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ORIGINAL ARTICLE

Evolving trends in the surgical, anaesthetic, and intensive care management of acute spinal cord injuries in the UK

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Abstract

Purpose We surveyed the treatment of acute spinal cord injuries in the UK and compared current practices with 10 years ago.

Methods A questionnaire survey was conducted amongst neurosurgeons, neuroanaesthetists, and neurointensivists that manage patients with acute spinal cord injuries. The survey gave two scenarios (complete and incomplete cervical spinal cord injuries). We obtained opinions on the speed of transfer, timing and aim of surgery, choice of anaesthetic, intraoperative monitoring, targets for physiological parameters, and drug treatments.

Results We received responses from 78.6% of UK units that manage acute spinal cord injuries (33 neurosurgeons, 56 neuroanaesthetists/neurointensivists). Most neurosurgeons operate within 12 h for incomplete (82%) and complete (64%) injuries. There is a significant shift from 10 years ago, when only 61% (incomplete) and 30% (complete) of neurosurgeons operated within 12 h. The preferred anaesthetic technique in 2022 is total intravenous anaesthesia (TIVA), used by 69% of neuroanaesthetists. Significantly more intraoperative monitoring is now used at least sometimes, including bispectral index (91%), non-invasive cardiac output (62%), and neurophysiology (73–77%). Methylprednisolone is no longer used by surgeons. Achieving at least 80 mmHg mean arterial blood pressure is recommended by 70% neurosurgeons, 62% neuroanaesthetists, and 75% neurointensivists.

Conclusions Between 2012 and 2022, there was a paradigm shift in managing acute spinal cord injuries in the UK with earlier surgery and more intraoperative monitoring. Variability in practice persists due to lack of high-quality evidence and consensus guidelines.

Keywords Audit · Intensive care · Neurosurgery · Spinal cord injury · Survey

Introduction

In the UK, about 16 people per million suffer a traumatic spinal cord injury (TSCI) each year [1]. TSCI is life-altering, often causing limb paralysis, sensory loss below the injury, difficulty breathing, impaired control of blood pressure and body temperature, urinary and faecal incontinence, impaired sexual function, pressure ulcers, renal damage, chronic pain, spasticity, joint stiffness and heterotopic ossification, muscle contractures, delayed neurological deterioration (syrinx), as well as frequent chest and urinary infections [2]. Surgery for acute TSCI is controversial: some studies suggest that early (< 24 h after TSCI) decompression improves outcome [3, 4], but others show no benefit [5]. The non-surgical management of TSCI is also debated with no agreed blood pressure target because high-quality data are lacking [6].

In 2012, the management of acute TSCI by UK neurosurgeons, neuroanaesthetists, and neurointensivists was surveyed [7]. A key finding was that management was variable. Compared with North American and European neurosurgeons, fewer British neurosurgeons advocated early decompression for incomplete (23.9% UK vs. 72.9%) and complete (11.8% UK vs. 46.2%) TSCI [8]. The 2012 survey also found that British neuroanaesthetists and neurointensivists did not follow the AANS/CNS guideline to maintain mean arterial blood pressure 85–90 mmHg for a week after TSCI [9].

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In the last decade, UK patients with acute TSCI have been managed in Major Trauma Centres rather than Spinal Injury Units (now rehabilitation centres). Spinal surgery has become an established sub-specialty and minimally invasive [10], the concept of spinal cord perfusion pressure has been developed [11, 12], and the use of methylprednisolone has been questioned [13]. In high-income countries, the trend is for earlier decompression, according to a global survey of AO spine members [14]. To determine if such developments have influenced the management of acute TSCI, we re-surveyed UK neurosurgeons, neuroanaesthetists, and neurointensivists.

Materials and methods

Neurosurgical survey

We obtained approval from the Academic Committee of the Society of British Neurological Surgeons (SBNS); the survey was then disseminated online using the same questionnaire as in 2012. Neurosurgeons were presented with two clinical scenarios, one patient with an incomplete and the other with a complete acute TSCI at C6/7, both 42 years old. The survey asked about timing of transfer to the neurosurgical unit, timing of surgery, need for a pre- and/or postoperative MRI, aspects of perioperative medical management, blood pressure target, and surgery aims. The survey questionnaire is Supplement 1.

