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Original Article

Spinal Arachnoid Cysts: Presentation, management and pathophysiology

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ABSTRACT

Objective: Evaluation of the presentation and outcomes associated with surgical marsupialisation of spinal arachnoid cysts and formulation of a putative hypothesis explaining their pathogenesis.
Patients and methods: Cases were identified from electronic and theatre records at a single centre. All patients underwent pre-operative assessment and radiographic evaluation with subsequent spinal multidisciplinary discussion. Following surgery patients were reviewed at 6, 12 weeks, 6-months and beyond.
Results: A total of 17 patients with dorsal thoracic arachnoid cysts with a mean age at time of surgery of 58 years with a male to female ratio of 1.8:1 were identified. Paraesthesia (76%), neuropathic pain (76%), weakness (47%) and unsteadiness (53%) were the commonest presenting complaints. Abnormal gait (76%), altered sensation (71%) and weakness (47%) were the most commonly observed signs. Average cyst volume was observed to be 2570 mm^3 (sd ± 1682, range 544 to 7644 mm^3), spanning a median of 2 thoracic levels, with a resultant reduction of cord volume of 33% (sd 12%). A syrinx was associated with 35% of SAC. All cases underwent marsupialisation of the arachnoid cyst. Six months following surgery all patients experienced improvement in at least of one their presenting symptoms and or clinical signs. Weakness, gait and paraesthesia were most likely to improve following surgery. Only 29% of cases had resolution of neuropathic pain, with 13% of the rest reporting an improvement in the sensitivity component of their pain. Clinical improvements correlated with an average 45% (sd 18%) volume increase in previously compressed cord.
Conclusion: Intradural arachnoid cysts commonly present with paraesthesia, neuropathic pain and gait disturbance. Marsupialisation of the SAC heralds immediate and long-term improvement in symptoms. Cysts putatively arise within a dissection in the septum posticum and give rise to both dynamic and static compression of cord parenchyma secondary to the complex CSF flow dynamics within the thoracic spine.

1. Introduction

Spinal arachnoid cysts (SAC) are rare entities that present with progressive thoracic myelopathy. There has been little clarity with respect to the precise classification of these lesions and the nomenclature used to describe them is often confusing which has led to conflicting descriptions of their clinical and radiological characteristics. The term “spinal meningeal cyst” has often been used as an umbrella term for cysts located within the extra- and intra-dural spaces within the spinal canal as well as lesions associated with nerve roots [1]. Nabors et al. were the first to categorise “spinal meningeal cysts” [1] on the basis of their anatomical location and tissue of origin following histological assessment. The classification describes three distinct cystic entities; type 1 lesions being anterior or lateral meningocoeles (extra-dural cysts), type 2 are extradural meningeal cysts containing nerve root fibres and type 3 representing the true intra-dural arachnoid cysts which are the subjective of this study. This classification has garnered much attention in the literature but despite this the use of the term “arachnoid cysts” is often used to described both extra- and intra-dural lesions [2,3]. A more recent classification for the pathologies of the spinal meninges concurs that SAC are fundamentally intra-dural lesions that are either primary in origin (i.e. idiopathic) or secondary to inflammatory reactions as a result of trauma, infection, haemorrhage or a surgical procedure [4]. Here in we describe our experience on the presentation and surgical management of 15 cases of primary SAC, review the current literature on the subject and postulate a hypothesis as to how they arise.

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2. Patients and methods

All patients who presented to a single tertiary neurosurgical centre over a 10-year period (January 2008 to December 2017) with a primary arachnoid cyst were retrospectively identified using a key word search of the hospital electronic medical records and the theatre operative logbooks. The search terms used were arachnoid cyst and spinal intradural cyst. The first and second authors, for relevance to the current study, reviewed the returned documentation. Electronic records and case notes were reviewed for collation of demographics, comorbidities, clinical presentation, outline of operative management and post-operative course. The Picture Archiving and Communication System (PACS) by Sectra was used to confirm the anatomical location of the SAC.

