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Management of incidental durotomies in an integrated Orthopaedic and Neurosurgical Spinal Unit

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ABSTRACT

Introduction: Incidental durotomy (ID) is an intraoperative event associated to prolonged bed rest and hospital stay, antibiotic use, higher patient dissatisfaction, and leg pain among other complications of its postoperative course. Several repair techniques and postsurgical care have been proposed for its management. This study was designed to develop an agreed protocol in cases of ID among Orthopaedic Surgeons (OS) and Neurosurgeons (NS) integrated into a Spinal Surgery Unit.
Research question: Incidental durotomies management protocol.
Materials and methods: From 997 eligible cases operated in Hospital del Mar (Barcelona, Spain) from April 2018 to March 2022, demographic, clinical, surgical and postoperative data was collected for statistical analysis from the morbidity and mortality database, with 79 identified IDs. Redo procedures were significantly associated to OS, and cervical and anterior/lateral approaches to NS, both groups were not comparable.
Results: ID occurred in 7.9% of cases, more frequently after the lockdown ($p=0.03$), in females ($p=0.04$), during posterior approaches ($p=0.003$), and less frequently in the cervical spine ($p=0.009$). IDs were linked to postoperative infections ($p< 0.001$) and nerve root damage ($p< 0.001$). Patients without ID evolved more satisfactorily during the postoperative period ($p=0.002$), and those with CSF leak (20/79) spent on bed rest more than twice the time as those without ($p<0.001$). Multivariable logistic regression showed strong association between posterior approaches and ID, between complicated postoperative courses and ID.
Discussion and conclusions: ID is linked to an adverse postoperative recovery, and it should be primarily repaired under microscope, with early mobilization of patients after surgery.

1. Introduction

Incidental durotomy (ID) is an unwanted and unexpected incidence that can happen during spine surgery. The term ID is preferred to “dural tear”, which may imply carelessness when none was present. In fact, dural opening is often a standard part of the operation in many spinal procedures, and alone, opening the dura intentionally or otherwise is not expected to have a deleterious effect on the patient. But unintended or planned durotomies can also have a wide range of severe sequelae like the well-documented cerebrospinal fluid (CSF) leak with contained pseudo-meningocele or external fistula, associated nerve root contusion or laceration caused by the herniation of the nerve roots through the opening, or even the collapse of the thecal sac increasing the chances of epidural bleeding (Mark, 2016). IDs can cause deleterious secondary symptoms to the patient, linked to CSF hypotension syndrome (from mild orthostatic headache, nausea or photophobia to subdural hematomas or acquired Chiari malformation), meningitis, and sensitive or motor nerve root dysfunction (2–10, 32). ID is also associated with prolonged bed rest, hospital stay, antibiotic use, higher patient dissatisfaction, and leg pain (Strömqvist et al., 2019; Enders et al., 2018). Chronic pain, bladder, bowel and/or sexual dysfunction caused by arachnoiditis are other less documented possible sequelae of the dural opening.

According to the literature, the frequency of ID durotomy ranges

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[1] In memoriam of José Juan Rodríguez, beloved father and mathematician.

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from 1.1 to 20% (McMahon et al., 2012; Klingler et al., 2015; Kogias et al., 2017; Çivi, 2020; Aspalter et al., 2021; Kim et al., 2020; Enders et al., 2018) depending on the type of surgical procedure. Most IDs occur during surgeries involving the lumbar region, but some series report a higher incidence in the thoracic spine (McMahon et al., 2012). In the SPORT study, there was a 9% incidence of unintended durotomy in patients undergoing first-time open lumbar laminectomy for spinal stenosis, where the thinning of the dura can be anticipated in long-standing cases (Weinstein et al., 2010). ID is more frequently seen during procedures performed by less experienced surgeons (Enders et al., 2018), in elder patients, with high body mass index (BMI) (Klingler et al., 2015; Strömqvist et al., 2019; Aspalter et al., 2021; Kim et al., 2020), in multilevel surgeries, or when instrumentation of the spine is required (Enders et al., 2018). These factors can intuitively explain some of the frequent etiologies of the ID: unanticipated anatomic variations, firm adhesion of the dura to removed bone, obscure deep surgical field with folds of dura that can be caught in a rongeur or curette, slippage of instruments or simply surgeon's exhaustion (D'Astorg et al., 2020). The most common reported factor associated with ID is repetitive spine surgeries (McMahon et al., 2012; Gautschi et al., 2014; Klingler et al., 2015; Strömqvist et al., 2019; D'Astorg et al., 2020; Çivi, 2020; Aspalter et al., 2021; Enders et al., 2018), as tissue integrity and quality are worse in re-do than in first-time procedures, and secondary fibrosis makes difficult the surgical dissection of the dural plane during reinterventions. As with blood loss, minimally invasive (MISS) and endoscopic spinal surgeries are also beneficial when reducing the occurrence of ID (McMahon et al., 2012; Aspalter et al., 2021; Kim et al., 2020), as per this technique minimum dead space is created (Aspalter et al., 2021; Kim et al., 2020), although some authors have pointed out that incidence of this complication during MISS is underrated and expected to increase as these procedures become more widely spread (Kim et al., 2020).

