European Spine Journal (2022) 31:575–595
https://doi.org/10.1007/s00586-021-07081-y

ORIGINAL ARTICLE

Dural tear repair surgery comparative analysis: a stitch in time saves nine

Charles Taylor[1] · Amad Khan[2] · Emad Shenouda[2] · Nicholas Brooke[2] · Ali Nader-Sepahi[2]

Received: 6 July 2021 / Revised: 14 October 2021 / Accepted: 29 November 2021 / Published online: 10 December 2021

Abstract

Purpose A dural tear is a common iatrogenic complication of spinal surgery associated with a several post-operative adverse events. Despite their common occurrence, guidelines on how best to repair the defect remain unclear. This study uses five post-operative outcomes to the compare repair methods used to treat 106 dural tears to determine which method is clinically favourable.

Methods Data were retrospectively collected from Southampton General Hospital's online databases. 106 tears were identified and grouped per repair method. MANOVA was used to compare the following five outcomes: Length of stay, numbers of further admissions or revision surgeries, length of additional admissions, post-operative infection rate and dural tear associated neurological symptoms. Sub-analysis was conducted on patient demographics, primary vs non-primary closure and type of patch. Minimal clinically important difference (MCID) was calculated via the Delphi procedure.

Results Age had a significant impact on patient outcomes and BMI displayed positive correlation with three-fifth of the predefined outcome measures. No significant difference was observed between repair groups; however, primary closure ± a patch achieved an MCID percentage improvement with regards to length of original stay, rate of additional admissions/surgeries and post-operative infection rate. Artificial over autologous patches resulted in shorter hospital stays, fewer readmissions, infections and neurological symptoms.

Conclusion This study reports primary closure ± dural patch as the most efficient repair method with regards to the five reported outcomes. This study provides limited evidence in favour of artificial over autologous patches and recommends that dural patches be used in conjunction with primary closure.

Level of evidence I Diagnostic: individual cross-sectional studies with consistently applied reference standard and blinding.

Keywords Dural tear · Incidental durotomy · Primary closure · Dural patch

Introduction

A dural tear, also known as an incidental durotomy, refers to when the outer most layer of the meninges, the dura mater, is torn [1]. Dural tears most commonly occur as a complication of spinal surgery and patients who sustain a dural tear often recover well and do not commonly require further intervention following repair of the defect [2, 3]. However, patients may complain of low-pressure headaches, photophobia and nausea [1, 4, 5]. More serious consequences of poorly managed tears include meningitis, arachnoiditis and the development of pseudomeningoceles [1, 4, 5]. Therefore, further research to better define the management of dural tears may have beneficial clinical outcomes.

Despite the common occurrence of this complication, there are currently no definitive guidelines on how to best to manage an intraoperative tear [4]. Consequently, patient outcomes vary on a case by case basis [4]. This may be in part due to the inconsistent and varied methods of repair that surgeons use along with the absence of high quality comparative data [4, 6].

This retrospective study identifies 106 patients who sustained an intraoperative dural tear in Southampton University General Hospital, in either the Orthopaedic or Neurosurgery departments between 01/01/2016 and 04/11/2019. This

✉ Charles Taylor
ct1g17@soton.ac.uk

[1] Faculty of Medicine, University of Southampton, Southampton General Hospital, Southampton, UK

[2] Department of Neurosurgery, Southampton General Hospital, Southampton, UK

study consequentially compares the method of dural repair against five primary outcome measures; length of hospital stay, length of additional admissions, numbers of further admissions or revision surgeries, post-operative infection rate and dural tear associated neurological symptoms. Sub-analysis was conducted regarding patient age and body mass index (BMI) as well as against primary vs non-primary closure and artificial vs autologous patches.

Methods

H_1 With respect to the studies five predetermined outcome measures, primary closure is the most advantageous form of repair for intraoperative dural tears.

H_0 With respect to the studies five predetermined outcome measures, primary closure is not the most advantageous method of dural tear repair.

Data were collected from Southampton General Hospital's online 'surgery complications' 'Charts' and 'E-documents' databases. All patients with the terms 'Dural Tear', 'CSF Leak', 'durotomy' or 'pseudomeningocele' in their records were identified and later included in the study if it could be confirmed that they sustained an intraoperative dural tear from the Orthopaedics or Neurosurgery department between the 46-month period (Fig. 1). To ensure all relevant patients were included, the term 'dural tear' was entered into the main patient database search-bar and patients were cross-searched.

The following patient information was recorded; age at the time of surgery, BMI, title of procedure in which the tear was sustained, length of original stay, character of dural complication, method of repair, post-operative neurological symptoms, infection rate, readmission date(s), readmission procedure(s), duration of readmission(s) (Table 1). Patients were grouped per the method of repair used so that no patient appeared in more than one group (Table 2).

Statistical analysis

All statistical analysis was conducted on SPSS (IBM Corp. Released 2019. IBM SPSS Statistics for Windows, Version 26.0.). Minimal clinically important difference (MCID) was calculated for the primary repair analysis and for the artificial vs autologous patch analysis. MCID was calculated via the Delphi method amongst resident neurosurgeons to enable a formal consensus to be developed.

Delphi procedure

Four resident neurosurgeons were provided with a two-round Delphi survey. In the first round, surgeons were provided with information regarding the study and independently suggested MCID values for each outcome. In the second round, surgeons were provided with the group ranges and medians and their own answers so they may adapt their decisions. 100% consensus was achieved