Neuroanaesthesia/neurointensive care survey

We obtained approval from the Neuro Anaesthesia and Critical Care Society (NACCS) council; the survey was then disseminated online using the same questionnaire as in 2012. Neuroanaesthetists and neurointensivists were asked questions about managing acute TSCI in general. We asked about their preferences regarding anaesthesia, gas mixtures, intraoperative monitoring, control of physiological parameters, use of glucocorticoids, and management in the neurointensive care unit (NICU) the week following the injury. The survey questionnaire is Supplement 2.

Neurosurgeon participants

All 399 full members of the SBNS based in the 33 neurosurgical units in the UK were contacted online and invited to participate (i.e. consultant neurosurgeons across the UK). Participants were given three months to complete the online link; then, the survey was closed. There were 33/399 responders (8.3% response rate).

Neuroanaesthetist/neurointensivist participants

All 480 full members of the NACCS were contacted online and invited to participate (i.e. consultant neuroanaesthetists and neurointensivists across the UK). Participants were given three months to complete the online link; then, the survey was closed. We received 56/480 responses (11.7% response rate).

Setup of spinal services

We asked spinal fellows at each unit which specialty is referred acute TSCIs, whether TSCIs are managed by neurosurgeons or spinal orthopaedic surgeons or both (hybrid service), and whether patient management is based on individual surgeons or consensus following discussion between local spinal surgeons.

Statistical tests

Fisher's exact or chi-square test was used to compare the matched responses for dichotomous variables for incomplete and complete TSCI. When variables had > 2 possible responses, the matched responses for incomplete and complete TSCI were compared using the McNemar–Bowker test of symmetry. Both tests were investigated for symmetry around paired responses—that is, if responses differed for incomplete and complete scenarios, whether this disagreement was greater for some categories of responses than others. If the frequency of disagreements was equal, the changes balanced each other out, and there was no significant change in the way the incomplete and complete scenarios scored overall in the sample. The test was statistically significant if the frequency of disagreements was unequal. Responses from 2012 were compared with responses from 2022 in incomplete and complete TSCI. Fisher's exact or chi-square (sample size dependent) was used for dichotomous variables and Mann–Whitney U for variables with > 2 possible responses. The critical level of significance was 0.05. IBM SPSS Statistics for Windows software was used for analysis (Version 29.0. Released 2022. Armonk, NY: IBM Corp).

Results

Revised response rate

In each of the 22 responding units, the surgical management of a patient with TSCI is discussed and agreed amongst the local spinal surgeons before surgery. The neuroanaesthetic

and neurointensive care is also by consensus between colleagues. Therefore, a more meaningful response rate is the % of responding units rather than the % or responding consultants. Because we received responses from neurosurgeons and neuroanaesthetists/neurointensivists representing 22 units and because 4/10 of the non-responding units do not treat TSCI, the unit response rate is 22/(32–4) = 78.6%.

Setup of acute TSCI services

In the UK, TSCI patients are referred to the on-call neurosurgeon. Orthopaedic surgeons do not accept TSCI referrals when on call. Of the 32 units, 22 gave us a clear picture of their spinal setups: In 13/22 (59.1%), all TSCI patients are surgically managed by spinal neurosurgeons. In 6/22 (27.3%), TSCI patients are surgically managed by spinal neurosurgeons or spinal orthopaedic surgeons. In 3/22 (13.6%), all TSCI patients are surgically managed by spinal orthopaedic surgeons. Therefore, our survey of spinal neurosurgeons (without contacting spinal orthopaedic surgeons) is estimated to cover the management of 59.1 + 27.3 = 86.4% of the TSCI patients in the UK