2.1. Clinical protocol

All cases were discussed in a multidisciplinary team meeting prior to surgery. Pre-operative MRI with CSF flow studies was performed in all cases. Cyst dimensions were measured on sagittal and axial images and volumes were subsequently calculated using Sectra PACS and Microsoft Excel. Volume changes in compressed cord parenchyma were deduced by assumed “true volume” of cord as a mean volume of the cord above and below the area of constriction minus the volume of the primary arachnoid cyst. Cord “re-expansion” was calculated on post-operative sagittal and axial T2 weight MR images for consistency.

Prior to surgery the senior author examined all patients. A laminectomy and excision or marsuplisation of the arachnoid cyst was performed in all cases. Post-operative MRI was performed to confirm obliteration of the primary arachnoid cyst and to observe for re-expansion of the previously compressed cord parenchyma. CSF flow studies were obtained to observe flow post-operatively. All patients underwent intensive ward based physiotherapy prior to discharge back to their usual residence or regional hospital. All patients were reviewed at the outpatient clinic at 6 weeks by a specialist spinal physiotherapist and subsequently at 12 weeks, 6 months and beyond by the senior author. At each review the patients’ history and clinical examination was evaluated and documented to observe for improvement or worsening symptoms and signs. Patients that had no improvement in symptoms or signs had repeat radiographic imaging. In those cases, were the cyst recurred a further surgical procedure was performed to address the cyst. Operative complications were documented.

2.2. Clinically measured markers of surgical outcome

Paraesthesia and its effect on activities of daily living was scored using the National Cancer Institute scoring system (NCIS) [5], neuropathy was evaluated using the neuropathic pain scale (NPS) [6] and muscle power the Medical Research Councils grading system (MRC) [7]. Gait was assessed on the basis of a 4 point scale derived from the Japanese Orthopaedic Association Score (gJOAS) (Normal = 3, > 500 m with resulting pain = 2, unable to walk 500 m = 1, unable to walk more than 100 m = 0)[8]. Scores were documented prior to surgery and at each follow-up. Other sensory changes were documented and tabulated for each patient.

2.3. Inclusion and exclusion criteria

Only cases of primary SAC were included in the study. Radiographically identified cases of primary SAC by the senior author were reviewed by senior a neuro-radiologist to confirm the diagnosis. All cases associated with a preceding history of trauma, haemorrhage or infections were excluded. Only adult patients were included in the study.

2.4. Statistical analysis

All statistical analysis was performed in Microsoft Excel and IBM SPSS Statistics. For descriptive analysis, mean values, medians and standard deviations of numerical data were calculated. Clinically scored scales of muscle power (MRC), neuropathy (NPS), paraesthesia (NCIS), and gait (gJOA) before and after surgical intervention were compared to define outcomes using the Mann–Whitney test as appropriate. A p-value of 0.05 was adopted to indicate statistical significance.

2.5. Literature review

A literature search of PubMed was performed using the key words “spinal arachnoid cyst”. All returned searches that described secondary SAC were excluded. Cases studies and case series of three or less of primary SACs were excluded. All paediatric cases and those associated with spinal dysraphism or deformity were also excluded.

3. Results

Review of the theatre database, personal theatre logbook of the senior surgeon and the electronic patient records identified a total of 17 primary SAC from 2008 to 2017. A single case of primary SAC had spontaneous improvement in symptoms without any surgical intervention. One patient with a preceding history of haemorrhage and another with preceding trauma were also identified and were classified as secondary SAC and not included in the study.

3.1. Demographics

A summary of the demographic details and radiographic findings are outlined in Table 1. The average age at time of presentation, of surgically managed primary SAC (n = 15) was 58.2 years (sd ± 15) with a male to female ratio of 1.8:1. Female patients on average were observed to be 13-years older than their male counterparts, at initial presentation, however this was not observed to be statistically significant (mean age 52.8 vs. 66.7 years old, p = 0.07 Mann–Whitney test). Duration of symptoms preceding first neurosurgical review was observed to be an average of 19 months (sd ± 17.8, range 6–60 months). All fifteen patients underwent a laminectomy to incorporate the complete length of the SAC and marsupialisation of the cyst.