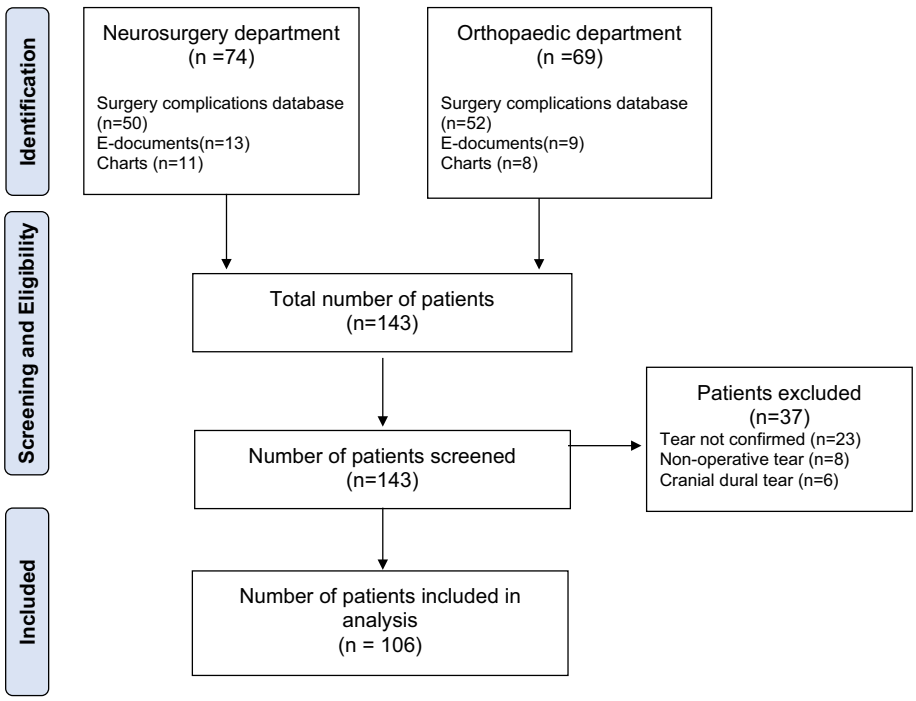

Fig1 Flow diagram outlining patient screening for study inclusion

Table 1 Patient data

Patient Number	Department	Age	BMI	Procedure	Length of stay	Dural complication	Method of repair	Symptoms post repair	Infection post repair	Readmissions	Readmission procedures	Duration of readmissions
1	Neuro	42	27.17	L5/S1 microdiscectomy	3	Small dural puncture and Psudomeningocoele	5.0 Vicryl, duraseal, 6.0 Prolene, tissue dural patch and lumbar drain	Fluid collection, sciatica, back and leg pain, headache and low-pressure symptoms	None	2	Dural tear repair	9
2	Neuro	70	28.73	Laminectomy, fusion and fixation for L3-4 instability with radiculopathy	5	CSF Leak whilst drilling the pars/facet complex	5/0 Vicryl, Tisseel glue and muscle patch	Back pain	None	1	None	4
3	Neuro	48		L4/L5 decompression and microdiscectomy		CSF leak /lumbar pseudmeningocele and persistent CSF fistula	Lumbar drain, 5.0 Prolene, muscle patch, fat graft and duraseal	Back and leg pain, pins and needles, L5 distribution numbness	Yes	2	Revision of lumbar wound and washout	43
4	Neuro	38	34.26	Microdiscectomy for L5-S1 lateral disc prolapse	2	Post-operative CSF leak and pseudomeningocele	Lumbar drain, fat graft and Tisseel	Occasional pain or tingling in lateral 3 toes of left foot	None	1	Repair of pseudomeningocele, re-do microdiscectomy and insertion of lumbar drain	7
5	Neuro	54	42.19	L4/L5 decompression	3	Post-operative CSF leak and pseudomeningocele	5/0 Prolene muscle patch and Tisseel	Sudden onset headache and photophobia	None	1	Repair of dural tear	7
6	Neuro	45	26.03	C5/6 ACDF and bilateral foraminotomy	5	Intra-op dural tear with CSF leak	Micro patty, muscle patch and Tisseel	Headaches, right arm pain, burning sensation and hypersensitivity	None	0		0
7	Neuro	48	20.23	L4/L5 laminectomy and discectomy	2	Dural tear due to blunt instruments	Primary repair failed. Patch of fascia, durogen patch and Tisseel glue	Headaches and mild wound swelling	None	1	Repair of lumbar pseudomeningocele	3

Table 1 (continued)

Patient Number	Department	Age	BMI	Procedure	Length of stay	Dural complication	Method of repair	Symptoms post repair	Infection post repair	Readmissions	Readmission procedures	Duration of readmissions
8	Neuro	28	32.98	Cervical Intramedullary Ependymoma	4	CSF leak requiring lumbar drain	Lumbar drain	Complete numbness in band around trunk and numb abdomen. Reduced bladder sensation. Keloid scar	None	1	Lumbar drain insertion	10
9	Neuro	58	24.87	Midline Primary anterior cervical decompression	2	Intra-op dural tear with CSF leak	flowseal, spongistan. Tisseel	Residual weakness in left hand	None	0		0
10	Neuro	42		Large inferior central disc taken out in 3 large fragments (L5/S1)	7	Two pinhole tears made to the dura with CSF leak	5.0 Prolene and tissue patch	Weakness of left leg calf muscles and reduced toe-off. Numb saddle region. Plantar flexion weakness	None	0		0
11	Neuro	50	29.35	L4/5 decompression and L4/5 discectomy for Cauda Equina Compression	3	Dural tear and CSF leak noticed post-operatively in relation to a bony spur	5/0 Vicryl, muscle, Tisseel and lumbar drain	Headaches, lower back pain, wound swelling	None	1	Insertion of Lumbar drain, wound exploration and re-do microdiscectomy	6
12	Neuro	74		Laminectomy for L4/5 stenosis	3	Intraoperative dural tear with CSF leak on and pseudomeningocele	5.0 Vicryl sutures and tissue dura patch	Intermittent pain in both legs	None	1	None	8
13	Neuro	77	29.00	L3/L4 decompression and laminectomy for spinal stenosis	12	Small dural tear and CSF leak from wound	Tissue patch Vicryl suture, 6/0 Prolene, Surgical, floseal and Tisseel glue	Trifascicular block and bradycardia	None	1	Repair of CSF leak	0

Table 1 (continued)

Patient Number	Department	Age	BMI	Procedure	Length of stay	Dural complication	Method of repair	Symptoms post repair	Infection post repair	Readmissions	Readmission procedures	Duration of readmissions
14	Neuro	37	37.60	Re-exploration of L5 nerve root	8	Intraoperative dural tear requiring further surgery	Dural glue, stitches, 5/0 Vicryl, muscle patch, Tisseel and lumbar drain	Positional headaches, worsening pain, soft/fluctuant swelling at lumbar site, large pseudomeningocele	Yes	1	Repair of pseudomeningocele and lumbar drain insertion	7
15	Neuro	59	31.51	L3/L4 decompressive laminectomy	5	Adherent thickened ligamentum flavum causing dural tear	Primary repair and muscle graft	Continued numbness in right leg, shooting pain bilaterally, L4 nerve root irritation and mechanical lower back pain	None	0		0
16	Neuro	68	24.94	Laminectomy at L3/4 and L4/5	6	L3/L4 dural tear	Bioglue	Occasional pain down the back of the leg and back	Yes	0		0
17	Neuro	47		L5 laminectomy and L5/S1 discectomy	8	Small dural tear below L5	5–0 Prolene, tissupath and bioglue	Numbness in left side of genital area through to buttock. Pins and needles in left buttock	None	0		0
18	Neuro	74	26.79	L3/4, L4/5 decompression and L4 laminectomy	5	ligamentum flavum adherent to dura	6.0 Vicryl and tissue patch	Constant stinging painful sensation in feet, ankles and shins, hypersensitivity to light touch	None	0		0
19	Neuro	67	23.24	L4/L5 intersegmental decompression	4	Intraoperative dural tear with a CSF leak	6/0 Prolene and tissue patch	Severe sciatica from the buttock to the Achilles area	None	0		0
20	Neuro	77	27.66	L3-S1 posterior lateral fusion, L3/4, L4/5, L5/S1 TLIF	11	Dural tear and 3.1 L blood loss	Dura tissue patch, lumbar drain and 5–0 Prolene	None	None	0		0

Table 1 (continued)

Patient Number	Department	Age	BMI	Procedure	Length of stay	Dural complication	Method of repair	Symptoms post repair	Infection post repair	Readmissions	Readmission procedures	Duration of readmissions
21	Neuro	52	29.55	L4/5 intersegmental decompression	5	Two small dural tears at inferior edge	7–0 Prolene sutures and tissue patch	None	None	0		0
22	Neuro	69	43.07	L4/L5 posterior lumbar interbody fusion and decompression	6	Small dural tear intraoperatively on right side	Tissue patch dura, Duraseal and Flowseal	Back pain and right-sided sciatica	None	0		0
23	Neuro	22	33.56	Revision of paddle SCS and insertion of Surpass Electrode	4	Dura stuck to bone. Dural tear was seen in 3 places	Tissue Dura and Adherus	Multiple back pain symptoms and complications	Yes	1	None	5
24	Neuro	74	31.20	L3/L4 Decompression and Discectomy	3	Dural tear observed on closure	Subfascial drain	None	None	0		0
25	Neuro	46	27.86	T10/T11 Decompression and posterior instrumented fusion	10	Dural tear observed on closure	Muscle graft, duraseal and subfascial drain	Patient was unable to move his legs	Yes	0		0
26	Neuro	51	22.10	C7/T1 ACDF and plate stabilisation	3	Dural tear sustained	Duraseal	None	None	0		0
27	Neuro	44	20.13	Removal of posterior lumbar spine instrumentation	3	Small longitudinal dural tear adjacent to midline below S1	6–0 Prolene, duragen, durasel, surgical patty and lumbar drain	None	None	0		0
28	Neuro	38	27.14	Urgent L5-S1 decompression and microdiscectomy	4	Intraoperative dural tear following dissection of the ligamentum flavum	Vicryl 5–0 and Tisseel	Problems with bowel control as well as altered saddle region sensation and sexual dysfunction	None	0		0
29	Neuro	47	28.18	L4/L5 discectomy	20	Two intraoperative dural tears	Vicryl 5/0, Floseal and Tisseel	Persistent lower back pain and neuropathic pain on the right leg	None	0		0