Different protocols have been proposed for the management of IDs, direct suture repair of the dural tear during the operation is the gold standard prioritised in most institutions (McMahon et al., 2012; Gautschi et al., 2014; Klingler et al., 2015; Kogias et al., 2017; Strömqvist et al., 2019; D'Astorg et al., 2020; Enders et al., 2018). Different stitch materials are used to obtain a watertight closure (Gautschi et al., 2014) over the dural defect, most of them non-absorbable ones, and including non-traumatic titanium clips in MISS (Kim et al., 2020). There is not complete agreement about the use of grafts to prevent CSF leak from ID site (McMahon et al., 2012; Gautschi et al., 2014; Strömqvist et al., 2019; D'Astorg et al., 2020). Tissue autografts such as muscle, fat or blood patches are used when direct repair is insufficient or impossible, or when adjacent material is required to strengthen the suture (McMahon et al., 2012; Gautschi et al., 2014; Klingler et al., 2015; D'Astorg et al., 2020; Enders et al., 2018), as allo

or synthetic grafts are used as well. Sealants are also effective and safely used to prevent CSF leakage from ID (Gautschi et al., 2014; Klingler et al., 2015; D'Astorg et al., 2020; Kim et al., 2020), with a great variety of products and manufacturers reported, from coated collagen sponges to different kind of glues containing human coagulation factors such as fibrinogen and thrombin. Sealants act as gelatine-like material and constitute a firm protection over the patch, graft or suture placement. After dural repair Valsalva manoeuvre is performed with sealant in situ as a proof of the integrity of the closure. The use of these different sealants has a very low reported rate of complications during the post-operatory evolution.

Early mobilisation is recommended, and more than 72 h of bed rest is not advised, preventing therefore haemodynamic and other post-operative complications (Gautschi et al., 2014; Klingler et al., 2015; D'Astorg et al., 2020). When ID evolution leads to CSF fistula, repair by re-do open spine surgery is favoured in comparison to the insertion of an external lumbar drain (ELD).

In April 2018, four senior Spinal Surgeons with similar degrees of experience and competence joined together to establish a Spinal Surgery Unit in Hospital del Mar, Barcelona (Spain). Their academic background, training and professional practice resulted in two of these surgeons being from Neurosurgery, and in the other two from Orthopaedic Surgery (Shaffrey and Buell, 2021; Lad et al., 2021). The observed incidence, intra- and postoperative management of IDs seemed to be completely different in these two groups of surgeons since the establishment of the Unit, so we decided to perform a retrospective and observational analysis on IDs and to establish a standard protocol in the management of this topic in our institution according to the results of this analysis.

2. Material and methods

Hospital del Mar is a tertiary University Hospital attending a population of 310.000 in the northeast metropolitan area of Barcelona, Spain. As a Trauma Centre, it is provided with state-of-the-art spinal surgery facilities including intraoperative CT scan, neuronavigation, and two latest generation surgical microscopes, also offering modern minimally invasive techniques such as spinal endoscopy, anterior and lateral retroperitoneal approaches to the lumbar spine or percutaneous spinal fixations. Around 400 elective and emergency spinal surgeries per year were performed regularly by four spinal surgeons in two available operating theatres before the Covid lockdown. This event had a dramatic effect on Hospital del Mar due to its long tradition in infectious diseases since its foundation in 1905, with worldwide media reports during the pandemic (Dean, 2020).

A Spinal Unit was formally constituted of two neurosurgeons (NS) and two orthopaedic surgeons (OS) since the 1st of April 2018. Data was analysed according to the registry of patients collected for quarterly morbidity and mortality sessions. 1066 spinal procedures performed in patients over 15 years of age until April the 1st 2022 were potentially eligible for statistical analysis. Exclusion criteria involved 69 cases: a non-operated patient, a duplicated one, and 67 procedures consisting of radiofrequency neurolysis, local nerve infiltrations and spinal cord stimulator implantations (pain treatment percutaneous procedures).