Patients were followed up for an average of 17 months after surgery (sd ± 10 months, range 8–50 months). Cyst recurrence was observed in 11.8% (n = 2) of cases. One recurrence was observed 6 months after following surgery, the patient underwent a re-exploration and placement of the cysto-subarachnoid shunt with subsequent improvement in symptoms. The second patient was noted to have cyst recurrence 24-months following surgery. The patient experienced improvement in their symptoms immediately following surgery with an absence of symptoms until approximately 18 months following the procedure. A re-exploration and re-marsupialisation of the cyst was performed and the patient has had no further recurrence in cyst and improvement in symptoms. A single patient in our case series had spontaneous improvement in symptoms, signs and radiographic findings in the absence of any surgical intervention.

3.2. Clinical presentation

Paraesthesia (76%), neuropathic pain (76%), weakness (47%) and unsteadiness (53%) were the commonest presenting complaints. Abnormal gait (76%), altered sensation (71%) and weakness (47%) were the most commonly observed signs (Table 2). Of the 8 patients who complained of weakness as a symptom; on examination only 47% of cases had a 1-point reduction MRC muscle power in a lower limb compartment. Paraesthesia, typically described as pins and needles by patients, was a prominent symptom of primary SAC. Seventy-one

Table 1
Patient demographics and radiographic findings.

Patient	Age	Sex	Level	Location	Syrinx	Duration of symptoms prior to presentation	Recurrence	Follow up (months)	Outcome of f/u MRI	Further surgery
1	64	F	T6-7	Dorsal	No	7	No	8	NAD	
2	70	F	T4-5	Dorsal	No	60	No	12	NAD	
3	49	M	T2-3	Dorsal	No	12	No	12	NAD	
4	63	F	T4-9	Dorsal	Yes	6	Yes- after 6 months	18	Recurrence	Shunt
5	41	M	T3-5	Dorsal	No	12	No	21	NAD	
6	60	M	T2-3	Dorsal	No	60	No	12	NAD	
7	49	F	T7-9	Dorsal	Yes	24	No	24	NAD	
8	57	M	T5-6	Dorsal	No	32	No	32	NAD	
9	77	M	T8-11	Dorsal	No	15	No	15	NAD	
10	77	F	T3-6	Dorsal	No	12	No	12	NAD	
11	25	M	T9	Dorsal	No	8	Yes- after 24months	50	Recurrence	Re-exploration & marsupialisation
12	77	F	T3-6	Dorsal	No	12	No	12	NAD	
13	68	M	T7	Dorsal	Yes	36	No	12	NAD	
14	61	M	T4	Dorsal	Yes	6	No	12	NAD	
15	37	M	T8-9	Dorsal	Yes	12	No	12	NAD	
16	64	M	T2-3	Dorsal	No	6	No	12	NAD	
17	50	M	T5-6	Dorsal	No	6	No	12	NAD	

percent of patients (12/17) reported that their paraesthesia had a detrimental effect on their instrumental activities of daily living (NCIS grade 2. iADL; preparing meals, shopping and using the telephone). The remaining 5 patients complained that the paraesthesia was so severe that it effected their self-care ADL (NCIS grade 3. scADL; washing, dressing and toileting). Neuropathic pain was an equally common complaint observed in 80% of patients. Out of the ten modalities defined on the Neuropathic Pain Scale [6] a sensitive patch of skin or an unpleasant sensation over a specific region featured often on subjective description of pain associated with SAC. Unsteadiness and gait disturbance were both common presenting complaints and examination findings respectively. Half of patients reported unsteadiness with increasingly frequent falls. Seven patients were unable to walk more than a 100 m (gJOA score 0). Reduced gait velocity, step-length and inability to heel to toe walk was observed in all cases with gJOA scores of 2 or less.