Table 1 (continued)

Patient Number	Department	Age	BMI	Procedure	Length of stay	Dural complication	Method of repair	Symptoms post repair	Infection post repair	Readmissions	Readmission procedures	Duration of readmissions
30	Neuro	56		C4/C5 anterior cervical discectomy	4	Intraoperative dural tear	Surgical, Tisseel, Flowseal and subfascial drain	Left hand numbness, pain behind neck, hypersensitivity superior to the wound	None	0		0
31	Neuro	72	30.72	L3-4 decompression and discectomy	10	Intraoperative dural tear caused by removal of the ligamentum flavum	6/0 Vicryl, surgical and Tisseel	CSF leak, sciatic pain and sensory changes over buttocks	None	0		0
32	Neuro	82	27.06	L3/4 and L4/5 lumbar decompression and body fusion	10	Small dural tear with arachnoid intact, no CSF leak	Tissue dura	Ongoing back pain and bilateral lower limb symptoms	None	0		0
33	Neuro	46	36.57	C5/6 and C6/7 ACDF and fusion	2	C5/6 small dural tear but no CSF leak	Surgical and Tisseel	Gait abnormalities and light touch sensation abnormalities	None	0		0
34	Neuro	50	34.90	Laminectomy at L3-4	3	Small dural tear with arachnoid intact, no CSF leak	Not Recorded	Back pain, frontal headaches and widespread sensory deficit to light touch	None	0		0
35	Neuro	50	25.14	Microdiscectomy at L5-S1	3	Small dural tear with arachnoid intact, no CSF leak	Tisseel	Discitis and infection	Yes	1	None	1
36	Neuro	84	26.89	L3/4 and L4/5 intersegmental and lateral recess decompression	3	Ligamentum adherent to dura, tore the dura when lifted	6.0 Prolene, Tissue patch dura and Flowseal	Aching in anterior thighs and pelvis	None	0		0
37	Neuro	54	32.42	L2/3 and L4/5 intersegmental decompression	6	Ligamentum was stuck to the dura dorsally under L4	6.0 Vicryl and duraseal	Pain and weakness in legs, made worse on walking	None	0		0

Table 1 (continued)

Patient Number	Department	Age	BMI	Procedure	Length of stay	Dural complication	Method of repair	Symptoms post repair	Infection post repair	Readmissions	Readmission procedures	Duration of readmissions
38	Neuro	45	24.22	L4/5 decompression and discectomy	4	L5 dural tear	Vicryl 5/0, Prolene 7/0, TissuePatch-Dural and Tisseel	Headaches	None	1	L4/L5 wound exploration and repair of pseudomeningocele	16
39	Neuro	39	26.04	Right side L4/L5 microdiscectomy	4	Dural tear and pseudomeningocele noted 2 months post-operatively	5/0 Prolene, Surgical, Tisseel and lumbar drain	Residual saddle anaesthesia and episodes of bladder incontinence	None	1	Repair of CSF leak and pseudomeningocele	24
40	Neuro	42		L5/S1 decompression	11	Dural tear in lateral aspect of S1 nerve root	Surgical and Tissue patch Dura	Infection and erythema with slight back pain and reduced light touch and pinprick sensation	Yes	0		0
41	Neuro	30	31.8	L5/S1 decompression	4	Small dural tear with subarachnoid intact	6/0 Prolene, fat graft, Tisseel and lumbar drain	None	None	0		0
42	Neuro	20	45.7	L4-5 decompression and microdiscectomy		Dural tear with bulging arachnoid	Lumbar drain	None	Yes	0		0
43	Neuro	73	30.93	C5-6 and C6-7 ACDF	2	Small dural tear with arachnoid intact, no CSF leak	Surgical and Floseal	Right arm radicular pain and slight sensory deficit	None	0		0
44	Neuro	65	18.34	C6-7 corpectomy and iliac crest bone grafting and plating	15	Small dural tear with arachnoid intact, no CSF leak	Surgical, Floseal, blood patch and subfascial drain	Electric shock like symptoms in the right chest, dysphagia and weakness in the right C7 distribution	None	0		0
45	Neuro	69	31.67	Anterior discectomy, fusion and fixation at C3-4	2	Small dural tear with arachnoid intact, no CSF leak	Tisseel	Headaches, mild myelopathic gait and right L5 distributed sciatica	None	2	Nerve root block and L4/L5 laminectomy	3

Table 1 (continued)

Patient Number	Department	Age	BMI	Procedure	Length of stay	Dural complication	Method of repair	Symptoms post repair	Infection post repair	Readmissions	Readmission procedures	Duration of readmissions
46	Neuro	53		Two level ACDF		Small dural tear with arachnoid intact, no CSF leak	Fat graft, muscle graft, spongostan, Tisseel and Adherus	None	None	0		0
47	Neuro	1		Bilateral Excision of spinal neurofibroma	5	Small dural tear and CSF leak seen in axilla of C4 nerve root	Suture, tissue patch, muscle graft and duraseal	CSF leak	None	1	Aspiration of cervicothoracic pseudomeningocele, repair of dural tear and drain insertion	94
48	Neuro	66	34.62	Bilateral Excision of spinal neurofibroma	4	Small dural tear in right lateral aspect of L4	Prolene, muscle patch, bioglue and flowseal	Left hip and buttock pain with weakness of left hip flexion	Yes	0		0
49	Neuro	72	28.71	Left L5 nerve root decompression and laminectomy	3	Small dural tear with arachnoid intact, no CSF leak	6.0 Prolene, muscle graft and duraseal	Back pain	None	0		0
50	Neuro	35	30.07	Insertion of right frontal VP shunt	4	Small dural tear causing haemorrhage	Bipolar diathermy	Severe hypotensive headaches and occipital pain with neck stiffness	None	3	Removal of shunt, lengthening and re-implantation of distal shunt catheter into peritoneum	11
51	Neuro	78	31.23	L4/L5 Discectomy and laminectomy	4	Small tear with adherent dura	Duragen patch, Duraseal and lumbar drain	None	None	0		0
52	Ortho	89	26.10	L2/L3, L3/L4 and L4/L5 Decompression	15	Dural tear at L4/L5	Duragen patch, Duraseal and lumbar drain	Right middle cerebral artery infarct	None	0		0
53	Ortho	77	31.75	Midline primary surgery for lumbar disc degeneration	12	Small CSF Leak due to calcified ligamentum flavum	Vicryl 6.0	Wound leak	None	0		0
54	Ortho	35	22.30	L5/S1 decompression and discectomy	8	Small dural tear noted at the end of the procedure	Fat graft, nylon suture, duragen patch and duraseal	Left-sided foot drop	None	0		0

Table 1 (continued)