Demographic and descriptive data are resumed in Table 1, with variables selected for analysis including age, sex, BMI, codified diagnosis and location of pathology, redo procedures, anterior/posterior/lateral surgical approach, decompressive, instrumented and minimally invasive surgeries, and type of surgeon (NS vs OS). 79 IDs were identified in the total number of spinal procedures, with variables analysed in these cases according to the repair technique applied. Dural defect repairs under a surgical microscope were also registered. Nonabsorbable monofilament four or five zero sutures made of polypropylene/Prolene ® (Ethicon Inc., Somerville NJ, USA) or expanded polytetrafluoroethylene/Goretex ® (WL Gore Inc., Flagstaff AZ, USA) were used as stitch material with an adequate tensile strength of the wire and atraumatic needle. Type of graft autologous fat vs. Duraform® (Codman Inc., Raynham MA, USA) and type of sealant used as Tisseel ® (Baxter Healthcare Corporation, Hayward CA, USA), TachoSil® (Takeda GmbH, Linz, Austria) or DuraSeal ® (Integra LifeSciences, Princeton NJ, USA) were analysed variables as well. Long and thin bayonet-type specific instruments for dural repair as the Scanlan® (Scanlan Int., St. Paul MN, USA) dura closure system was used during MISS tubular procedures.

In all cases of ID, the number of postoperative flatbed resting days was recorded. Postoperative CSF happened in 20 cases of ID, being β2-transferrin determined to confirm the presence of CSF fistula through the surgical wound. It was also recorded as a variable when an ELD was inserted (11 cases), regulating the drip chamber height to obtain 10 cc of CSF per hour for a minimum of five days. Patients again had flat bed rest for the time the ELD was in situ, and the drain was closed five days after its insertion when it was effective to dry the leak, being removed the day after if no fistula was observed. When a surgical revision was required (8 cases), all the variables related to the dural repair and postoperative management were recorded and analysed again.

Statistical analysis of data was performed using the Statistical

Table 1
Sample descriptive by surgeon and by position. T-test p-value for continuous variables; Chi-squared p-value test for categorial variables.

