosign 100 has been extensively used in the excision of acoustic neuromas to help in the identification and preservation of the facial nerve. The use of the concentric probe has enabled the surgeon to positively discriminate between the VIIth and VIIIth cranial nerves, and its small diameter has proved useful when opening the Internal Auditory Meatus. Upon reaching the tumour, the surface can be stimulated with the bipolar probe to ensure that the nerve is not stretched over its surface, and the stimulator should be used during the debulking of the tumour capsule to warn of the approaching nerve. As the capsule is rotated and the nerve stretched, the monitor will let the surgeon know if the manipulation is too great. Nerves not visible under the microscope have been anatomically preserved. With the opening of the IAC, the monitor will detect the vibrations caused by the drill, and will give a subjective warning of the distance to the nerve. Once opened, the nerve can be identified again and tumour removed from the nerve sheath whilst the monitor warns of excessive manipulation.

At the end of the tumour removal, the nerve can be stimulated at the brainstem and a prognosis made of the condition of the nerve. There has been considerable work done to show that the lower the current required to stimulate the nerve at the brainstem, the better the chances of its full recovery. Typical stimulation levels at the brainstem lie in the range of 50µA to 0.2mA.

In order to monitor more than just the facial nerve using the Neurosign 100, 4 channels can be created using the Dual Pod Switch. This device allows 2 preamplifiers to be connected to a Neurosign 100 so that 1 preamplifier is summed to appear on channel 1, and the second preamplifier on channel 2. The surgeon may wish to monitor the IXth and Xth as well as the VIIth cranial nerves. This can be achieved by using needles in the laryngeal muscles or by using the Magstim laryngeal electrode, a non-invasive device which attaches to the endotracheal tube. The electrodes monitoring the facial nerve will be connected to Pod A; the laryngeal electrode will be connected to Channel 1 of Pod B. The Magstim laryngeal electrode contains pick up areas to monitor both vocal cords; obviously only one part of the electrode is required in the majority of instances. The remaining channel could be used to monitor the trigeminal, accessory or hypoglossal nerve by means of an extra pair of needle electrodes.

**Using the Neurosign 800 during Acoustic Neuromas**

The problem above is easily overcome when using the Neurosign 800 because the 4 main branches...
can be monitored individually. It is quite possible to use the concentric probe at the brainstem and stimulate different areas of the facial nerve to stimulate different parts of the face. The value of monitoring several cranial nerves is twofold; it helps protect the nerves, and it helps in their identification. In terms of protection, the monitor detects any disturbance of the relevant nerve and relays that information to the surgeon. It is also helpful in larger tumours to be able to rapidly identify nerve structures and to determine which they are! This can speed up the decision-making process, saving time and reducing stress!

Monitoring a larger number of nerves also leads to some complications. For example, the surgeon stimulates a nerve, and the monitor shows responses from both VII and V. Does this mean that there are two genuine responses? There are 2 possible answers to this event.

- If VII was stimulated, the contraction of the face may cause the masseter to move, generating a CMAP. If so, the latency of V will be equal to or slightly delayed with respect to VII.
- If V was stimulated, sensory fibres within the nerve may also be stimulated. This would be interpreted as pain by the brain, causing an involuntary wince from the facial muscles. In this case, the latency of V will be considerably shorter than that of VII.

It is also possible to stimulate either V or VII yet get no response from the other nerve. In the case of VII, this probably means that the mandibular branch of the nerve is being stimulated, which is unlikely to result in contraction of the masseter. In the case of V, if only the motor part is stimulated, the facial muscles will not be affected.

An example of this is shown in Figure 7. This waveform shows stimulation of the trigeminal nerve at 0.1mA, shown on channel 5; the cursor line is shown at the takeoff point, and the latency is 2.8ms. The facial response is limited to channel 1, the electrodes being in frontalis; the other channels are in the facial muscles running down the face. The response on channel 1 is a further 2.6ms after the trigeminal response, showing that some of the sensory fibres of the Vth have been stimulated, as well as the motor fibres of the Vth, causing a grimace around the eye. This is translated into a biphasic response - note how even and pure this response is, compared to the more typical CMAP recorded from the masseter. This is presumably because the masseter has many motor units recruited, resulting in a Compound MAP - whereas the Channel 1 response is more likely to be a very few motor units.

![Figure 7: beware confusion between V and VII](image)

Figure 7 to figure 10 are examples of waveforms recorded during acoustic neuromas using the Neurosign 800. In the case of figure 7, 4 branches of VII and the motor part of V were being monitored; in the other cases, IX was also monitored.

Figure 8 shows a spontaneous response from V; note the very small response from IX showing on channel 6. This was probably the result of the masseter contracting rather than direct IXth nerve activity, as the small deflection can be seen in the middle of the Vth nerve response.