3.3. Radiographic findings

Radiographic imaging demonstrated that all primary SACs where located within the dorsal aspect of thoracic spine. All cysts were non-enhancing on MRI and located in an intradural extramedullary location. SACs had signal intensities similar to that observed in CSF. They spanned an average of 2.1 thoracic vertebrae (sd ± 0.7) with a predilection around the thoracic 4 to 6 vertebrae (Fig. 1). A syrinx was observed in one-third of cases ($n = 5$). The location of the syrinx was noted to be above the SAC in 3 cases and below the SAC in 2 cases. The length of the associated syrinx ranged from 2 to 5 thoracic vertebra. We did not observe any significant relationship between syrinx location and clinical presentation or size of the SAC. The location of the dome-capped on the cyst, whether cranial or caudal, would define whether the syrinx was above or below the SAC (Fig. 2). Average cyst volume was noted to be 2570 mm^3 (sd ± 1682, range 544 to 7644 mm^3). The resulting degree of focal cord compression [as a result of the cyst] was on average 33% (sd ± 12%, range 17 to 36%). There was a positive Pearson product-moment correlation coefficient between cyst volume and degree of focal cord compression (r 0.48). However we did not observe any significant correlation between degree of focal cord compression and clinical presentation of the SAC.

3.4. Operative outcomes

All patients underwent a laminectomy with excision of the thickened polar arachnoid cap (Fig. 2). Laminectomies were performed as our previously published case series on their use in the management of intradural pathology demonstrated that progressive post-laminectomy deformity was rare in adult patients [9]. Intra-operatively SACs and cyst-CSF pulsations were observed under the operating microscope (Movie number 1). Consistently a dense polar cap was observed either at the superior or inferior pole of the SAC (Fig. 2). The arachnoid layer defined the dorsal wall of the cyst. The ventral wall was defined by the pia overlying the cord parenchyma (Fig. 3). No dense fibrotic arachnoid bands were observed arising or within the cysts. Cyst walls were thin and translucent. All SAC were centred at the midline of the dorsal aspect of the thoracic spine. No adhesions were noted to the surrounding existing dorsal nerve roots. No evidence of haemosiderin staining was observed within or around the cyst walls prior to marsupilisation. Strict haemostasis was maintained throughout the procedure to prevent potential ensuing arachnoiditis. Following resection/marsupilisation, CSF was noted to flow without obstruction in both a cranial and caudal direction. Dura was always closed in a continuous manner with a non-absorbable 5/0 suture and the dura covered with Tissue-Patch dura™. Prior to application of the Tissue-Patch duraTM, a valsalva manoeuvre was performed to check for the integrity of the watertight dural closure. No patients developed a pseudomeningocoele either during their immediate post-operative admission or on subsequent follow-up.

Six months following surgery all patients experienced improvement in at least of one their presenting symptoms and or clinical signs. Of the 5 cases with a 1-point pre-operative MRC power reduction all experienced an improvement. All patients with paraesthesia (as scored by NCIS) had an improvement (see Table 2) dropping from a median score of 2 to 1. Four patients had complete resolution of their paraesthesia. Only 29% ($n = 5$) of cases had complete resolution of their neuropathic pain. Twenty-percent reported that the neuropathic pain was no longer unpleasant and classified it subjectively as an area of sensitivity. Thirteen-percent reported an improvement in the sensitivity component of their neuropathic pain. An improvement in gait was observed in 47% of patients ($n = 8$). Two patients went from a gJOA score of 0 to 3 six months following surgery. Four patients did not experience any improvement in their gJOA scores at six months and beyond. Post-operatively we observed that 4 out of the 5 patients had complete collapse of their syrinx with the remaining case having a reduction in syrinx volume at six months. Follow-up MRI at 6-months demonstrated an average cord re-expansion at the point of focal compression by 45% (SD ± 18%, range 17–79%) following surgery.

Table 2
Clinical and radiographic pre- and post-operative findings.