Patient Number	Department	Age	BMI	Procedure	Length of stay	Dural complication	Method of repair	Symptoms post repair	Infection post repair	Readmissions	Readmission procedures	Duration of readmissions
55	Ortho	48	41.62	C3—C7 Laminectomy and C5/C6 Foraminotomy	5	Incidental small durotomy at C5/C6	Prolene 6/0, Dural patch and Duroseal	Significant neck pain and worsening numbness in right thumb	None	0		0
56	Ortho	61	20.58	Cervical decompression C2-C4 and instrumented fusion of C2-C5	38	Post-op persisting wound leak and pseudomeningocele	Subfascial drain	Left ulnar neuropathy and grade 4 weakness and some muscle wasting	None	0		0
57	Ortho	34	33.14	L4/L5 primary posterior laminectomy	9	Small dural tear noted during procedure	8.0 Nylon, Everseal and lumbar drain	Saddle analgesia and S1 light touch sensory deficit	None	0		0
58	Ortho	41	42.90	L4/L5 Decompression and discectomy	3	Small pin prick CSF leak	6.0 Prolene and everseal	None	None	0		0
59	Ortho	69	34.57	L2/L3 and L3/L4 Decompression	7	Ligamentum flavum partially adherent to dura	6/0 Prolene, Duraseal and lumbar drain	Urinary retention	None	0		0
60	Ortho	76	27.55	Instrumented fusion and decompression at L3-L5	5	Inadvertent durotomy due to thickened calcified ligamentum adherent to dura	Duragen graft, duraseal and lumbar drain	Significant back and right-sided pain in the L5 distribution	None	0		0
61	Ortho	66	39.92	L3-L5 posterior decompression and fusion and L4/5 PLIF	9	Incidental dural tear during the decompression at L4/L5	Fat graft, Durogen and duroseal	None	None	0		0
62	Ortho	84	20.40	L4/5 spinal decompression		Intraoperative dural tear	Duragen, Duraseal, Floseal, Patch and lumbar drain	Patient died	None	0		0
63	Ortho	32		L4/L5 discectomy	3	Incidental dural tear at L5 dorsal region	Prolene 5.0, durogen and duroseal	Back pain and occasional sharp pain	None	0		0

Table 1 (continued)

Patient Number	Department	Age	BMI	Procedure	Length of stay	Dural complication	Method of repair	Symptoms post repair	Infection post repair	Readmissions	Readmission procedures	Duration of readmissions
64	Ortho	31	29.63	Bilateral L4/L5 discectomy	12	Small central posterior durotomy	Fat graft, nylon suture, durapatch and duraseal	Weakness of the right leg distal to the knee associated with tingling and numbness	None	0		0
65	Ortho	82	32.76	L3/L4 Decompression	11	Small inadvertent durotomy at L3 root	Prolene 6/0, Duragen and Evicell	pack pain, altered perianal and genital sensation with numbness	None	0		0
66	Ortho	60	36.54	T10-L5 instrumented decompression and fusion	43	Dural tear intraoperatively at L3/L4	Duragen patch and Everseal	Patient became paraplegic with major motor and sensory deficits	Yes	0		0
67	Ortho	59	32.18	L2/3 and L3/4 decompression with dynamic stabilisation	5	Inadvertent dorsal linear tear of dura	6–0 Prolene and Duraseal	Weak arms, hand tremor, numbness of left buttock and pelvic region	Yes	0		0
68	Ortho	55		Posterior L2/3 decompression	11	Large complex dural tear	Duragen, durseal, flowseal and drain	Severe loss of sensation and power of the right leg	None	0		0
69	Ortho	30	33.24	Anterior and posterior correction and instrumentation of scoliosis	13	Small dural puncture in lumbar spine	Duragen, duraseal, Lumbar drain and local graft	Back pain	None	0		0
70	Ortho	16	23.75	Posterior L5-S1 instrumented fusion	8	Small dural tear	Information not available	None	None	1	Revision left lateral ligament reconstruction	5
71	Ortho	36	31.88	L4/5 discectomy and decompression	12	Small Dural tear	6–0 Prolene, duragen, duraseal	None	None	0		0
72	Ortho	52		C5/6 reduction and instrumented fusion	72	Disc completely disrupted with dural tear at C5/C6	Duroseal and subfascial drain	None	None	0		0

Table 1 (continued)

Patient Number	Department	Age	BMI	Procedure	Length of stay	Dural complication	Method of repair	Symptoms post repair	Infection post repair	Readmissions	Readmission procedures	Duration of readmissions
73	Ortho	74	29.39	Right anterior cervicotomy C6-C7 spinal cord decompression and fusion	Patient died	Medial dural tear	Spongostan	Patient died	None	0		0
74	Ortho	68	35.49	L3 to S1 lumbar decompression	7	5 mm longitudinal dural tear	6–0 Prolene, Flowseal, Duraseal and lumbar drain	Back pain	None	0		0
75	Ortho	77	23.96	L3/L4 and L4/L5 spinal decompression	7	Small linear dural tear at L5	6–0 Prolene, Flowseal and lumbar drain	None	None	0		0
76	Ortho	57	28.20	Microdiscectomy of lumbar intervertebral disc	6	Dural tear at S1 root	6–0 Prolene, Duragen, Duraseal and lumbar drain	Dysaesthesia in the left S1 distribution with marked cramps in left thigh	None	0		0
77	Ortho	57	31.79	Spine decompression and pedicle subtraction osteotomy, T9-L4	45	Dura adherent to the lamina resulting in dural tears at multiple levels	6–0 Prolene, Duragen and Duraseal	Left foot numbness and loss of function at L5 in right foot	None	0		0
78	Ortho	76	18.49	Posterior instrumented stabilisation T11-L3 and L1 laminectomy	13	Small dural tear	6–0 Prolene Duragen, Duraseal and lumbar drain	Aching in mid thoracic spine	None	0		0
79	Ortho	65	23.66	L1 and L2 laminectomy and L1 and L3 decompression	Patient died	Adherent dura resulting in small tear	6–0 Prolene Duragen, Duraseal and lumbar drain	Patient died	None	0		0
80	Ortho	62	35.24	Two Level spine decompression at the lumbar spine	9	Small dural tear	6–0 Prolene, Duraseal and lumbar drain	Headache, photosensitivity and wound hypersensitivity	None	0		0
81	Ortho	73	27.21	Two Level spine decompression at the lumbar spine	5	Small dural tear	6–0 Prolene, Duraseal and lumbar drain	Leg aching	None	0		0

Table 1 (continued)

Patient Number	Department	Age	BMI	Procedure	Length of stay	Dural complication	Method of repair	Symptoms post repair	Infection post repair	Readmissions	Readmission procedures	Duration of readmissions
82	Ortho	74	38.67	Three Level spine decompression at the lumbar spine	23	Small dural tear	Fat graft, duragen patch and durasell glue	Fluid collection, faecal and urinary retention and loss of anal tone and squeeze	None	0		0
83	Ortho	85	23.85	Three Level spine decompression at the lumbar spine	Patient died	Intraoperative dural tear	Lumbar drain, glue and patch	Patient died	None	0		0
84	Ortho	29		Posterior laminectomy decompression	3	Pinprick sized tear with CSF leak	Duraseal and dural patch	Pseudomenongocele, faecal and urinary incontinence	None	1	Dural tear repair	8
85	Ortho	74	40.88	L3/4 decompression	4	Incidental small dural tear at L4	Durogen and duroseal	None	None	0		0
86	Ortho	55	37.03	L4-S1 posterior instrumented fusion and L5/S1 discectomy	5	Incidental dural tear at L5 root	Durogen, duroseal and lumbar drain	Right-sided back pain	None	0		1
87	Ortho	38	24.78	Three Level spine decompression at the lumbar spine	17	Traumatic dural tear at L1 level posteriorly and anterior laterally	Durogene dressing, duroseal, 6–0 Prolene and lumbar drain	Incontinence	None	0		2
88	Ortho	25	38.31	Open reduction of C6/7, ACDF	6	Traumatic dural tear	Duroseal and subfascial drain	None	None	1	Posterior cervical spine fusion	7
89	Ortho	30		L4/L5 discectomy	3	Small dural tear noted on left L4 nerve root	Dural patch, Duraseal and lumbar Drain	Good post-operative recovery	None	0		0
90	Ortho	83	27.82	L4/L5 Decompression	16	Dural tear noted distally	6–0 Nylon, dural patch, duraseal and lumbar drain	0/5 weakness of ankle dorsiflexion and toe extension in the right foot and reduced sensation	None	0		0