![Figure 8: spontaneous Vth nerve response](image)

Figures 9 and 10 demonstrate that you can have stimulated and spontaneous IXth nerve activity! The IXth nerve appears to be most stimulated when instruments are being inserted and withdrawn during retro-sigmoid and sub-occipital approaches to CPA tumours. Figure 9 shows a spontaneous response, figure 10 a stimulated response. Note the short latency of about 2.8ms (compared to the VII nerve which has a latency of about 8ms from the same point of stimulation).
Figure 11 shows stimulated Vth nerve activity. Although the cursor is not set on this screen, it can be estimated that the latency is about 5ms.

Figure 12 shows the facial nerve being stimulated. Although the cursors are not set, the differing latency from each of the branches is clearly visible. Note that channel 4, with electrodes in the mentalis, has the shortest latency. This is not uncommon, and the mandibular branch often gives the greatest response - something to do with the amount we talk, perhaps?!

Figure 9: IX spontaneous response

Cranial nerve X can be monitored by placing short (12mm) needle electrodes in the false cords on the ipsilateral side, or by using the laryngeal electrode available from the Company. This electrode, which is not available in the USA, consists of conductive ink printed onto a polyester substrate, and adheres to the standard endotracheal tube, lying between the vocal cords. It is therefore surgically non-invasive. Setting up the electrode does require some care, and it is desirable to be able to see the cords and electrode before the tube is taped to the face. The use of the Impedance Meter is also desirable, as this helps to ensure that the electrode is still in place after the patient has been placed in the final operating position.

For both sub-occipital and retro-sigmoid approaches to acoustic neuromas, cranial nerve IX is often disturbed, especially as instruments are inserted into and withdrawn from the surgical site. IX is easily monitored using a pair of needles inserted into the soft palate on the ipsilateral side, ie to the left or right of the uvula. This needs to be done immediately after intubation, before the access to the pharynx is obstructed, so the cooperation of the anaesthetist is required. The electrodes should be inserted, and then a piece of wadding placed in the pharynx in order to prevent the electrodes from being pulled out whilst the patient is being prepared for surgery.

Cranial nerve XI can be monitored by placing electrodes in the trapezius muscle. Since this is a large muscle, the electrodes can be quite widely spaced, about 3cm apart. The ability to monitor XI can be quite important since, apart from the serious result of permanent injury to this nerve, any unexpected stimulation of this nerve can lead to sudden movement of the patient, with potential distraction to the
surgeon. Therefore, its simple identification is desirable.

Cranial nerve XII is unlikely to be encountered in a ‘normal’ acoustic, but can be monitored by placing a pair of electrodes in the lateral posterior aspect of the tongue on the ipsilateral side.

Finally, cranial nerve VI, the abducens, originates in the Pons, where the tumour lies. However, in order to monitor this nerve, an electrode needs to be placed in the lateral rectus muscle, which controls the movement of the eyeball. Injury to this nerve is serious for the patient as it creates major problems in terms of sight, but such injury is thankfully rare. If a neurophysiologist is available, a single needle should be inserted into the lateral rectus, (see figure 13), with the second electrode inserted into the frontalis. This means that the latency of the waveform will have to be measured to determine whether a response which shows as both VII and VI is in fact VI. The latency of VI is much shorter than that of VII.

Surgery of the brachial plexus using the Neurosign 100

The Neurosign 100 has been widely used in the monitoring of the facial nerve during maxillo-facial and skull base surgery, but it is also suited to use during surgery involving the brachial plexus. The Ulnar, Median and Radial nerves can be easily identified using the concentric series of probes. Whilst these nerves may be electrically stimulated and the response from the arm or hand observed, the Neurosign will differentiate between these nerves and surrounding tissue without visible movement. Not only is this an advantage to the neurosurgeon, but the smaller stimulation currents used allow the surgeon to make a better prognostic evaluation at the completion of surgery.

The Neurosign 100 Motor Nerve Monitor works by detecting the EMG responses in the muscles fed by the nerves at risk. The Stimulator part of the Neurosign allows the surgeon to electrically stimulate the nerve and to gain a response from the muscle, which is immediately interpreted audibly and visually.

Therefore, with electrodes suitably located to monitor the three major nerves, the surgeon can identify each nerve with confidence and with a suitable anaesthetic protocol, will be able to hear the result of mechanical stimulation of the nerves as well.

The arrangement of electrodes

In order to gain EMG information which is specific to each nerve, sub-dermal needle electrodes are recommended. Surface electrodes may be used, but will collect EMG from a wider area and it may be more difficult to differentiate between the Median, Radial and Ulnar nerves.

It can be seen from figure 15 that with careful positioning of the electrodes it is possible to differentiate between the three nerves using muscles in the hand and lower arm. Although the electrodes could be posi-
tioned in a number of places on the arm, the hand provides easily identifiable, though small, muscles from which to monitor. Electrodes can be inserted to monitor particular branches where necessary; for example, the Posterior Interosseous nerve can be individually monitored.

Both the Ulnar and the Radial nerves may be monitored from the posterior surface, and the Median may be monitored from the anterior surface. Another advantage of using these particular sites in the hand is that the same electrode positioning can be used when investigating possible damage to the Median nerve in the carpal tunnel.