	Surgeon				Position			
	All sample (n = 997)	Neurosurgery (n = 434)	Orthopedic S. (n = 563)	p-value	Cervical (n = 146)	Thoracic (n = 96)	Lumbar (n = 755)	p-value
Surgeon								
Neurosurgery	434 (43.5%)				86 (58.9%)	38 (39.6%)	310 (41.1%)	**< 0.001**
Orthopedic Surgery	563 (56.5%)				60 (41.1%)	58 (60.4%)	445 (58.9%)	
Position								
Cervical	146 (14.6%)	86 (19.8%)	60 (10.7%)	**< 0.001**				
Thoracic	96 (9.6%)	38 (8.8%)	58 (10.3%)					
Lumbar	755 (75.7%)	310 (71.4%)	445 (79.0%)					
Age, mean (SD)	61.0 (14.5)	60.1 (14.4)	61.6 (14.5)	0.119	57.5 (15.1)	60.7 (13.6)	61.7 (14.4)	**0.006**
Gender								
Male	512 (51.4%)	229 (52.8%)	283 (50.4%)	0.468	99 (68.3%)	45 (46.9%)	368 (48.8%)	**< 0.001**
Female	483 (48.4%)	205 (47.2%)	278 (49.6%)		46 (31.7%)	51 (53.1%)	386 (51.2%)	
BMI, mean (SD)	28.0 (5.1)	28.1 (5.1)	28.0 (5.1)	0.825	26.6 (4.8)	27.7 (6.0)	28.3 (5.0)	**0.001**
Underweight - Normal	284 (29.3%)	125 (29.6%)	159 (29.1%)	0.884	58 (40.3%)	30 (34.9%)	196 (26.5%)	**0.002**
Overweight - Obese	685 (70.7%)	298 (70.4%)	387 (70.9%)		86 (59.7%)	56 (65.1%)	543 (73.5%)	
Treatment Number								
1	941 (94.4%)	416 (95.9%)	525 (93.3%)	0.135	139 (95.2%)	83 (86.5%)	719 (95.2%)	**0.003**
2	54 (5.4%)	18 (4.1%)	36 (6.4%)		6 (4.1%)	13 (13.5%)	35 (4.6%)	
3	2 (0.2%)	0 (0.0%)	2 (0.4%)		1 (0.7%)	0 (0.0%)	1 (0.1%)	
Invasive								
No	64 (6.4%)	34 (7.8%)	30 (5.3%)	0.110	2 (1.4%)	8 (8.3%)	54 (7.2%)	**0.024**
Yes	933 (93.6%)	400 (92.2%)	533 (94.7%)		144 (98.6%)	88 (91.7%)	701 (92.8%)	
Approach								
Anterior or lateral	115 (11.5%)	69 (15.9%)	46 (8.2%)	**< 0.001**	97 (66.4%)	2 (2.1%)	16 (2.1%)	**< 0.001**
Posterior	882 (88.5%)	365 (84.1%)	517 (91.8%)		49 (33.6%)	94 (97.9%)	739 (97.9%)	
Reintervention								
No	792 (79.4%)	371 (85.5%)	421 (74.8%)	**<0.001**	137 (93.8%)	76 (79.2%)	579 (76.7%)	**< 0.001**
Yes	205 (20.6%)	63 (14.5%)	142 (25.2%)		9 (6.2%)	20 (20.8%)	176 (23.3%)	
Complications								
No	766 (76.8%)	340 (78.3%)	426 (75.7%)	0.321	131 (89.7%)	67 (69.8%)	568 (75.2%)	**< 0.001**
Yes	231 (23.2%)	94 (21.7%)	137 (24.3%)		15 (10.3%)	29 (30.2%)	187 (24.8%)	
Number of complications								
0	766 (76.8%)	340 (78.3%)	426 (75.7%)	0.471	131 (89.7%)	67 (69.8%)	568 (75.2%)	**0.001**
1	202 (20.3%)	84 (19.4%)	118 (21.0%)		12 (8.2%)	27 (28.1%)	163 (21.6%)	
≥2	29 (2.9%)	10 (2.3%)	19 (2.4%)		3 (2.1%)	2 (2.1%)	24 (3.2%)	
Type								
Durotomy	79 (7.9%)	35 (8.1%)	44 (7.8%)	0.885	5 (3.4%)	3 (3.1%)	71 (9.4%)	**0.009**
Infection	58 (5.8%)	23 (5.3%)	35 (6.2%)	0.540	1 (0.7%)	8 (8.3%)	49 (6.5%)	**0.013**
Medical complication	14 (1.4%)	2 (0.5%)	12 (2.1%)	**0.026**	0 (0.0%)	2 (2.1%)	12 (1.6%)	0.274
Death	7 (0.7%)	2 (0.5%)	5 (0.9%)	0.423	1 (0.7%)	4 (4.2%)	2 (0.3%)	**< 0.001**

Package for Social Sciences (SSPS version 23, SPSS Inc., Chicago IL, USA). Quantitative variables were expressed as a mean with standard deviation or median with the first and third quartile values (Quartile 1, Quartile 3); qualitative variables were expressed as percentages and frequencies. ANOVA parametric test was used to compare continuous variables; and the chi-square test was used to compare proportions in categorical variables. Multivariate analysis was performed using a multiple logistic regression model. A p-value < 0.05 was considered significant. The database was anonymised and processed to remove any personally identifiable information from the statistical analysis. Approval for an observational and retrospective study was obtained from the Ethics Committee.

3. Results

Out of 997 reviewed procedures, 534 were performed in the pre-pandemic period. 766 underwent without any complications, while 23.2% had complications. Out of these 231 complicated cases, ID occurred in 79 (7.9% of the total serie), and its significant associated variables are resumed in Table 2. IDs were more frequently seen after the lockdown (p=0.03). (Table 1).

Cases of IDs were more frequent in females (59.5%, p=0.04). 78.2% of IDs happened in overweight or obese patients, but this higher proportion was not statistically significant. When we looked at the number of codified diagnoses in the cases of ID, the vast majority of them (94.9%) happened in patients whose diagnoses were codified with a single item (e.g., lumbar disc herniation or degenerative spondylolisthesis). Of the analysed procedures, 14.6% were performed in the cervical region, 9.6% in the thoracic, and 755 (75.7%) in the lumbar spine. 89.9% (71/79) of IDs happened in the lumbar or lumbosacral spine, 3.8% (3/79) in the thoracic

(most in patients treated for scoliosis), and 6.3% (5/79) in the cervical or cranio-cervical region. IDs were seen less frequently in cervical procedures, and this association was significant (p=0.009). 59.5% of IDs happened during spinal instrumentations and 32 cases (40.5%) in simple decompressive procedures. Just two cases of IDs happened during MISS surgeries. Invasive interventions were related to the majority of IDs: 77/79 of the cases (97.5%) occurred in invasive interventions. 78/

Table 2
Patients characteristics by Durotomy. Chi-squared p-value test for categorial variables.