Neurosurgical survey in 2022

Table 1 summarises the neurosurgeons' opinions. We first asked about surgery. Most patients are admitted within 24 h of TSCI (94%, 31/33 for incomplete, 88%, 29/33 for complete), and most (91%, 30/33) have MRI before surgery regardless of injury severity. Surgery is performed within 12 h by 82% (27/33) for incomplete and by 64% (21/33) for complete TSCI, with only a few (< 10%) advocating delayed surgery or no surgery. The surgical aim is to decompress the theca in 94% (31/33) of incomplete and 82% (27/33) of complete TSCI. Some neurosurgeons also perform a duroplasty for incomplete (12%, 4/33) and complete (9%, 3/33) TSCI. We then asked about non-surgical management. The priorities are blood pressure augmentation (97%, 32/33 for incomplete injuries and 85%, 28/33 for complete injuries with 70% (23/32) targeting mean arterial pressure ≥ 80 mmHg), oxygen supplementation (58%, 19/33 regardless of injury severity), and thromboprophylaxis (91%, 30/33 regardless of injury severity). No one recommended corticosteroids, and the manoeuvres used to reduce oedema in traumatic brain injury (mannitol, hypertonic saline, lowering arterial pCO_2) are rarely employed for TSCI. Finally, we compared the managements of incomplete versus complete TSCI. Injury severity had no significant impact on timing of admission, need for MRI, medical management, or surgical aim (Supplements 3–5). However, neurosurgeons operated earlier for incomplete than complete TSCI (Supplement 4).

Neuroanaesthesia/neurointensive care survey in 2022

Table 2 summarises the neuroanaesthetists' and neurointensivists' opinions regarding intraoperative and postoperative management. We first asked about monitoring and preferred targets of physiological parameters during surgery. About 5% (3/56) neuroanaesthetists always monitor central venous pressure (CVP), 77% (43/56) always monitor invasive arterial blood pressure, 91% (51/56) always monitor body temperature, and 82% (46/56) always monitor urine output. Intraoperative somatosensory (SSEP) and motor evoked (MEP) potentials are always monitored by 14% (8/56) and 13% (7/56) neuroanaesthetists. Most aim for arterial pCO_2 4.5–5.0 kPa (78%, 43/55) and arterial $pO_2 > 10$ kPa (98%, 54/55). Mean arterial blood pressure target ≥ 80 mmHg is preferred by 62% (34/55), whereas 25% (14/55) target blood pressure within 20% of what is deemed normal for the patient. We then asked about anaesthesia and ventilation. Most 69% (39/56) neuroanaesthetists use target-controlled infusion (TCI) propofol + remifentanil or sevoflurane (23%, 13/56). All (100%) neuroanaesthetists ventilate with O_2/air, and no one uses nitrous oxide. Most (89%, 49/55) use positive end expiratory pressure (PEEP). Finally, we asked about management in the NICU. Mean arterial blood pressure target ≥ 80 mmHg is preferred by 75% (29/39) neuroanaesthetists, whereas 15% (6/39) aim for blood pressure within 20% of normal for each patient. The targets of physiological parameters for intubated patients were the same as during surgery, i.e. arterial pCO_2 4.5–5.0 kPa (82%, 31/38) and arterial $pO_2 > 10$ kPa (100%, 38/38). Hyperosmolar agents are only used by 5% (2/37) and methylprednisolone by 15% (7/47).

Neurosurgical survey in 2022 versus 2012

The responses in the 2022 versus 2012 neurosurgery surveys are compared in Table 3 for incomplete, and Table 4 for complete TSCI. We had 33 responders in 2022 compared with 79 responders in 2012. A major surgical management difference is significantly earlier timing of surgery in 2022 versus 2012 with 82% (27/33) versus 61% (43/71) patients having surgery within 12 h for incomplete and 64% (21/33) versus 30% (20/68) for complete TSCI. Another significant surgical difference is the use of duroplasty in 12% (4/33) of incomplete and 9% (3/33) of complete injuries in 2022 compared with no duroplasties in 2012. Significantly fewer neurosurgeons in 2022 versus 2012 recommended oxygen supplementation (58% vs. 87% for incomplete and 58% vs. 82% for complete TSCI), nasogastric tube insertion (27% vs. 51% for incomplete TSCI), body temperature regulation (21% vs. 46% for incomplete and 18% vs. 50% for complete