Patient	Symptoms				Signs		Clinical scales of assessment								Volumetric radiographic analysis		
	Pins & needles	Pain	Weakness	Unsteadiness	Abnormal Gait	Altered sensation	MRC muscle power grade		NPS neuropathy		NCIS paraesthesia		gJOA		Cyst volume (mm^3)	Degree of focal cord compression[a]	Percentage re-expansion in compressed cord
							Pre-op	Post-op	Pre-op	Post-op	Pre-op	Post-op	Pre-op	Post-op			
1	Y	Y	Y	Y	Y	Y	4	5	S	R	3	1	0	3	1620	0.69	47
2	Y	N	Y	Y	Y	↓pinprick	5	5	S, U	S	2	1	0	2	1967	0.83	17
3	Y	Y	N	Y	Y	Y	5	5	S, U	S, U	2	1	0	3	4574	0.64	46
4	N	Y	N	Y	Y	Y	5	5	U	U	2	1	1	2	7644	0.44	79
5	Y	Y	N	N	N	N	4	5	S, U	S	2	1	0	0	2500	0.64	60
6	Y	Y	Y	N	Y	↓T &P	4	5	U	U	2	1	0	0	3140	0.52	69
7	Y	Y	Y	N	Y	Y	4	5	S, U	U	3	1	0	2	1130	0.79	42
8	Y	Y	N	N	Y	Y	5	5	S, U	U	3	1	0	1	803	0.65	41
9	N	N	Y	Y	Y	N	5	5	S, U	S	2	1	1	1	3216	0.61	54
10	Y	Y	N	N	N	Y	4	5	S, U	R	2	1	2	3	1153	0.45	73
11	Y	Y	Y	N	Y	↓pinprick	5	5	S, U	R	2	1	3	3	2800	0.76	48
12	Y	Y	N	Y	Y	N	5	5	S, U	S	2	1	2	2	3769	0.72	26
13	Y	N	Y	Y	Y	N	5	5	S, U	R	2	1	3	3	2610	0.75	38
14	N	Y	Y	Y	Y	N	5	5	S, U	S	2	1	3	3	544	0.78	40
15	Y	Y	N	N	N	N	5	5	S,U	S	3	1	3	3	2040	0.57	44
16	N	Y	N	Y	Y	Y	5	5	S, U	S	3	2	2	3	2094	0.83	11
17	Y	Y	N	N	N	Y	5	5	S	R	2	1	3	3	2089	0.89	35

[a] Value of 1 representing normal volume (non-compressed cord).

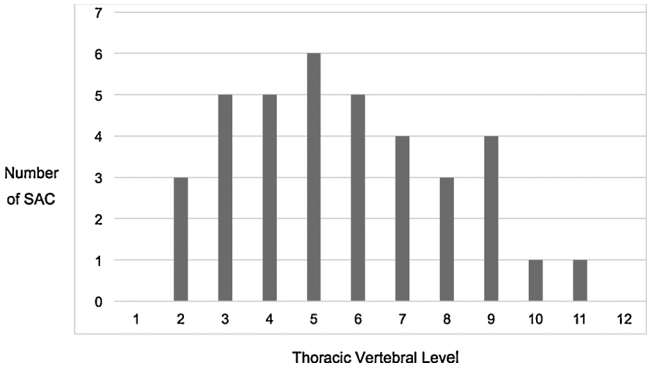

Fig. 1. Thoracic localisation of primary SAC. Bar chart demonstrating the localisation of primary SAC throughout the dorsal aspect of the thoracic spine. Primary SAC had a predilection of localisation within the upper mid-thoracic spine.