Table 1 (continued)

Patient Number	Department	Age	BMI	Procedure	Length of stay	Dural complication	Method of repair	Symptoms post repair	Infection post repair	Readmissions	Readmission procedures	Duration of readmissions
91	Ortho	75	24.82	L4/L5 Decompression and TILF	8	Small dural tear noted	6–0 Nylon sutures, dural patch, Duraseal and lumbar drain	Headaches	None	0		0
92	Ortho	67	22.46	Posterior correction of scoliosis with instrumentation	11	3 dural tears noticed	Primary repair, duragen patch and duraseal	Reduced L2 sensation	None	1	Elective posterior correction of post junctional kyphosis	23
93	Ortho	69	36.09	Posterior instrumented fusion L3-L5 and decompression laminectomy	5	Small dural tear at the axilla of L5 root	Duragen and Duraseal	None	None	0		0
94	Ortho	64	34.48	T10-Pelvis scoliosis correction, fusion and decompression L4-S1	11	Small dural tear at L5/S1	6–0 Prolene, Duraseal and lumbar Drain	Significant mid-lumbar pain	None	1	Revision degenerative scoliosis correction and TILF	10
95	Ortho	36	31.90	L4/L5 decompression discectomy	4	Small dural tear at L5	Duraseal	Urinary leakage and ongoing right-sided back pain	None	0		0
96	Ortho	58	31.37	Left L5 lateral recess decompression	2	Small dural tear at L5	Duragen and patch	None	None	0		1
97	Ortho	58	35.32	left L4/L5 discectomy/decompression	5	Dural tear at L4	6–0 Prolene, Dural patch and duraseal	Ongoing back ache and altered sensation over lateral left thigh	None	0		2
98	Ortho	60	28.16	L4/L5 laminectomy, decompression and discectomy	3	Dural tear and CSF leak at L5	Durseal and Duragen	Left-sided back pain	None	0		3
99	Ortho	66	34.09	Discectomy	2	Small dural tear	Duraseal	Superficial wound infection	Yes	0		4

Table 1 (continued)

Patient Number	Department	Age	BMI	Procedure	Length of stay	Dural complication	Method of repair	Symptoms post repair	Infection post repair	Readmissions	Readmission procedures	Duration of readmissions
100	Ortho	30	38.41	Lumbar decompression	5	Small dural tear	6/0 nylon, Duragen, Duraseal and lumbar drain	Reoccurring CES symptoms	None	3	S1 nerve root block, bilateral S1 root decompression and re-do discectomy	21
101	Ortho	69	37.96	Lumbar decompression	11	Dural tear at superior edge of decompression	6/0 Prolene, Duragen, duraseal and lumbar drain	Dysaesthesia in the perineal area and posterior aspect of both thighs and urinary urge sensation	None	0		0
102	Ortho	34	33.14	Lumbar decompression	8	Small dural tear	8.0 Nylon, Everseal and lumbar drain	Weaker erection than normal. Some sensory deficit	None	0		0
103	Ortho	64	31.46	L3/L4 and L4/L5 Lumbar Decompression	4	Pinprick dural tear at L4/L5	Duragen, Duraseal and lumbar drain	None	None	0		0
104	Ortho	49	35.11	L5/S1 discectomy and decompression of the right S1 nerve root	2	Pseudomenngocele noticed postoperatively	Not recorded	Continued pain	None	1	Dural tear repair	7
105	Ortho	66	25.06	L3/L4 L4/L5 /S1 fusion	7	Small intraoperative dural tear at L3 root	Duragen and duraseal	Struggle with quadriceps post-operatively	None	0		0
106	Ortho	38	38.52	L3/4 and L5/S1 decompression	4	Adherent dura at L3/4	6/0 Prolene and Duraseal	None	None	0		0

Patient data extracted from Southampton General Hospital databases. *TILF*—Transforaminal lumbar interbody fusion. *ACDF*—Anterior cervical discectomy and fusion. *PLIF*—Posterior lumbar interbody fusion. *Paddle SCS*—Paddle spinal cord stimulation. *VP shunt*—Ventriculoperitoneal shunt

Table 2 Repair method grouping

Group number percentage	Number of patients (n)	Percentage of patients (%)
Primary closure alone	1	0.94
Primary closure and artificial patch	4	3.77
Primary closure and autologous patch	3	2.83
Primary closure and sealant	7	6.60
Primary closure and drain	1	0.94
Primary closure, sealant and drain	11	10.4
Primary closure, sealant and artificial patch	10	9.43
Primary closure, sealant, artificial patch and drain	10	9.43
Primary closure, sealant and autologous patch	6	5.66
Primary closure, sealant and autologous patch and drain	2	1.89
Primary closure, sealant, artificial patch and autologous patch	2	1.89
Primary closure, artificial patch and drain	2	1.89
Autologous patch and sealant	1	0.94
Autologous patch and drain	1	0.94
Sealant alone	9	8.49
Sealant and drain	3	2.83
Sealant and artificial patch	9	8.49
Sealant, artificial patch and drain	8	7.55
Sealant and autologous patch	1	0.94
Sealant, autologous patch and drain	2	1.89
Sealant, artificial patch and autologous patch	2	1.89
Artificial patch alone	2	1.89
Drain alone	4	3.77
Unknown	5	4.72
Total	106	100

following round two. Final answers were averaged to give an MCID for each outcome:

1. Length of hospital stay: ≤ 3 days.
2. Rate of readmissions or revision surgeries: < 2 readmissions or revision surgeries.
3. Length of additional admission(s): ≤ 7 days.
4. Infection rate: No infection present.
5. Neurological symptoms: ≤ 3-point score.

Benefit rate (patients surpassing MCID/total patients) was calculated for each MCID outcome and reported as a percentage improvement (benefit rate of intervention—benefit rate of the control) (Table 3).

Incidence rate

Descriptive statistics were used to identify the surgery and spinal level with the greatest incidence of tears.

Patient demographics

Two MANOVAs were conducted against BMI and age for the five outcomes. Patients were grouped into the following age categories: 1–10, 11–20, 21–30, 31–40, 41–50, 51–60, 61–70, 71–80 and 81–90. Patients were grouped into the following BMI categories: Underweight (16.00–18.49), healthy weight (18.50–24.99), overweight (25.00–29.99), moderately obese (30.00–34.99), severely obese (35.00–39.99), very seriously obese (40.00–44.99) and morbidly obese (45.00–49.99).

Type of repair method

Patients were grouped as per their repair method as shown in Table 2. Repair groups were compared via MANOVA of the five outcome measures. Neurological symptoms are scored as per Table 4.