Table 1 2022 neurosurgical survey responses

	Incomplete injury		Complete injury	
	n	(%)	*n*	(%)
Timing of admission	*n* = 33		*n* = 33	
Immediately (< 4 h)	20	(61)	12	(36)
Within 4–24 h	11	(33)	17	(52)
Within 1–4 days	1	(3)	3	(9)
Do not admit	0		0	
Not specified	1	(3)	1	(3)
Routine MRI	*n* = 33		*n* = 33	
Pre-operation "yes"	30	(91)	30	(91)
Post-operation "yes"	15	(45)	10	(30)
Routine medical management	*n* = 33		*n* = 33	
Oxygen	19	(58)	19	(58)
Nasogastric tube to prevent aspiration	9	(27)	14	(42)
Deep vein thrombosis prophylaxis	30	(91)	30	(91)
Glucocorticoids	0		0	
Mannitol	1	(3)	1	(3)
Hypertonic saline	0		0	0
Control of blood pressure	32	(97)	28	(85)
Control of arterial pCO_2	3	(9)	3	(9)
Temperature regulation	7	(21)	6	(18)
Timing of surgery	*n* = 33		*n* = 33	
Immediately (< 4 h)	15	(46)	2	(6)
Emergency list (4–12 h)	12	(36)	19	(58)
Elective list (12–72 h)	4	(12)	9	(27)
Delayed (> 72 h)	1	(3)	2	(6)
Other	0		0	0
Not specified	1	(3)	1	(3)
Aim of surgery	*n* = 33		*n* = 33	
Bony stabilisation ± instrumentation	2	(6)	6	(18)
Bony decompression of theca	11	(33)	10	(30)
Bony stabilisation and decompression	20	(61)	17	(52)
Including durotomy ± patching	4	(12)	3	(9)
Not specified	0		0	
Mean arterial pressure control	*n* = 32 (%)			
	≥ 60 mmHg	≥ 80 mmHg	± 20% normal	As per Intensive Care Unit
	3 (9)	23 (70)	2 (6)	4 (12)

TSCI) and glucocorticoids (0% vs. 20% for incomplete and 0% vs. 16% for complete TSCI).

Neuroanaesthesia/neurointensive care survey in 2022 versus 2012

The responses in the 2022 versus 2012 surveys are compared in Table 5 for intraoperative, and Table 6 for neurointensive care management. We had 56 responders in 2022, compared with 49 in 2012. In the last decade, there are several significant changes in anaesthetic management. There is now more extensive intraoperative monitoring including bispectral index (BIS, used at least sometimes by 91%, 51/56 neuroanaesthetists in 2022 versus 23%, 11/48 in 2012), non-invasive cardiac output (used at least sometimes by 62%, 35/56 neuroanaesthetists in 2022 vs. 41%, 20/48 in 2012), and SSEP/MEP (used at least sometimes by 73–77%, 41–43/56 in 2022 vs. 21–27%, 10/47–13/48 in 2012), though CVP monitoring is less used (90%, 43/48 monitored at least sometimes in 2012 vs. 53%, 30/56 in 2022). Desflurane is no longer preferred, and TCI propofol + remifentanil has become the anaesthetic of choice:

Table 2 2022 Neuroanaesthetic/neurointensive care survey responses (TCI Target-controlled infusion)