	Durotomy (n=79)	No-Durotomy (n=918)	p-value
Position			
Cervical	5 (6.3%)	141 (15.4%)	0.009
Thoracic	3 (3.8%)	93 (10.1%)	
Lumbar	71 (89.9%)	684 (74.5%)	
Gender			
Male	32 (40.5%)	480 (52.4%)	0.042
Female	47 (59.5%)	436 (47.6%)	
Pandemy			
Pre	33 (41.8%)	501 (54.6%)	0.029
Lockdown	46 (58.2%)	417 (45.4%)	
Surgical approach			
Anterior or lateral	1 (1.3%)	114 (12.4%)	0.003
Posterior	78 (98.7%)	804 (87.6%)	
Other Complications (excluding durotomy)			
No	55 (69.6%)	766 (83.4%)	0.002
Yes	24 (30.4%)	152 (16.6%)	
Number of complications			
0	55 (69.6%)	766 (83.4%)	< 0.001
1	17 (21.5%)	147 (16.0%)	
2	6 (7.6%)	4 (0.4%)	
3	1 (1.3%)	1 (0.1%)	
Type			
Infection	12 (15.2%)	46 (5.0%)	< 0.001
Paresis	10 (12.7%)	17 (1.9%)	< 0.001

79 IDs happened during posterior surgical approaches in comparison to anterior or lateral ones (p=0.003). Just 27.8% (n=22) of IDs occurred in redo interventions. Bed rest was almost systematically (78/79) used during the postoperative admission of IDs, for a period of time ranging from 48 to 720 h (median=72 h), with equal mode values for 48 and 72 h. We excluded in our analysis those patients whose strict bed rest was prescribed by other causes different to postoperative management of ID, like in polytrauma patients.

30.4% IDs were linked to other postoperative complications (Table 2). Among them, postoperative infection was the most frequent associated complication ($p< 0.001$), with two meningitis and nine surgical site infections, most of them caused by Gram-negative bacteria. Transitory or permanent nerve root damage was also significantly ($p< 0.001$) associated to ID, with nine cases causing pain, motor or sensory impairment. Intracranial hypotension syndromes (five cases ranging from orthostatic headache with nausea, vertigo and hearing disturbances to pneumocephalus and bilateral caudal cerebellar infarction), postoperative medical complications related to prolonged bed rest (four cases, including a deep venous thrombosis) and one epidural haematoma requiring surgical evacuation were the other ID associated postoperative complications. Longer courses of postoperative antibiotics in infection-complicated cases were also noticed. Prolonged postoperative bed rest, higher doses of analgesia and the use of caffeine and epidural blood patches were used as a treatment for intracranial hypotension syndromes. Patients without ID evolved more satisfactorily during the postoperative period, and they were very significantly associated to a lower number of other postsurgical complications (p=0.002).

Pseudo-meningocele and/or CSF leak happened in the postoperative period of 22 patients, with three of them in whom no ID was noticed during surgery, being these three surgical procedures performed without surgical microscope. The CSF leak was confirmed in these three patients with β2-transferrin analysis of the fluid coming from the surgical wound. As CSF came in these three patients from a non-noticed ID, the final incidence of pseudo-meningocele and/or CSF leak in our series of IDs was 27.8% (22/79). Patients with CSF leaks were very significantly ($p<0.001$) impaired by other medical complications during the postoperative period.

Patients with CSF leak (Table 3) had more than twice the bed rest time compared to those without leak ($p<0.001$). Just two of the postsurgical pseudo-meningoceles were satisfactory resolved with compressive wound dressing and prolonged bed rest. ELD was implanted in 16.5 % (13/79) of IDs, during a median time of 11 days. According to Chi-square analysis, ELD insertion significantly reduced the probability of requiring a re-do surgical repair (p=0.035).

Table 3
Descriptive of Duromoty patients, by CSF Leak. Chi-squared p-value test for categorial variables.