Radial nerve damage is indicated by wrist droop and an inability to extend the hand at the wrist. There is a risk of Radial nerve damage when deltoid intramuscular injections are given. Median nerve damage is indicated by numbness, tingling and pain in the palm and fingers; weak thumb movements; and an inability to pronate the forearm and flex the wrist. The Median nerve can also be affected by compression within the carpal tunnel, sometimes caused by flexion of the wrist. Ulnar nerve damage is indicated by an inability to flex and adduct the wrist and difficulty in spreading the fingers.

The anterior views show the suggested positioning for the electrodes for monitoring the Median nerve. Note that there is no reference electrode mentioned. The Neurosign is a two channel instrument, and so in order to allow more channels to be monitored, a switch arrangement has been devised so that four channels may be monitored either individually or simultaneously.

The use of the Neurosign 100 to monitor the nerves of the arm need not be restricted to the three major nerves, but may extend to their branches. For example, the Musculocutaneous nerve which branches from the Lateral cord of the brachial plexus may be monitored from the Coracobrachialis, Biceps Brachii and Brachialis muscles; the Axillary nerve (circumflex), a branch of the Posterior cord, supplies the Deltoid and Teres Minor muscles. The Latissimus Dorsi muscle is innervated by a branch of the Posterior cord; and the Upper and Lower Subscapular nerves also divide from the Posterior cord to innervate the Subscapularis and Teres Major muscles.

**Table 2: upper limb nerves and muscles**

<table>
<thead>
<tr>
<th>Nerve</th>
<th>Muscles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radial</td>
<td>Brachioradialis; triceps brachii; anconeus; extensor carpi radialis longus</td>
</tr>
<tr>
<td>Posterior</td>
<td>Supinator; extensor carpi ulnaris; extensor digitorum; extensor indicis; extensor pollicis longus</td>
</tr>
<tr>
<td>Interosseous</td>
<td></td>
</tr>
<tr>
<td>Median</td>
<td>Pronator teres; pronator quadratus; flexor carpi radialis; palmaris longus; flexor digitorum superficialis</td>
</tr>
<tr>
<td>Ulnar</td>
<td>Flexor carpi ulnaris</td>
</tr>
<tr>
<td>Axillary</td>
<td>Deltoid; teres minor</td>
</tr>
<tr>
<td>(Circumflex)</td>
<td></td>
</tr>
<tr>
<td>Musculocutaneous</td>
<td>Coracobrachialis; biceps brachii</td>
</tr>
<tr>
<td>Suprascapula</td>
<td>Supraspinatus; infraspinatus</td>
</tr>
<tr>
<td>Medial pectoral</td>
<td>Pectoralis major; pectoralis minor</td>
</tr>
<tr>
<td>Some muscles are innervated by more than one nerve, for example:</td>
<td></td>
</tr>
<tr>
<td>Musculocutaneous</td>
<td>Brachialis</td>
</tr>
</tbody>
</table>

**Four Channel Monitoring**

The Dual Pod Switch allows two pre-amplifier pods to be connected to the Neurosign 100 simultaneously. Pod A could be used to monitor the Radial and Ulnar nerves, and Pod B the Median; with the switch set to Both Pods, the surgeon will hear the responses from any of the three nerves. A response from either the Radial or Ulnar nerves will appear on Channel 1; and the Median nerve responses on Channel 2. With the switch set to Pod A, the Radial and Ulnar nerves are monitored separately, and the surgeon can stimulate and identify each nerve. The Median nerve is not monitored with the switch set in this position. Similarly, with the switch set to Pod B, only the
Median nerve is monitored, and the Radial and Ulnar are ignored. Therefore the surgeon can start with the switch set to Both Pods and locate the nerves; with the switch set to either A or B the surgeon can identify the three nerves; and then with the switch set to Both Pods the nerves will be continually monitored.

Using the Dual Pod Switch to gain 4 channels requires planning and care; if regular surgery needs to be monitored, and more than 2 channels are involved, it is strongly recommended that the Neurosign 800 is used.

**Using the Neurosign 800 for brachial plexus surgery**

Whilst the Neurosign 100 is used for brachial plexus surgery, monitoring the full elements of the motor portion of the plexus requires more than 2 channels to be effective. The Neurosign 800 has sufficient channels to permit comprehensive monitoring. Table 2 shows a list of possible monitoring sites, although it is not suggested that any cases would require so many electrodes! However, it may be appropriate to monitor more than just one muscle innervated by a particular portion of the plexus or peripheral nerve, especially given the subtle and important strength and delicacy peculiar to the muscles of the arm and hand. Refer to figures 15 and 16 for information on the location of the muscles to be monitored.

Serious injury to the brachial plexus may well involve Sensory Evoked Potential (SEP) monitoring. Often, neurophysiology departments have been able to offer SEP monitoring because they have the equipment. They may not have been able to offer EMG monitoring, since several channels are required or their equipment cannot be used in the operating theatre for some reason. Therefore, it is not unlikely that the Neurosign 800 may be used alongside an SEP machine. Refer to the Operating Manual for information on using the two machines together, and in particular how to connect the machines so that the stimulus artifact from the SEP stimulus can be minimised. Special interconnecting cables are available from the Company for this purpose. The manufacturer, model number and description of the SEP machine’s trigger output will be required.