Intraoperative management	No. (%) of responders				
Intraoperative monitoring, $n = 56$	Sometimes		Always		Never
Temperature	5 (9)		51 (91)		0
Central venous pressure	27 (48)		3 (5)		26 (47)
Urine output	10 (18)		46 (82)		0
Peripheral nerve stimulator	31 (55)		16 (29)		9 (16)
Bispectral index	30 (54)		21 (37)		5 (9)
Non-invasive cardiac output	27 (48)		8 (14)		21 (38)
Invasive arterial blood pressure	12 (21)		43 (77)		1 (2)
Somatosensory evoked responses	33 (59)		8 (14)		15 (27)
Motor evoked responses	36 (64)		7 (13)		13 (23)
Preferred anaesthetic technique, $n = 56$	Sevoflurane	Isoflurane	Desflurane	TCI propofol	TCI propofol+remifentanil
	13 (23)	1 (2)	2 (4)	1 (2)	39 (69)
Preferred fresh gas mixture, $n = 56$	O_2/N_2O	O_2/Air			
	0	56 (100)			
Positive End Expiratory Pressure? $n = 55$	Yes	No			
	49 (89)	6 (11)			
Preferred physiological parameters, $n = 55$					
Arterial pCO_2	<4 kPa	4–4.5 kPa	4.5–5 kPa	>5 kPa	
	0	10 (18)	43 (78)	2 (4)	
Arterial pO_2	<10 kPa	10–12 kPa	>12 kPa		
	1 (2)	20 (36)	34 (62)		
Invasive arterial blood pressure	≥60 mmHg	≥80 mmHg	±20 % normal	Controlled hypotension	
	7 (13)	34 (62)	14 (25)	0	
Intensive care management					
Mannitol, $n = 37$	2 (5)				
Hypertonic saline, $n = 37$	2 (5)				
Temperature regulation, $n = 39$	25 (64)				
Mean Arterial Pressure control (inotropes if required), $n = 39$	≥60 mmHg	≥80 mmHg	±20 % normal	No active control	
	2 (5)	29 (75)	6 (15)	2 (5)	
If intubated:					
Arterial pCO_2, $n = 38$	<4 kPa	4–4.5 kPa	4.5–5 kPa	>5 kPa	
	0	5 (13)	31 (82)	2 (5)	
Arterial pO_2, $n = 38$	<10 kPa	10–12 kPa	>12 kPa		
	0	27 (71)	11 (29)		
High dose methylprednisolone, $n = 47$	Within 8 hours	Within 24 hours	Not used		
	6 (13)	1 (2)	40 (85)		

in 2012 neuroanaesthetists used desflurane (35%, 17/49), TCI propofol + remifentanil (33%, 16/49), and sevoflurane (26%, 13/49) compared with TCI propofol + remifentanil (69%, 39/56), and sevoflurane (23%, 13/56) in 2022. NICU management has not changed significantly; most aim for mean arterial pressure ≥ 80 mmHg, arterial pCO_2 4.5–5.0 kPa, and arterial $pO_2 \geq 10$ kPa, though in 2022 the preference is for arterial pO_2 10–12 kPa rather than > 12 kPa.

Discussion

We showed a paradigm shift in managing acute TSCI in the UK in the last decade. Key findings are that neurosurgeons now opt for (ultra)early surgery (82% for incomplete and 64% for complete TSCI within 12 h of injury) with added emphasis on decompressing the spinal cord (including duroplasty in some cases), methylprednisolone

Table 3 2012 versus 2022 neurosurgical survey responses for incomplete TSCI (*ns* Not significant)

	2012		2022		*P*
	n	(%)	*n*	(%)	value
Timing of admission	*n* = 79		*n* = 33		ns
Immediately (< 4 h)	55	(70)	20	(61)	
Within 4–24 h	14	(18)	11	(33)	
Within 1–4 days	2	(3)	1	(3)	
Do not admit	8	(10)	0		
Not specified	0		1	(3)	
Routine MRI	*n* = 71		*n* = 33		
Pre-operation "yes"	64	(90)	30	(91)	ns
Post-operation "yes"	28	(39)	15	(45)	ns
Routine medical management	*n* = 71		*n* = 33		
Oxygen	62	(87)	19	(58)	0.002
Nasogastric tube to prevent aspiration	36	(51)	9	9 (27)	0.033
Deep vein thrombosis prophylaxis	59	(83)	30	(91)	ns
Glucocorticoids	14	(20)	0		0.004
Mannitol	1	(1)	1	(3)	ns
Hypertonic saline	1	(1)	0		ns
Control of blood pressure	62	(87)	32	(97)	ns
Control of arterial pCO_2	15	(21)	3	(9)	ns
Temperature regulation	33	(46)	7	(21)	0.017
Timing of surgery	*n* = 71		*n* = 33		0.013
Immediately (< 4 h)	17	(24)	15	(46)	
Emergency list (4–12 h)	26	(37)	12	(36)	
Elective list (12–72 h)	19	(27)	4	(12)	
Delayed (> 72 h)	6	(8)	1	(3)	
Other	3	(4)	0		
Not specified	0		1	(3)	
Aim of surgery	*n* = 71		*n* = 33		ns
Bony stabilisation ± instrumentation	14	(20)	2	(6)	
Bony decompression of theca	8	(11)	11	(33)	
Bony stabilisation and decompression	47	(66)	20	(61)	
Including durotomy ± patching	2	(3)	4	(12)	0.009