	CSF Leak no (n = 59)	CSF Leak yes (n = 20)	p-value
Durotomy treatment			
Suture (yes)	32 (54.2%)	7 (35.0%)	0.137
Microscope (yes)	23 (39.0%)	4 (20.0%)	0.122
Graft (yes)	15 (25.4%)	6 (30.0%)	0.689
Glue/foam (yes)	49 (83.1%)	13 (65.0%)	0.090
Bed rest in hours, median [IQR]	72 [48–96]	168 [78–240]	**< 0.001**

In seven cases a re-do surgical repair of the ID was required, all of them performed under a surgical microscope, using 4-0 Prolene® as suture, autologous fat as graft, Tisseel® and TachoSil® as sealants, being a bone fragment. found impinging the dura in one of these cases and with no durotomy found in the other of them.

A logistic regression analysis was performed in all samples comparing the group of patients with ID vs. those not harbouring it (Table 4). The variable of type of surgeon (NS vs. OS) was not introduced in this model as the two OS performed significantly more re-do procedures and more lumbar surgeries in our series in comparison to the other two NS. A propensity score was performed for the two groups of surgeons with a c-statistic of 0.61 what was considered not accurate enough. Multivariable logistic regression showed that posterior surgical approaches have ten times more risk of ID in our series and that the group of patients with other complications different to ID have nearly double the risk of belonging to the group with ID.

4. Discussion

Unintended durotomy can constitute a major complication during spinal surgery, and its incidence is related to multiple factors linked to

Table 4
Logistic multiple regression model of Durotomy. Reference category is no durotomy.

	OR	IC	p-value
Intercept	0.00		0.000
Surgeon			0.176
Neurosurgery	Ref		
Orthopedic Surgery	0.80	[0.49; 1.30]	0.368
Age			0.361
$<$ 55 years	Ref		
55–75 years	1.19	[0.68; 2.09]	0.533
$>$ 75 years	0.73	[0.34; 1.57]	0.417
BMI			0.176
Normal	Ref		
Overweight	1.65	[0.85; 3.19]	0.139
Obese	1.90	[0.96; 3.76]	0.066
Reintervention			
No	Ref		
Sí	1.30	[0.75; 2.26]	0.353
Invasive			
No	Ref		
Sí	2.60	[0.61; 11.08]	0.196
Pandemics			
Pre	Ref		
Lockdown	1.63	[1.00; 2.66]	0.052
Approach			
Anterior or lateral	Ref		
NO anterior or lateral	9.95	[1.35; 73.11]	0.024
Other complications			
No	Ref		
Sí	1.78	[1.04; 3.07]	0.037

the characteristics of the patient, diagnosis, surgical technique and type of surgeon (McMahon et al., 2012; Gautschi et al., 2014; Klingler et al., 2015; Kogias et al., 2017; Strömqvist et al., 2019; D'Astorg et al., 2020; Çivi, 2020; Aspalter et al., 2021; Kim et al., 2020; Enders et al., 2018). Its postoperative impact varies from a mild uneventful postoperative recovery to a severe CSF hypotension syndrome or even permanent sensitive or motor impairment, as dural tears reduce the CSF pressure and place increased traction on its supported structures. It must be considered an adverse event that can potentially lead to a permanent chronic neurological deficit in the patient and to an acute episode of heart failure in the surgeon (Wong et al.). IDs and its associated complications increase hospital resource utilization, and costs (Nandyala et al., 2014; Buck and Yoon, 2015).

Several studies show that there is a significant relationship between ID and old age (Klingler et al., 2015; Strömqvist et al., 2019; D'Astorg et al., 2020; Kazarian et al., 2020), as fragility increases and tissue integrity and reparation capacity decrease over the years. The impact of extended bed rest in the elderly can be severe, with a higher risk of delirium in the group of IDs as compared with the control for the same age group (Kazarian et al., 2020). In our analysis, the risk of ID was slightly higher in patients > 65 years with an incidence of 8.6%, and 7.4% in patients < 65. The incidence of ID was also higher in women (9.7% vs 6.3%), which is also supported in the literature (Takahashi et al., 2013; Yoshihara and Yoneoka, 2014). Being overweight has been repeatedly linked with a higher incidence of ID (Klingler et al., 2015; Burks et al., 2015). In our series, this relationship was close to statistical significance (p=0.06). With three cases of ID in our group of ten underweight patients, it more than tripled its incidence in comparison to the rest of the BMI groups and impacted severely in the final statistical calculations. High BMI foresees longer surgical times and difficulties to be found with the use of conventional instruments, therefore MISS procedures are increasingly indicated in this group of patients, with its reduced incidence of IDs.