Combined SEP and EMG monitoring is likely to provide the best solution in serious brachial plexus trauma. Careful planning before the operation, and liaison with the neurophysiologist, are required so that the surgeon can be given the most accurate and professional information.
Elbow replacements

There is a 16% risk of ulnar nerve injury during an elbow replacement. The Neurosign 800 can be used to monitor the motor nerves to reduce this risk.

Injury to nerves can vary, depending on which fibres have been compromised and what type of injury has been sustained. It follows that comprehensive monitoring is required if the risk is to be minimised. To this end, the nerves should be monitored as listed in Table 3. The muscles listed require 8 channels, although it would be possible to share some channels by spreading the electrodes. For example, the hypothenar and adductor pollicis are both supplied by the ulnar; but a single electrode in both would monitor the ulnar, although the discrimination may be reduced.

Table 3: muscles to monitor the hand and forearm

<table>
<thead>
<tr>
<th>Ulnar</th>
<th>Flexor carpi ulnaris, hypothenar, adductor pollicis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median</td>
<td>Flexor carpi radialis, abductor pollicis brevis</td>
</tr>
<tr>
<td>Radial</td>
<td>Brachioradialis, anconeus, extensor muscles of forearm</td>
</tr>
</tbody>
</table>

The value of such thorough monitoring is that injury to a nerve can be subtle and difficult to predict. It avoids the risk of injuring selective fibres, leading to slight but potentially disfiguring impairment.

A major problem with monitoring nerves during an elbow replacement is created if a tourniquet is used to restrict blood flow to the arm. In this event, all responses will die away, and even direct and high stimulation of the nerve will produce no response. In this event, consideration must be given to the balance between the requirement for a bloodless field and the risk of nerve injury if the nerve cannot be monitored.

Spinal applications

The Neurosign 100 is not recommended for spinal applications as 2 channels is too limited for this form of monitoring. However, the Neurosign 800 is ideally suited for use during many spinal operations, and was primarily designed for this purpose.

Some applications which are applicable are:

- lumbar fixation
- pedicle screws
- inter-body fusion
- Graf Bands
- nerve root decompression
- release of tethered cords

Traditionally, little monitoring has been used during orthopaedic surgeries of the lower spine, excepting occasional use of SEPs. However, SEPs have a serious disadvantage when used to monitor the lumbar and sacral nerve roots, since there are multiple levels at which the sensory fibres reach the spinal cord; in effect, a SEP recording could be perfectly normal, yet the patient could awake with complete paralysis of the lower limbs.

Motor pathways are, however, more selective, and it is much easier to monitor several leg muscles than it is to stimulate several sensory nerves! It is possible to thoroughly cover the levels L3 to S4 using the Neurosign 800; and perhaps the best news is that the electrode montage is the same for almost all the operations listed.

Principle of operation

The theory behind using the Neurosign 800 in these spinal applications is identical to that of facial nerve monitoring. Electrodes are positioned in the leg muscles controlled by the nerve roots at risk; fortunately, since most of the surgeries listed involve the levels L3 to S1, the electrodes can be placed in the same muscle groups consistently. A minor variation is needed to cope with monitoring the lower sacral nerve roots.

What is important is that nerve root discrimination is maintained as far as possible. Whilst it may be valuable to monitor L4 in 2 muscle groups, it must not be at the expense of not monitoring L3, for example. The electrode positioning has been carefully evaluated and it is strongly recommended that the advice is followed. The montage shown for the various procedures will ensure that all the possible nerve roots are being monitored.

Depending on the operation, either monopolar or bipolar probes can be used. In placing pedicle screws, for example, a specially designed pedicle probe should be used as the stimulator - this is a monopolar probe with a 3mm ball on its end, and is run down the pilot hole made for the screw.

Pedicle screws

Under this heading lumbar fixation, pedicle screws and Graf Bands can be included. Electrodes are placed in the muscles shown in figures 18 to 28 and referring to Table 4. It is strongly recommended that these electrode positions are always
used; if they are varied, unexpected results may be obtained, especially the false negative.

Once the pilot hole for the screw is made, the specially designed pedicle screw probe is run up and down the hole at a threshold level of 7mA, when there should be no response and the screw can then be inserted. The screw itself can then be stimulated at 10mA; if the wall has been breached and threads have broken through, stimulating the screw will cause some response.

**Figure 17: stimulation of L3 pedicle hole at 7mA**

Figure 17 shows the result of stimulating the L3 pedicle pilot hole at 7mA. A small response was elicited with a latency of about 11ms (the cursor is not aligned in the screen shot), and this disappeared at 6mA. The screw was placed normally. This type of response is not uncommon, and is probably due to a slight misalignment of the pilot hole.