Table 3 MCID percentage improvement analysis for artificial vs autologous patches in conjunction with primary closure

Category	length of original stay	Infection	Readmissions	Length of additional stays	Symptoms
Group 1: Artificial patch					
Patient	5	0	0	0	4
Patient	4	0	0	0	1
Patient	5	0	0	0	0
Patient	7	0	0	0	3
Number passed MCID	4	4	4	4	3
Number not passed MCID	0	0	0	0	1
Benefit rate (number passed/total number)	100%	100%	100%	100%	75%
Group 2: Autologous patch					
Patient	3	0	1	7	2
Patient	5	0	0	0	5
Patient	3	0	1	8	1
Number passed MCID	2	3	1	2	2
Number not passed MCID	1	0	2	1	1
Benefit rate (number passed/total number)	67%	100%	33%	67%	67%
Percentage improvement	**33**	**0**	**67**	**33**	**8**

Table 4 Scoring for neurological symptoms

Symptoms scoring 1	Symptoms scoring 2
Headache	Fistula formation
Nausea	Pseudomeningocele
Vomiting	Meningitis
Stiffness or tightness across the neck or back	Abscesses
Mild sensory disturbances	Arachnoiditis
Temporary loss of power	Severe shooting pain
Radicular pain	Sciatica
Dizziness	Bladder, bowel or sexual problems
Diplopia	
Tinnitus	
Fluid leak/collection	
Vertigo	

Primary ± patch vs non-primary ± patch

A MANOVA and series of independent samples t-tests were use against the five outcome measures between patients that received primary closure ± a patch vs non-primary closure ± a patch. MCID percentage improvement was calculated.

Artificial vs Autologous patches

Artificial patches and autologous patches in conjunction with primary closure were compared against each outcome via independent t-tests. MCID percentage improvement was calculated.

Results

A total of 106 patients sustained an intraoperative tear across the 46 months. Of the included patients, 51 (47.7%) belonged to the neurosurgery department and 55 (51.4%) belonged to Orthopaedics department.

Incidence rate

1,824 spinal operations were identified in the date range, giving an incidence rate of 5.81%. Of the 106 tears, 43.40% (46) were caused during L4/L5 operations and 72.64% (77) were caused during L3-S1 operations. 44% (47) of tears were elective surgeries, and 56% (59) were emergency surgeries.

Age

The average age was 55.3 (SD = 18.10, Min: 1, Max: 89). MANOVA analysis indicated that age has a statistically significant impact on the post-operative outcomes (F (40, 360.224) = 5.287, $p < 0.000$; Wilk's $\Lambda = 0.134$, partial $\eta^2 = 0.331$). Infection was most common in the 41–50 and 61–70 age group.

BMI

The average BMI was 30.54 (SD = 6.00, Min: 18.34, Max: 45.70). 60.71% of patients were overweight or moderately obese, and only 13.10% were of a healthy weight. BMI did not have a significant impact on post-operative outcomes, (F (25, 276.400) = 0.685, $p = 0.870$; Wilk's $\Lambda = 0.800$, partial $\eta^2 = 0.44$).

Readmissions and rate of revision surgeries were greatest in the moderately obese ($M = 0.41$, SD = 0.747) and severely obese ($M = 0.64$, SD = 1.082) categories. Infections were only present in the overweight ($M = 0.12$, SD = 0.332), moderately obese ($M = 0.15$, SD = 0.362) and severely obese ($M = 0.14$, SD = 0.363) and neurological symptom severity generally increased with BMI.

Type of repair method

Primary closure, sealant and a lumbar drain was the most common repair technique 10.4% ($n = 11$). Primary closure was used in 55.7% of cases (n = 59). However, combinations of sealants, patch's, lumbar and subfascial drains without any form of primary closure were also commonly opted for (32.1% ($n = 34$)). Figure 2 illustrates the frequency of use of each method.

Following MANOVA, no significant difference in the five outcomes was observed between all repair methods (F (105, 342.101) = 0.793, $p = 0.921$; Wilk's $\Lambda = 0.345$, partial $\eta^2 = 0.192$).

Primary ± a patch vs all other repair methods

When comparing primary closure ± a patch ($n = 7$) against all other forms of repair ($n = 99$), primary closure ± a patch scored better in 4/5 clinical outcomes:

1. Length of original stay was over 3.5 days shorter ($M = 4.57$, SD = 1.40 vs $M = 8.58$, SD = 10.16, $p > 0.05$). 4% MCID percentage improvement.
2. The rate of additional admissions/surgeries was almost half ($M = 0.29$, SD = 0.49 vs $M = 0.41$, SD = 0.805 $p > 0.05$). 27% MCID percentage improvement.
3. Length of additional stays was on average 1.35 days less (M = 2.14, SD = 3.671 vs $M = 3.45$, SD = 11.43 $p > 0.05$). No MCID percentage improvement (− 2%).
4. Infection rate post-operatively was 0 for the primary repair ± patch group (M = 0.00, SD = 0.000) and 0.11 in all other treatment groups ($M = 0.12$, SD = 0.328, $p > 0.05$). 12% MCID percentage improvement.

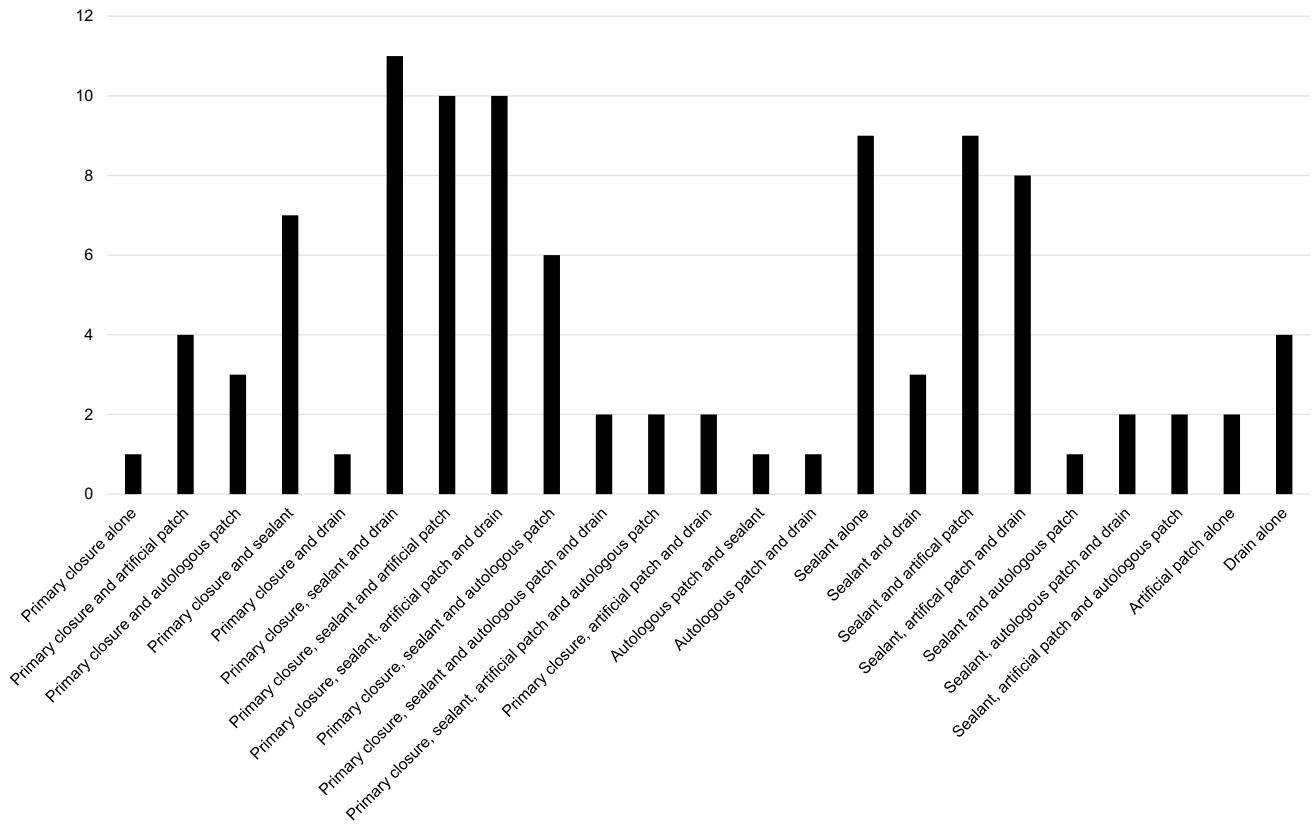

Fig. 2 Bar graph displaying dural tear repair methods used and the frequency of each methods use

5. Severity of neurological symptoms was slightly greater in the primary repair ± patch group ($M = 2.29$, SD = 1.799 vs $M = 1.78$, SD = 1.59), this was reflected by an MCID of − 14%.