When we observe IDs according to their location on the spine, we observed that most of the ID has occurred in the lumbar (89.9%), followed by cervical (6.3%) and thoracic (3.8%) region with a significant relationship in the cervical group "protecting" the occurrence of ID (p= 0.009). The higher incidence of ID in the lumbar region according to our data is also supported by many other studies (McMahon et al., 2012; D'Astorg et al., 2020; Yoshihara and Yoneoka, 2014). As the integrity and quality of tissues are not the same as in first-time surgeries, repetitive procedures carry a significantly higher risk of ID. In our series an ID RR=1.6 was observed in re-do interventions in comparison to first-time procedures (11.7% vs. 6.9%); this evidence is highly supported by other studies as well (McMahon et al., 2012; Kogias et al., 2017; Strömqvist et al., 2019; D'Astorg et al., 2020; Enders et al., 2018; Tafazal and Sell, 2005).

Most of the IDs (78/79) occurred during non-anterior approaches to the lumbar spine in our series, with a remarkable significance (p=0.003). Nevertheless, posterior surgical approaches are also indicated in pathologies linked with a higher frequency of ID during the surgical procedure: none of the three cases of ossification of the posterior longitudinal ligament operated by posterior cervical or thoracic approaches in our series sustained an ID. There is controversy about whether invasive interventions carry a higher risk of ID in comparison to minimally invasive procedures (McMahon et al., 2012; Kogias et al., 2017; Ruetten et al., 2009). In our data, the incidence of ID was 8.25% in invasive procedures in comparison to 3.14% in MISS ones, with an RR= 2.6. Lower tissue damage supported by tubular and endoscopic visual amplification systems diminished substantially the incidence of ID in our series. We did not observe a higher incidence of unintended durotomies during those decompressive procedures performed with drill in comparison with those accomplished just with manual tools.

With a 7.9% incidence of ID in our series, 55.7% IDs happened during procedures performed by OS, the difference not being significant when compared with those caused in procedures performed by NS. OS perform in our series significantly more lumbar and re-do interventions, which is the most frequent scenario for ID, and therefore, both groups of surgeons were not comparable. All the surgical procedures were performed by non-resident staff with a similar degree of training and experience in both groups of surgeons (Shaffrey and Buell, 2021; Lad et al., 2021). We analysed data about surgical procedures performed before the Covid-19 pandemic lockdown and after it. Postsurgical complications were significantly more frequent in patients operated on after the lockdown (p=0.001) and IDs were also more frequently observed among spinal surgeons after the beginning of the CoviD-19 pandemic (p<0.003). Incidence of durotomy in the pre-lockdown period was 6.18%, and 9.9% after it, with a relative risk (RR) of 1.6. The inherent stress of the adaptation to the "new reality" impacted understandably in spinal surgery teams all around the world (Power et al., 2022; Hodges et al., 1999).

49.4% of our ID cases were repaired by primary suture of the dural defect during the surgical procedure, and these patients had less postoperative complications (p=0.02). This technique is considered the gold standard treatment for ID in medical literature, even in experimental animal models (McMahon et al., 2012; Gautschi et al., 2014; Klingler et al., 2015; Kogias et al., 2017; Strömqvist et al., 2019; D'Astorg et al., 2020; Çivi, 2020; Aspalter et al., 2021; Enders et al., 2018; Boukebir et al., 2017; Dafford and Anderson, 2015; ousefzadeh-et al., 2014). No significant differences in the incidence of postoperative pseudo-meningocele or CSF fistula were observed according to the stitch nonabsorbable type of material used to repair the ID, but with such a little sample of 39 primary repaired IDs is difficult to obtain a reliable conclusion in this sense, which constitutes a limitation in our study. In 34.2% of ID cases, the unintended event happened in an operation where the surgical microscope was used. When an ID happens during a direct eyesight intervention, we strongly recommend repairing it under a microscope view, usually placing a cottonoid over the dural opening during the closure to prevent aspiration of the nerve roots or incorporation of them into the stitch (Fig. 1). At least one Valsalva manoeuvre should be performed after completing the dural repair as a proof of the integrity of the closure and before moving the microscope away from the surgical field.