**Table 4: muscle sites for monitoring pedicle screws**

<table>
<thead>
<tr>
<th>Level</th>
<th>Muscle</th>
</tr>
</thead>
<tbody>
<tr>
<td>L3</td>
<td>Adductors</td>
</tr>
<tr>
<td>L4</td>
<td>Quadriceps; tibialis anterior</td>
</tr>
<tr>
<td>L5</td>
<td>Tibialis anterior; peroneus longus</td>
</tr>
<tr>
<td>S1</td>
<td>Medial gastrocnemius</td>
</tr>
</tbody>
</table>

The screw may be stimulated directly but should be done with some caution. The maximum current of 10mA should be used, and a negative result should only be considered true where stimulation of the pilot hole has also proved negative. As a complication, screws may be manufactured from either stainless steel or titanium, and the latter has relatively poor electrical conduction properties. There are apocryphal tales of the diathermy forceps being placed on the screw to see if anything moves - not an ideal form of monitoring!

I have found that careful stimulation of the pilot hole at the threshold level of 7mA, and intelligent use of the information, provides the most reliable form of monitoring.

It is reasonable to expect that a response may be gained at this threshold level from 1 hole in every 3 screws placed. This does not mean that the screw cannot be put in; there may be a number of factors which affect the response.

The **ideal** is that there is no response at the threshold level of 7mA; but

- individual patients may have different bone mass from the normal population
- bone electrical conductivity may vary from patient to patient
- a response may just indicate that the pedicle wall is thin, but not breached

In other words, if there is a response at the threshold level, do not panic! This is simply a warning flag indicating that the surgeon should investigate further before placing the screw.

Where there is a response at 7mA, reduce the current to the point at which the response disappears. If the response has rapidly fallen off, and the response has disappeared by 5mA, the surgeon should inspect the hole and try to establish whether there is a particular ‘hot spot’ where the stimulation is apparent. This may indicate a crack in the pedicle, a hole or a small foramina carrying a blood vessel or nerve fibres; the surgeon should use their experience to decide whether the screw should be placed. However, if the response does not disappear and continues to be present down to 1 or 2mA, this certainly indicates a breach in the pedicle wall. Between these two values of 5mA and 1mA, the surgeon must inspect the pedicle to ensure that the screw does not break through the pedicle wall, or if it does, that it will not impinge on the nerve root. If there is direct compression of the nerve root as the screw is inserted, this will be detected by the Neurosign 800 and the screw must be removed immediately.

**Electrode placement**

Table 4 gives a list of nerve roots and muscles innervated by those roots. There is considerable individual variability as to exactly which nerve root innervates which muscle in any one person; the levels in bold merely indicate the average anatomy. For this reason, the electrode montage recommended has been tried and tested, and unless there are good reasons to change it, these sites are currently recommended.
**Figure 22: lateral view of leg**

Gastrocnemius
Soleus
Peroneus longus
Peroneus brevis
Tibialis anterior
Extensor digitorum longus

**Figure 23: superficial posterior view of leg**

Semimembranosus
Gracilis
Biceps femoris
Gastrocnemius
Soleus
Flexor digitorum longus

**Figure 24: lateral view of thigh**

Gluteus maximus
Pectineus
Tensor fasciae latae
Vastus lateralis, medialis, and rectus femoris (quadriceps)
Iliotibial tract

**Figure 25: deep posterior view of leg**

Biceps femurs
Semitendinosus
Semitendinosus
Gastrocnemius
Soleus
Tibialis posterior
Flexor digitorum longus
Flexor hallucis longus
Peroneus longus
L5 is a little more difficult to monitor discretely than it appears, as tibialis anterior receives a major part of its innervation from L4. For this reason, it is worth inserting one needle in tibialis anterior, and the second needle in peroneus longus. A response which is displayed on both tibialis anterior/peroneus longus and quadriceps is therefore likely to be L4, whilst a response just on tibialis anterior/peroneus longus is likely to be L5.

By using this montage, you will use 4 channels on each leg, covering L3 to S1. Since most pedicle screws are used at levels L4 to S1, this montage covers all that is necessary.

Identify all the electrodes as they are inserted. I do this by using pieces of micropore tape and writing the muscle name and side on the end (for example, LTA for left tibialis anterior), then wrapping the tape around the connector end of the electrode lead. When all the electrodes are inserted, including the reference, it is good practice to wind all the leads together, taping them at 10cm intervals, in order to minimise noise pickup. At this point you will understand why identifying the leads is important! The leads should then be plugged into the pre-amplifier pod following a sensible order for the channels. One of the features of the Neurosign
800 is its default set-ups - these provide muscle names on the screen for specific operations - pedicle screws amongst them. Figures 27 and 29 show the on-screen muscle sites identified for pedicle screw placements; if you have a printed output of these screens, both the screens and a list of channel numbers and muscle sites will be available to you during the setting up process.