is no longer recommended, TCI propofol + remifentanil is the anaesthetic of choice, and there is more intraoperative monitoring. In contrast to 2012, in 2022 the management of TSCI patients is decided by consensus between surgeons and between neuroanaesthetists/neurointensivists.

The trend for early surgical decompression in the UK aligns with current international practice [14]. Though the timing of surgical decompression remains controversial, there is substantial evidence that the outcome of early surgery (< 24 h of TSCI) surgery either improves [3, 4] or does not worsen [5] neurological outcome, compared with delayed or no surgery. Some neurosurgeons also perform duroplasty; this was not practised in 2012 and is an investigative arm of the DISCUS randomised controlled trial, which is currently recruiting and aims to test the hypothesis that, after TSCI, the cord swells and becomes compressed against the dura [15].

Interestingly, British neurosurgeons advocate earlier decompression for incomplete than complete TSCI despite the potential for neurological improvement with complete TSCI [16]. The reasons for delayed surgery are probably logistical such as delay in patient transfer and more time needed to stabilise older patients with comorbidities [17]. In most UK neurosurgical units, the availability of a spine surgeon, anaesthetist, and an emergency operating theatre is probably no longer limiting, with many neurosurgical sites providing 24-h spinal on call separate from the general neurosurgical on call.

Neurosurgeons are less likely to recommend oxygen supplementation, nasogastric tube insertion, or body

Table 4 2012 versus 2022 neurosurgical survey responses for complete TSCI (*ns* Not significant)

	2012		2022		*P*
	n	(%)	*n*	(%)	value
Timing of admission	*n* = 76		*n* = 33		ns
Immediately (< 4 h)	32	(42)	12	(36)	
Within 4–24 h	23	(30)	17	(52)	
Within 1–4 days	11	(14)	3	(9)	
Do not admit	8	(11)	0		
Not specified	2	(3)	1	(3)	
Routine MRI	*n* = 68		*n* = 33		
Pre-operation "yes"	54	(79)	30	(91)	ns
Post-operation "yes"	19	(28)	10	(30)	ns
Routine medical management	*n* = 68		*n* = 33		
Oxygen	56	(82)	19	(58)	0.014
Nasogastric tube to prevent aspiration	35	(51)	14	(42)	ns
Deep vein thrombosis prophylaxis	54	(79)	30	(91)	ns
Glucocorticoids	11	(16)	0		0.015
Mannitol	0		1	(3)	ns
Hypertonic saline	0		0	0	ns
Control of blood pressure	56	(82)	28	(85)	ns
Control of arterial pCO_2	14	(21)	3	(9)	ns
Temperature regulation	34	(50)	6	(18)	0.002
Timing of surgery	*n* = 68		*n* = 33		0.006
Immediately (< 4 h)	8	(12)	2	(6)	
Emergency list (4–12 h)	12	(18)	19	(58)	
Elective list (12–72 h)	28	(41)	9	(27)	
Delayed (> 72 h)	13	(19)	2	(6)	
Other	7	(10)	0	0	
Not specified	0		1	(3)	
Aim of surgery	*n* = 68		*n* = 33		ns
Bony stabilisation ± instrumentation	29	(43)	6	(18)	
Bony decompression of theca	2	(3)	10	(30)	
Bony stabilisation and decompression	32	(47)	17	(52)	
Not specified	5	(7)			
Including durotomy ± patching	0		3	(9)	0.026

temperature control after TSCI. This is probably because neurosurgeons are now less involved in the medical care of these patients. Unlike 2012, in 2022, patients in the NICU are primarily managed by neurointensivists with less input from neurosurgery. In 2022, as was the case in 2012, blood pressure augmentation is considered important, with 70% neurosurgeons, 62% neuroanaesthetists, and 75% neurointensivists aiming for MAP ≥ 80 mmHg. A significant development is that methylprednisolone is no longer recommended, in line with meta-analyses [13], re-analysis of the NASCIS2 and Sygen dataset [18], and evidence from the CRASH trial in traumatic brain injury [19] showing no benefit from corticosteroids.