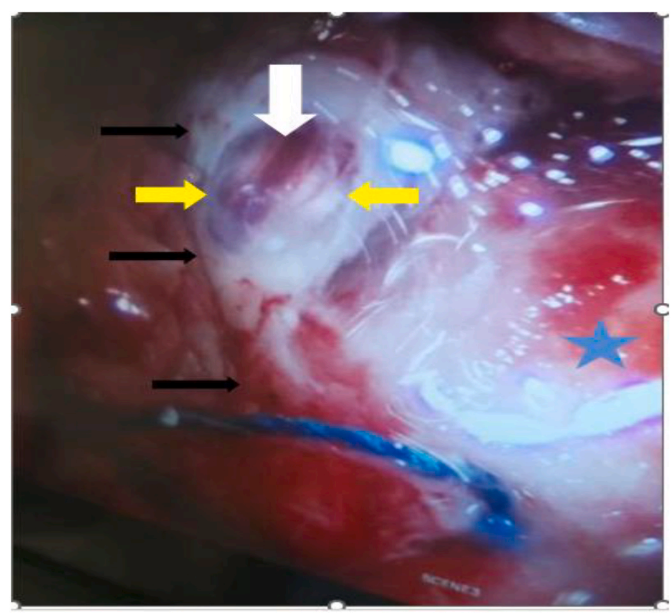

Fig. 1. Microsurgical repair of ID causing postoperative CSF leak and right L5 nerve root paresis. Edges of the durotomy (yellow arrows) and concussed herniated nerve rootlets (white thick arrow) can be seen through dural opening. Small cottonoid (blue star) and its blue indicator string placed by the dural deffect. Black thin arrows marking the right aspect of the L5 spinous process.

In 26.6% of IDs an autologous fat or Duraform® graft were used to complete and strengthen the repair. Autologous fat is favoured instead of muscle graft as muscle fibres can easily retract and make difficult the closure of the durotomy (Najjar et al., 2023). An epidural glue (Tisseel ® or DuraSeal

®) or a human fibrinogen and thrombin-coated collagen sponge (TachoSil®) was applied during the surgical procedure for the management of 62 IDs (78.5%) to allow a firmer repair. Grafts, glues and coated sponges play a particular relevant role in IDs where direct repair is insufficient or impossible, like when dural opening cannot de found or accessed, or when it occurs on the nerve root sleeve. Again, a small sample in our study precludes favouring one material instead the other.

In our study, the median postoperative flat bed rest after ID was 72 h. Longer than this period of time is not recommended in order to avoid other associated postoperative complications (Gautschi et al., 2014; Klingler et al., 2015; D'Astorg et al., 2020; Yoshihara and Yoneoka, 2014; Boukebir et al., 2017). According to the literature, normal post-op mobilization is not associated with a high failure rate, and bed rest is recommended only if CSF hypotension symptoms develop (Papavero et al., 2015).

Patients with ID were very significantly ($p<0.001$) impaired by other medical complications during the postoperative period in our series. Among them, post-operative infections and neurological impairment were the most frequent ones. Out of 79 patients with ID, CSF leak happened in 20 patients. All cases of CSF leak happened in IDs caused by invasive surgery. 46.6% of CSF leaks came from IDs related to repetitive surgeries. 90% of CSF leaks happened in high BMI patients. Most of them occurred in the lumbar region (90%) and 10% in the cervical region. CSF leaks happened in equal proportions in both genders and in both age groups (similar proportion in both groups of >65 and <65 years) without any remarkable difference. CSF fistulas were again significantly associated to other complications, and again infections and neurological impairment were the most frequent ones. This observation is also supported through the bibliographic references (Strömqvist et al., 2019; D'Astorg et al., 2020; Enders et al., 2018; Yoshihara and Yoneoka, 2014).

13 of these postoperative CSF leaks required external lumbar drainage and seven underwent repetitive repair surgery. According to Chi-square analysis, ELD insertion significantly reduced the probability of requiring a re-do surgical repair ($p=0.035$). We use in our institution ELD as a first treatment option for CSF leaks caused by ID. If the fistula persists, the patient is taken back to theatre to perform a microscopic repair, using 4-0 Prolene as suture, autologous fat as graft, and Tisseel ® and TachoSil ® as sealants.

As in other reference papers (32), we finally suggest a sequential tailored protocol for management of ID:

1) Intraoperative microsurgical dural closure should be attempted with non-absorbable sutures and interposed autologous fat graft.
2) Valsalva maneuver must be performed at the end of the dural closure to confirm its watertightness.
3) Careful epidural sealant and glue application is favoured after completing the repair.
4) ELD insertion at the end of the procedure or during the postoperative period is a management option.
5) Early postoperative patient mobilization is recommended.

5. Conclusions

Incidental durotomy is an unexpected intraoperative event that is significantly related to major undesirable postoperative complications. Primary repair of the dural defect is considered the gold standard for its treatment. Different repair techniques, materials and postoperative care measures must be protocolised among spinal surgeons in order to improve its prognosis.

Declaration of competing interest

The authors have no conflict of interest to declare

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