If you do not use the default settings, I recommend that you use channels 1 to 4 for the left leg, 5 to 8 for the right, and work down the leg either in terms of muscles ie. adductors, quadriceps, gastrocnemius, tibialis anterior, or in terms of levels, ie. L3, L4, L5, S1. What is important is that you know which electrode pair goes where! The default settings of the Neurosign 800 are designed to make life easy. If you prefer, you can print out the default settings so you have a record when inserting the leads into the pre-amplifier pod.

Nerve Root Decompression

This is often a concomitant part of putting in pedicle screws. The nerve root is to be decompressed because there is not enough room for it as it exits the foramen, in turn because the intervertebral disk has collapsed. The foramen has to be enlarged to allow the nerve root to exit without compression, thereby relieving pain and/or muscle weakness.

Because the surgeon will be working next to the nerve root, there is likely to be some spontaneous activity. It is not a case of identifying the nerve root; it is relatively large, and the anatomical space through which it is emerging can hardly be that unique! However, before the decompression starts, it is sensible to stimulate the nerve root at 0.5-1mA to check that the electrodes will detect any spontaneous activity.

As the decompression proceeds, you can expect to have very similar responses to those from the facial nerve. Responses which must be heeded are those which continue after the particular action has stopped (train responses); although those from irritation may be ignored.

As a broad principle, the less stimulation of a nerve, either spontaneous or stimulated, the better.

Figure 30 shows an example of nerve root activity during an L3/L4 decompression. The monitoring relied on the innervation of the quadriceps and tibialis anterior/peroneous longus at this level.

Two aspects of the screen-shot are significant. The first is that the spontaneous response is only apparent on one channel (left quadriceps) which demonstrates excellent discrimination; and secondly, since tibialis anterior also shares L4 innervation, it is more likely that the response has come from stimulating the L3 nerve root. The adductors receive their innervation from L2 and L3, but primarily from L2.

Figure 30: spontaneous nerve root response

Tethered cord

This operation is usually applied to children, but occasionally to adults. The spinal cord in young children extends down to L4 level, but as the child grows, the cord does not, resulting in the ‘bottom’ of the cord, the conus medul laris, only reaching L1/L2 level in the adult. However, sometimes the cord remains ‘tethered’, and results in the spinal cord stretching as the child grows. This leads to pain and muscle weakness as the spinal cord is affected.

The cord is released by separating it from its attachments at the filum terminale; it is very important that the nerve roots are monitored to prevent injury to them during this process, and to help identify nerve structures. In particular, where the patient is continent, the surgeon will want to preserve the pudendal nerves.

Monitoring tethered cords is basically the same as for pedicle screws, except that the pudendal nerve should also be monitored. This can be achieved by placing a pair of electrodes either side of the anal sphincter. Monitoring S2-S4 can be achieved by using the muscles of the perineum, but there is considerable cross-innervation at these levels. S3 appears to be largely sensory, but a few fibres may go to gastrocnemius.

This leaves 7 channels to monitor the legs. The easiest solution is to use one pair to monitor the adductors (L3) and the quadriceps (L4) on one leg; the remainder of the channels will then be as for the pedicle screw montage.
**Spinal tumours**

These depend on the exact level of the tumour, but broadly speaking all those between L3 and S1 can be monitored using the same electrode placement as for pedicle screws. The case should be discussed with the surgeon beforehand in order to check that any specific nerve roots are covered.

**Revision hip replacements and sciatic nerve**

About 20% of revision hips lead to some form of neurological deficit. Both the Neurosign 100 and the 800 can be used to monitor the sciatic nerve during this operation, especially in revision cases, acetabular and pelvic fractures; locating it may be no problem, but preventing damage to it during the necessarily traumatic surgery of a hip replacement may be made easier by monitoring. Stimulating different areas of the sciatic nerve give instantaneous and clearly defined responses from the various muscles; sensory fibres stimulated often cause a reflex action and response.

**Table 5: muscles innervated by the sciatic nerve**

<table>
<thead>
<tr>
<th>Nerve</th>
<th>Muscle</th>
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<tr>
<td>Common Peroneal</td>
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<tr>
<td>Deep peroneal</td>
<td>Tibialis anterior; extensor digitorum longus, brevis</td>
</tr>
<tr>
<td>Superficial peroneal</td>
<td>Peroneus longus, brevis;</td>
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<tr>
<td>Tibial</td>
<td></td>
</tr>
<tr>
<td>Deep tibial</td>
<td>Flexor hallucis longus; flexor digitorum longus; tibialis posterior</td>
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<tr>
<td>Superficial tibial</td>
<td>Gastrocnemius; soleus; planaris</td>
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<tr>
<td>Medial plantar</td>
<td>Abductor hallucis; flexor digitorum brevis</td>
</tr>
<tr>
<td>Lateral plantar</td>
<td>Abductor digiti minimi</td>
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</table>

As in facial nerve monitoring, the sciatic nerve can be irritated by excessive traction or compression resulting in a train response, which persists after the cessation of surgical activity, although the frequency of the nerve firing appears to be much slower than for the facial nerve - approximatively 5-10Hz as opposed to 60-100Hz. These train responses are important because they warn of possible injury, and repeated train responses should be avoided. The common peroneal branch of the sciatic nerve, monitored from tibialis anterior, appears to be at a higher risk of injury than the tibial branch, possibly because of an inferior blood supply or poorer tensile strength, so particular attention should be paid to irritation of the sciatic nerve detected in this muscle. Injury to the peroneal branch of the nerve can result in foot drop, weakness in the leg or numbness of the posterior thigh.