Following a MANOVA of primary closure ± a patch, no significant difference was observed (F (5, 89) = 0.559, $p = 0.731$; Wilk's $\Lambda = 0.97$, partial $\eta^2 = 0.197$).

Artificial vs autologous patches

When comparing artificial patches and autologous patches in conjunction with primary closure, no significant difference was seen in the length of original stay ($M = 3.67$, SD = 1.155 vs $M = 5.25$, SD = 1.258, $p > 0.05$).

No patient in the artificial group required further admission or surgery, however, two patients in the autologous group did (M = 0.00, SD = 0.000 vs M = 0.67, SD = 0.577, $p > 0.05$). This equated to a 67% MCID improvement. Due to no patients in the artificial patch group requiring further admission the artificial patch group had a 33% MCID improvement in the length of further admission(s) ($M = 0.00$, SD = 0.000 vs $M = 5.00$, SD = 4.359, $p > 0.05$).

No difference in infection rate between the two groups was observed as no patients in either groups sustained an infection (M0.00, SD = 0.00 and $M = 0.00$, SD = 0.00). However, the artificial group experienced less severe neurological symptoms post-operatively (M2.00, SD = 1.826 vs $M = 2.67$, SD = 2.08), with an 8% MCID improvement.

Discussion

An incidental durotomy refers to the intraoperative tearing of the outer most layer of the meninges [1]. The incidence rate of dural tears shows considerable inter-study variation dependent on the type of procedure, pathology and re-operative rate [7–11]. Owing to the increasing complexity of spinal procedures the rate of dural tears is increasing and they continue to be a common surgical complication [8]. Our incidence rate of 5.81% falls within the reported range of 1–17% [12, 13] and supports the literature theme that such tears most commonly occur at the lumbar spine with 72.64% of the 106 tears occurring between L3-S1 [8].

Further to their common occurrence, dural tears are associated with a range of side effects including fistula formation, meningitis and more commonly orthostatic low-pressure headaches [10, 13, 14]. The most common side effects reported in this study were low-pressure headaches, stiffness across the back and CSF leak.

Despite these side effects, the long-term implications of incidental durotomies is disputed [15, 16] as is the most suitable method for repair. Whilst, primary repair is generally considered a suitable management strategy [10], some studies have concluded that it may not be essential for successful management [13, 17] whilst others report the contrary [10]. Equally, there is little comparative data regarding patient outcomes associated with combinations of repair methods and the repair combinations commonly opted for.

In this study, patients were grouped per their specific repair method and compared against the five clinical outcomes. Further analysis using the same outcomes were conducted on patient age, BMI and on the use of primary closure and type of dural patches used. Minimal clinically important difference was reported according to the Delphi method [18, 19]

Our study demonstrated that when considering these five outcomes, the age of a patient has a significant impact post-operatively. Based on previously published research and the patients included within this study, this finding was suspected to be a result of generalised increased morbidity due to prolonged hospital stay and poorer wound healing as well as more complex initial operative indications within the more elderly patients [20, 21]. Despite BMI not having a significant impact, the rate of readmissions, revision surgeries and infection rate increased with BMI. Complications associated with bariatric spinal patients are well documented [22–24]; therefore, highlighting the significance that 60.71% of the patients were either overweight or moderately obese.

Primary closure, sealant and a lumbar drain was the most common repair method. However, despite primary closure being considered the gold standard [6, 10], it was only used in 55.7% of cases ($n = 59$). The sample size and grouping of patients resulted in each group containing a small number of patients which likely contributed to non-significant MANOVA results. However, the use of primary closure with or without a patch was shown to be superior in four out of the five of the outcomes**.** These data show that primary closure ± patch generates on average a shorter initial stay in hospital (4% MCID improvement), a reduced rate of readmission or need for additional surgeries (27% MCID improvement), a shorter readmission period (No MCID percentage improvement) and a lower infection rate (12% MCID percentage improvement). 'Future research may benefit by comparing the outcomes in a homogenous patient sample between those who received no drain, a subfascial drain or a lumbar drain as part of their tear management. Each type drain cannot be considered as equal and therefore an inter-drain outcome comparisons should be made'.

In recent years, synthetic patches such as a collagen matrix or gelatin sponge have received US Food and Drug Administration approval for use in the repair of a dural tears. This approval provided a growing alternative to the more traditionally used autologous fat, muscle and fascia based patches [25]. Previously opted for autologous patches have reported success rates as low as 70% when

performed within 24 h of a dural tear [26] and speculative evidence suggests that artificial patches may be better suited to adapt to all defects as they are more readily available, can be cut to shape and may achieve watertight closure in a possibly shorter operative time [25, 27]. Additionally, artificial grafts may display further benefits through their chemotactic interaction with dural fibroblasts [28]. However, there is little direct research between artificial and autologous patches and consequentially no consensus on which material is best.

Within this study, when comparing artificial and autologous patches in conjunction with primary closure, artificial patches resulted in shorter hospital admission (33% MCID percentage improvement), lower rates of readmission/need for revision surgeries (67% MCID percentage improvement) and shorter length of additional stays (33% MCID percentage improvement) as well as less severe neurological symptoms post-operatively (8% MCID percentage improvement). This is contrary to the results of Sabatino G, et al. [29] and Abla AA, et al. [30] who both reported no difference when comparing autologous and non-autologous grafts.

Conclusions

This study reports an incidental durotomy rate of 5.81% in a total of 106 patients from Southampton General Hospital's Neurosurgical and Orthopaedics departments. In accordance with the current literature, 72.64% were sustained at the L3-S1 spinal level.

In this study, age was shown to have a significant impact on post-operative outcomes and BMI displayed positive correlation with the rate of readmissions, revision surgeries and post-operative infection. No significant difference was observed between repair groups; however, primary closure ± a patch scored better in 4/5 clinical outcomes when compared to other forms of repair.

The use of primary closure, a sealant and a lumbar drain was the most commonly opted for repair method and primary was used in only 55.7% of cases. Further analysis showed that artificial patches in conjunction with primary closure achieved lower rates of readmission/need for revision surgery and shorter length of additional hospital stays as well as less severe neurological symptoms post-operatively than autologous patches.

This study highlights the importance of age and BMI on post-operative dural tear outcomes and supports the use of primary closure ± a patch. This study also provides limited evidence in favour of artificial over autologous patches and recommends that dural patches always be used in conjunction with primary closure.