The neuroanaesthetic and neurointensive care management of TSCI has also changed substantially in the last 10 years. Desflurane is no longer the anaesthetic of choice, with most anaesthetists now opting for TCI propofol + remifentanil. This may be related to the increased use of intraoperative neurophysiological monitoring, which requires total intravenous anaesthesia because volatile anaesthetics suppresses the signals, and a sustainability focus on using environment-friendly anaesthesia [20, 21]. We also note increasing use of intraoperative monitoring, not only SSEP/MEP, but also BIS as a precaution against anaesthetic awareness, and non-invasive cardiac output, but less CVP monitoring. Cardiac output monitoring provides pulse pressure waveform analysis for haemodynamic status assessment which affords the ability to titrate fluid and vasoactive drug administration. This has been shown to reduce perioperative morbidity and mortality [22]. CVP monitoring has fallen out of favour likely due to its invasive nature and unreliable predictive ability of fluid responsiveness [23]. For ventilated TSCI patients, in 2012 and 2022 neurointensivists avoided hypoxaemia (arterial $pO_2 < 10$ kPa). Now, most also avoid arterial $pO_2 \geq 12$ kPa, in line with the emerging evidence of the deleterious effects of hyperoxia [24].

Our survey has weaknesses. First, the consultant response rate is low, likely attributable to survey fatigue with staff having to catch up on long waiting lists. Because the management is decided following discussion between colleagues, the percentage of responding units is more meaningful than the percentage of responding consultants. The unit response rate of 78.6% thus provides an accurate view of TSCI management in most UK units. Second, we did not survey spinal orthopaedic surgeons. The management of TSCI patients is discussed amongst neurosurgeons and spinal orthopaedic surgeons, and thus, our survey is estimated to cover the management of 86.4% of TSCI patients. Third, we obtained opinions, which may differ from what happens. Fourth, our survey excludes polytrauma and other types of TSCI such as central cord syndrome. Fifth, the survey did not include new practices such as intraoperative ultrasound to confirm adequate decompression [25] or advanced monitoring of intraspinal pressure [11, 12].

To conclude, we have shown a paradigm shift in the management of TSCI in the UK The surgical, anaesthetic, and neurointensive care practices remain variable due to the lack of high-quality evidence and consensus guidelines for several aspects of patient management.

Table 5 2012 versus 2022 neuroanaesthetic survey responses (*ns* Not significant, TCI Target-controlled infusion, MAP Mean arterial pressure)