Although the sciatic nerve is very large, it is not to be assumed that it is any less tolerant to damage than any other nerve. Therefore it is sensible to monitor the nerve thoroughly using the muscle sites shown in the Table 5. The recommended muscle sites are in bold, and utilise 6 channels. Although it may be assumed that this is an unnecessary degree of monitoring, experience has shown that this is a useful technique and that responses are easily achieved from individual muscle sites.

If using the Neurosign 100, more than two muscles need to be monitored, so the Dual Pod Switch is necessary. This provides four channels; but where it is not important to know which nerve has been stimulated, only that a nerve has been, then the Dual Pod Switch can be used to create up to eight channels.

**Pelvic repairs**

This is usually undertaken because of traumatic injury to the pelvis - motor cycle accidents, for example. There are risks of injury to the sciatic, femoral, obturator and pudendal nerves, both from the initial accident and from the repair surgery.

**Table 6: muscles innervated by the lower sacral nerves**

<table>
<thead>
<tr>
<th>Nerve/Level</th>
<th>Muscle</th>
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<tr>
<td>L2-L3</td>
<td>Adductors</td>
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<tr>
<td>L4-L5</td>
<td>Tibialis anterior</td>
</tr>
<tr>
<td>S1</td>
<td>Medial gastrocnemius</td>
</tr>
<tr>
<td>S2</td>
<td>Gastrocnemius; Abductor digiti minimi</td>
</tr>
<tr>
<td>S3</td>
<td>Ischiocavernous; bulbocavernosus; transverse perineus</td>
</tr>
<tr>
<td>S4-S5</td>
<td>Levator ani; external anal sphincter</td>
</tr>
</tbody>
</table>

Most of the nerves can be monitored using the pedicle screw montage, except that it is important to also monitor the pudendal. Use 3 channels on each leg to monitor the adductors, tibialis anterior and gastrocnemius (L3 to S1), with a fourth channel split between the anal sphincter and the levator ani muscles. These are innervated by levels S3 to S4 and the perineal branch of the pudendal nerve, whilst the anal sphincter is innervated by S4 and the inferior rectal branch of the pudendal nerve.
(see Table 6). If more precise monitoring of the sacral nerves is needed, then some higher level (L2-L4) monitoring may need to be sacrificed.

**Cervical Plexus**

SEPs are often used to monitor nerve function to the arms and neck during operations at the cervical levels. This form of monitoring has proved effective, but there is no reason not to use EMG monitoring either as an adjunct or as a replacement. The cervical plexus provides mainly sensory nerves to the skin over the neck, with the exception of neck muscles supplied by C1-C3 and the phrenic nerve supplied by C3-C5. In addition, C1-C5 also supply the levator scapulae and scalene muscles of the neck, so it is easy to provide ‘catch all’ monitoring in this area. The advantage of SEPs is that the spinal cord can be monitored during the operation; the disadvantages are that, unless the spinal cord is likely to be compromised, this is not a particularly useful piece of informa-

**Table 7: muscles innervated by C1-C5**

<table>
<thead>
<tr>
<th>Ansa Cervicalis</th>
<th>C1</th>
<th>Infrahypoid and geniohyoid muscles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superior root</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lesser occipital</td>
<td>C2</td>
<td>Sensory, skin behind ear</td>
</tr>
<tr>
<td>Ansa Cervicalis</td>
<td>C2-C3</td>
<td>Omohyoid, sternohyoid and sternothyroid muscles</td>
</tr>
<tr>
<td>Inferior root</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Great auricular</td>
<td>C2-C3</td>
<td>Sensory, skin in front of ear</td>
</tr>
<tr>
<td>Transverse cervical</td>
<td>C2-C3</td>
<td>Sensory, skin on front of neck</td>
</tr>
<tr>
<td>Supraclavicular</td>
<td>C3-C4</td>
<td>Sensory, skin over chest and shoulder</td>
</tr>
</tbody>
</table>

**Figure 31: the muscles of the neck**
tion, and also SEP monitoring will not prevent or indicate that the motor nerves may be compromised. Since the phrenic nerve controls the diaphragm, essential in breathing, unnecessary injury is not to be welcomed. The other motor nerves to the neck control the patient’s ability to move their head, and importantly, to hold it up. The ideal monitoring montage is a combination of sensory and EMG.

Table 7 suggests some monitoring sites.

Other motor nerves derived from the plexus can be monitored by placing electrodes in the appropriate muscle. It may be advisable to consider using a reference channel at times, so that a response from stimulation of the nerve can be positively confirmed, otherwise a response may be obtained from a connecting fibre or via current spread through adjacent tissue and misinterpreted. Monitoring nerve roots at the cervical levels can best be achieved by using the segmental branches to sample the levator scapulae muscles.