Limitations

The limited data that could be obtained retrospectively restricted analysis to only five outcomes and the small sample size and patient grouping resulted in several groups containing a limited numbers of patients. The study analysis was also dependent on the accuracy of operative notes. Primary limitations of this study therefore include its retrospective method of data acquisition, small sample size, considerable patient and operative heterogenicity and reliance on the accuracy of operative procedural notes. It is important to note that clinical heterogenicity arose from differing preoperative diagnoses, type of procedure, duration of follow up and method of wound closure which due to insufficient data are unreported in this study. However, despite these causes of heterogenicity, the authors believe that the present study adequately addresses its primary aim of comparing all current methods of iatrogenic dural tear repair surgery across a variety of clinical scenarios and operative indications. This study should therefore serve as a generalizable and more widely applicable attempt to evaluate the most effective dural tear repair method in a boarder operative context. Future research should further define individual patient populations to subsequently eliminate causes of clinical heterogenicity. However, such studies must follow prior nonexclusive research.

Finally, it cannot be certain as to whether the reported neurological deficits in the study were the consequence of the dural tear or the primary surgical procedure. Despite these limitations, the authors believe that this study provides an important overall and generalised evaluation of dural tear repair methods and raises several questions on a clinically and scientifically important topic of spinal surgery.

Authors' contributions All authors contributed equally to the research conceptualisation and to the acquisition, analysis and interpretation of data. Data analysis and manuscript preparation were performed by CT and AK. All authors commented on previous versions of the manuscript and to the final version and agree to be accountable for all aspects of the work.

Funding No funds, grants, or other support was received.

Data availability All data generated or analysed during this study are included in this published article.

Declarations

Conflict of interests The authors declare that they have no conflict of interests.

Ethical approval Ethical approval was waived by the local Ethics Committee of The University of Southampton in view of the retrospective nature of the study and all the procedures being performed were routine care.

References

1. Kalevski SK, Peev NA, Haritonov DG (2010) Incidental dural tears in lumbar decompressive surgery: incidence, causes, treatment, results. Asian J Neurosurg 5:54–59
2. Sin AH, Caldito G, Smith D, Rashidi M, Willis B, Nanda A (2006) Predictive factors for dural tear and cerebrospinal fluid leakage in patients undergoing lumbar surgery. J Neurosurg Spine 5:224–227
3. Espiritu MT, Rhyne A, Darden BV (2010) 2nd Dural tears in spine surgery. J Am Acad Orthopae Surgeons 18:537–545
4. Wolff S, Kheirredine W, Riouallon G (2012) Surgical dural tears: prevalence and updated management protocol based on 1359 lumbar vertebra interventions. Orthopaed Traumatol, Surg Res 98:879–886
5. Epstein NE (2013) A review article on the diagnosis and treatment of cerebrospinal fluid fistulas and dural tears occurring during spinal surgery. Surg Neurol Int 4:S301–S317
6. Dafford EE, Anderson PA (2015) Comparison of dural repair techniques. Spine J: Official J North Am Spine Soci 15:1099
7. Kalevski S, Peev N, Haritonov D (2010) Incidental dural tears in lumbar decompressive surgery: Incidence, causes, treatment, results. Asian J Neurosur 5:54
8. Bosacco SJ, Gardner MJ, Guille JT (2001) Evaluation and treatment of dural tears in lumbar spine surgery: a review. Clinical Orthopaed Related Res 389:238–247
9. Tafazal SI, Sell PJ (2005) Incidental durotomy in lumbar spine surgery: incidence and management. Eur Spine J 14:287–290
10. Guerin P, El Fegoun AB, Obeid I, Gille O, Lelong L, Luc S, Bourghli A, Cursolle JC, Pointillart V, Vital J-M (2012) Incidental durotomy during spine surgery: incidence, management and complications. A retrospective review Injury 43:397–401
11. Cammisa FP Jr, Girardi FP, Sangani PK, Parvataneni HK, Cadag S, Sandhu HS (2000) Incidental durotomy in spine surgery. Spine 25:2663–2667
12. Shahin Y, Kett-White R (2010) Incidence of dural tears post lumbar spine surgery. In: Orthopaedic Proceedings. The British Editorial Society of Bone & Joint Surgery. pp. 239–239
13. Grannum S, Patel MS, Attar F, Newey M (2014) Dural tears in primary decompressive lumbar surgery. Is primary repair necessary for a good outcome? Eur Spine J 23:904–908
14. Saxler G, Krämer J, Barden B, Kurt A, Pförtner J, Bernsmann K (2005) The long-term clinical sequelae of incidental durotomy in lumbar disc surgery. Spine 30:2298–2302
15. Wang JC, Bohlman HH, Riew KD (1998) Dural tears secondary to operations on the lumbar spine. Management and results after a two-year-minimum follow-up of eighty-eight patients. JBJS 80:1728–1732
16. Jones AA, Stambough J, Balderston R, Rothman R, Booth R Jr (1989) Long-term results of lumbar spine surgery complicated by unintended incidental durotomy. Spine 14:443–446
17. Eismont FJ, Wiesel S, Rothman RH (1981) Treatment of dural tears associated with spinal surgery. JBJS 63:1132–1136
18. Black N, Murphy M, Lamping D, McKee M, Sanderson C, Askham J, Marteau T (1999) Consensus development methods: a review of best practice in creating clinical guidelines. J Health Serv Res Policy 4:236–248
19. Copay AG, Subach BR, Glassman SD, Polly DW Jr, Schuler TC (2007) Understanding the minimum clinically important difference: a review of concepts and methods. Spine J 7:541–546
20. Tsutsumimoto T, Yui M, Uehara M, Ohta H, Kosaku H, Misawa H (2014) A prospective study of the incidence and outcomes of incidental dural tears in microendoscopic lumbar decompressive surgery. The bone & joint journal 96:641–645
21. Deyo R, Cherkin D, Loeser J, Bigos S, Ciol M (1992) Morbidity and mortality in association with operations on the lumbar spine. The influence of age, diagnosis, and procedure. J Bone Joint Surg Am 74:536–543
22. Patel N, Bagan B, Vadera S, Maltenfort MG, Deutsch H, Vaccaro AR, Harrop J, Sharan A, Ratliff JK (2007) Obesity and spine surgery: relation to perioperative complications. J Neurosurg Spine 6:291–297
23. Passias PG, Horn SR, Vasquez-Montes D, Shepard N, Segreto FA, Bortz CA, Poorman GW, Jalai CM, Wang C, Stekas N (2018) Prior bariatric surgery lowers complication rates following spine surgery in obese patients. Acta Neurochir 160:2459–2465
24. Telfeian AE, Reiter GT, Durham SR, Marcotte P (2002) Spine surgery in morbidly obese patients. J Neurosurg Spine 97:20–24
25. Choi EH, Chan AY, Brown NJ, Lien BV, Sahyouni R, Chan AK, Roufail J, Oh MY (2021) Effectiveness of repair techniques for spinal dural tears: a systematic review. World Neurosurg 149:140–147
26. Turnbull D, Shepherd D (2003) Post-dural puncture headache: pathogenesis, prevention and treatment. Br J Anaesth 91:718–729
27. Zenga F, Tardivo V, Pacca P, Garzaro M, Garbossa D, Ducati A (2016) Nanofibrous synthetic dural patch for skull base defects: preliminary experience for reconstruction after extended endonasal approaches. J Neurol Surg Report 2:e50–e55
28. Narotam PK, van Dellen JR, Bhoola KD (1995) A clinicopathological study of collagen sponge as a dural graft in neurosurgery. J Neurosurg 82:406–412
29. Sabatino G, Della Pepa GM, Bianchi F, Capone G, Rigante L, Albanese A, Maira G, Marchese E (2014) Autologous dural substitutes: a prospective study. Clin Neurol Neurosurg 116:20–23
30. Abla AA, Link T, Fusco D, Wilson DA, Sonntag VK (2010) Comparison of dural grafts in Chiari decompression surgery: review of the literature. J Craniovertebral Junction Spine 1:29