	2012		2022		*P*
	n	(%)	*n*	(%)	value
Temperature	*n* = 49		*n* = 56		ns
Always, sometimes, never	41, 8, 0	(84, 16, 0)	51, 5, 0	(91, 9, 0)	
Central venous pressure	*n* = 48		*n* = 56		< 0.001
Always, sometimes, never	7, 36, 5	(15, 75, 10)	3, 27, 26	(5, 48, 47)	
Urine output	*n* = 49		*n* = 56		ns
Always, sometimes, never	37, 12, 0	(76, 24, 0)	46, 10, 0	(82, 18, 0)	
Peripheral nerve stimulator	*n* = 49		*n* = 56		ns
Always, sometimes, never	15, 26, 8	(31, 53, 16)	16, 31, 9	(29, 55, 16)	
Bispectral monitoring	*n* = 48		*n* = 56		< 0.001
Always, sometimes, never	1, 10, 37	(2, 21, 77)	21, 30, 5	(37, 54, 9)	
Non-invasive cardiac output	*n* = 48		*n* = 56		0.027
Always, sometimes, never	3, 17, 28	(6, 35, 58)	8, 27, 21	(14, 48, 38)	
Invasive arterial blood pressure	*n* = 49		*n* = 56		ns
Always, sometimes, never	38, 11, 0	(78, 22, 0)	43, 12, 1	(77, 21, 2)	
Somatosensory evoked potentials	*n* = 48		*n* = 56		< 0.001
Always, sometimes, never	3, 10, 35	(6, 21, 73)	8, 33, 15	(14, 59, 27)	
Motor evoked potentials	*n* = 47		*n* = 56		< 0.001
Always, sometimes, never	0, 10, 37	(0, 21, 79)	7, 36, 13	(13, 64, 23)	
Preferred anaesthetic technique	*n* = 49		*n* = 56		0.004
Sevoflurane	13	(26)	13	(23)	
Isoflurane	2	(4)	1	(2)	
Desflurane	17	(35)	2	(4)	
TCI propofol	1	(2)	1	(2)	
TCI propofol + remifentanil	16	(33)	39	(69)	
Preferred fresh gas mixture	*n* = 47		*n* = 56		ns
O_2/N_2O	2	(4)	0		
O_2/Air	47	(96)	56	(100)	
Positive end expiratory pressure?	*n* = 49		*n* = 55		< 0.001
"Yes"	23	(47)	49	(89)	
Arterial pCO_2 range	*n* = 49		*n* = 55		ns
< 4 kPa	0		0		
4–4.4 kPa	16	(33)	10	(18)	
4.5–5 kPa	31	(63)	43	(78)	
> 5 kPa	2	(4)	2	(4)	
Arterial pO_2 range	*n* = 49		*n* = 55		ns
< 10 kPa	1	(3)	1	(2)	
10–12 kPa	11	(29)	20	(36)	
> 12 kPa	26	(68)	34	(62)	
MAP target	*n* = 49		*n* = 55		ns
≥ 60 mmHg	12	(24)	7	(13)	
≥ 80 mmHg	20	(41)	34	(62)	
± 20% normal	17	(35)	14	(25)	
Controlled hypotension	0		0		

Table 6 2012 versus 2022 neurointensive care responses (*ns* Not significant, TCI Target-controlled infusion, MAP Mean arterial pressure)

	2012		2022		*P*
	n	(%)	*n*	(%)	value
Mannitol	*n* = 39		*n* = 37		ns
"yes"	1	(3)	2	(5)	
Hypertonic saline	*n* = 39		*n* = 37		ns
"yes"	1	(3)	2	(5)	
Temperature regulation	*n* = 39		*n* = 39		ns
"yes"	26	(67)	25	(64)	
MAP range (inotropes if required)	*n* = 38		*n* = 38		ns
≥60 mmHg	9	(23)	2	(5)	
≥80 mmHg	21	(54)	29	(75)	
±20% normal	7	(18)	6	(15)	
No active control	2	(5)	2	(5)	
Arterial pCO_2 range	*n* = 38		*n* = 38		ns
< 4 kPa	0		0		
4–4.4 kPa	6	(16)	5	(13)	
4.5–5 kPa	29	(76)	31	(82)	
> 5 kPa	3	(8)	2	(5)	
If intubated, arterial pO_2 target	*n* = 38		*n* = 38		ns
< 10 kPa	1	(3)	0		
10–12 kPa	11	(29)	27	(71)	
> 12 kPa	26	(68)	11	(29)	
High-dose methylprednisolone	*n* = 39		*n* = 47		ns
Within 8 h	4	(10)	6	(13)	
Within 24 h	4	(10)	1	(2)	
Not used	31	(79)	40	(85)	

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Declarations

Conflict of interest This study was supported, in part, by the Wings for Life Spinal Cord Research Foundation (to Dr. Saadoun and Prof. Papadopoulos) and by the National Institute for Health Research, Efficacy and Mechanism Evaluation Stream (to Dr. Saadoun and Prof. Papadopoulos), and The Neurosciences Research Foundation (to Prof. Papadopoulos and Dr. Asif). The remaining authors have disclosed that they do not have any potential conflicts of interest. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the article.

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