**Checking electrode impedance**

The Neurosign 800 does not measure impedance directly. A hand-held impedance meter is available from the Company if required. However, the waveform display of the Neurosign 800 can be used to measure effective impedance by looking at the flatness of the waveform. Enter the set-up menus, choose EMG, and alter the Wave Amplitude Scale to 0.025mV - 25µV per division. Change the Wave Trigger Source to FREE RUN and exit the menu system. The display will now update continuously, so check that the waveform is a (reasonably) flat line. If it is, the electrode impedance is good. If there is a particular channel which is poor - the waveform is undulating (at 50/60Hz), the impedance of the electrodes for that channel is poor, and if possible, replace the electrodes. If all the channels show noise, then try replacing the reference electrode. If the noise continues, the theatre may be electrically noisy and some form of shielding may be required. Once you are satisfied with the electrodes, reset the monitor by changing the Amplitude scaling to 0.05mV and the Trigger mode to AUTO TRIG (or as preferred).

A broken wire will be shown by a large waveform and a loud hum from the speaker.

**Care of electrodes**

Electrode impedance is not often a problem if the electrodes are not abused. Damaged electrodes should be renewed, electrodes should be washed and re-sterilised after use, and stored in a dark, dry atmosphere. After prolonged use, a layer of collagen may build up on the needle which will act as an insulator; after many autoclave cycles, the steel may also start to oxidise. In both cases, so long as the needles are straight and sharp, the deposits may be cleaned off using a fine grade emery paper. The needles should be washed in alcohol, then sterilised.

Do not attempt to straighten bent needles, as this could lead to a weakness in the steel, allowing the needle to break off in the patient.

If there is any doubt, replace the electrodes.
Thyroid Surgery

Surgery of the thyroid gland carries with it a small but extremely important risk to the recurrent laryngeal nerves which run underneath the lobes of the gland and which ultimately control the laryngeal muscles and vocal cords, and hence speech. Permanent damage is unusual, around 1% to 3%, but from the patient’s point of view a change in the quality or tone of speech is more common. For someone who uses their voice professionally, this change may have serious implications. Other complications may involve difficulty in swallowing and aspiration. It is not uncommon for patients to undergo thyroid surgery in two stages, initially removing only one lobe, but needing the other to be removed some years later. In these cases the first surgeon may well have explored both lobes before deciding to leave one side, thereby leaving scar tissue and making the identification of the recurrent laryngeal nerves more difficult.

Although injury of the superior laryngeal nerves is rare during thyroidectomy, their damage can cause subtle differences of voice production to the patient.

In some patients the vocal cords are innervated by non-recurrent laryngeal nerves, invariably on the right side. In these cases a reliable means of identifying and mapping the nerves, which because of their rarity value (0.2% to 0.4%) may prove difficult to locate, would be very helpful. The use of hooked wire electrodes carries some disadvantages because of their invasive nature, the difficulty of placing them and ensuring that they remain in place. Needle electrodes inserted externally during the surgery into the intrinsic laryngeal muscles are awkward and tend to be removed by the manipulation of the gland.

The Company now produces an electrode which is sited on the endotracheal tube and which rests between the vocal cords. The electrode is not surgically invasive and is manufactured using a flexible polyester substrate with conductive ink tracks to measure the EMG activity. The electrode is then connected to the pre-amplifier pod, and the Neurosign 100 or 800 used in the normal manner. Experience has shown that this electrode allows the laryngeal nerves, both recurrent and superior, to be reliably monitored during neck surgery. A higher stimulation current is required, usually in the range 0.5mA to 1mA, since the nerve seems to have a sharp threshold below which the nerve is not stimulated.

Care must be taken in positioning the electrode accurately, since the adjustment of the head and neck after intubation can change the relative position of the tube and hence the electrode.

The Impedance Meter produced by the Company is of considerable help in this process, especially when there is a large goiter which may prevent direct visualisation of the vocal cords.

Vagus Nerve

The electrode may also be used to monitor the Xth cranial nerve during skull-base procedures. Brief stimulation of the nerve can confirm the nerve’s identity, and the normal continuous monitoring is performed warning the surgeon of any unexpected activity.

Please note that the laryngeal electrode is not available in the USA
List of peer group papers

1. Anaesthesia


2. Facial Nerve Monitoring during Acoustic Neuroma Surgery


3. Facial Nerve Monitoring during Ear Surgery


4. Facial Nerve Monitoring during Parotid Surgery


5. Facial Nerve Monitoring - General


6. **Laryngeal Monitoring**


7. **Hearing Preservation**


8. **Spinal Surgery**


Segal L. *Combining Somatosensory and Motor Evoked Potentials for Posterior Spine Fusion*. Primer of Intraoperative Neurophysiologic Monitoring. Chapter; pp 205-219

9. **Multiple Nerve Monitoring**


10. **Miscellaneous**


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The Magstim Company Limited 30

20th March 1998

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