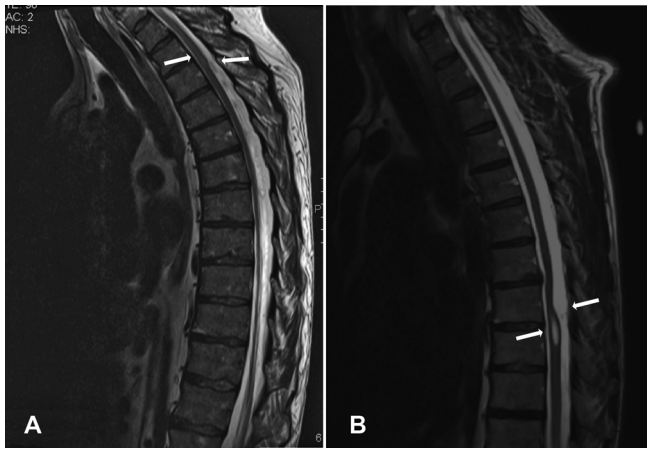

Fig. 2. Cranio-caudal orientation of SAC and localisation of syrinx. Cranially orientated SAC (A, *arrow*) were observed to have a syrinx (*arrow*) superior to the location of the polar cap. Caudally orientated SAC (B, *arrow*) were observed to have a syrinx inferior to the polar cap when a syrinx was observed. Figure A demonstrates the classical "scalpel sign" described in the literature as being "radiographically pathognomonic" of SACs. However this observation is mirrored in caudally orientated SACs.

3.5. Length of hospital admission and discharge destination

Mean length of hospital stay following surgery was 4.8 days (sd ± 2.34, range 2–8 days). Fifteen patients were discharged back to their usual place of residence. Two patients were not discharged back to their usual place of residence (mean length of stay within neurosurgical unit 8 days). One was referred to a specialist rehabilitation unit for ongoing physiotherapy to help with gait and balance. The other patient was transferred back to his regional hospital for management of ongoing medical issues unrelated to the surgical procedure. Of those that were discharged back to their usual place of residence the mean length of stay was 4.2 days (sd ± 1.99, range 2–7).

4. Discussion

Spinal arachnoid cysts are uncommon lesions that can result in neurological deficits secondary compression of the spinal cord. The nomenclature and pathogenesis relating to these lesions, described in the limited published case-series, has been a matter of debate [see references from Table 3]. More recently adherence to a proposed classification system by Nabors et al. [1] has meant that published work on the matter can be reviewed with uniformity [4]. We report the largest single-unit single-surgeon case series of surgically managed thoracic primary (idiopathic) SAC.

4.1. Anatomy

Arachnoid cysts are classified into primary or secondary. An inflammatory process as a result of trauma, infection, surgery, or haemorrhage is typically antecedent to the latter. The origin of primary idiopathic SAC is ill-defined with several theories proposed explaining their origin [10–14]. The leading theory [12,14] is that SAC arise from the septum posticum; a thin midline arachnoid membrane spanning the subarachnoid space from the pial surface to the arachnoid mater and was first described by Magendie [15] and more recently, using electron microscopy (see Fig. 3C and D, with kind permission of Dr R. Weller), by our neuropathology department at our institute [11]. Over time the septum posticum has been ascribed several titles; the septum arachnoidale, septum cervicale intermedium, septum leptomeningicum dorsale and the septum posticum of Schwalbe. Despite the disputed nomenclature the membrane has always been described to sit in the midline in the dorsal aspect of the spinal cord.

The membrane is not as distinct as the dentate ligaments and hence often it is overlooked during surgery. Anatomical studies have demonstrated that the septum posticum in the cervical spine is interrupted and is primarily formed by irregular bands, which become denser and unite to form a true membrane at the cervicothoracic junction [14,16]. Within the thoracic spine to the conus medullaris the septum is a clear structure but may have irregular perforations (see Fig. 4) [11,14]. At the conus medullaris the septum comes to an abrupt end and it is rarely observed beyond this level [14]. All early cadaveric and myelographic studies demonstrated the absence of any ventrally located arachnoid septums.

Perret et al. were the first to hypothesise that primary idiopathic arachnoid cysts arose from the septum posticum [12]. Although their speculation was based on a case series of 2, review of the preceding 36 reported cases in the literature [within their report] highlighted the propensity of these lesions, in the absence of an inflammatory insult, to primarily form within the dorsum of the thoracic spine. Cystic enlargement, secondary to fluctuations in CSF pressure (valsalva manoeuvres) and ensuing clinical presentation being explained by a one-way ball-valve effect at the cyst neck within the septum. Rather interestingly within our case series one patient avoided surgical intervention following a coughing episode after which they had complete obliteration of their SAC and relief of their symptoms.

To account for the observation of arachnoid cysts, although far less frequently, within the ventral aspect of the cord and in the lumbosacral region several authors are proponents of a hypothesis by Fortuna et al. that suggests that proliferation entrapped arachnoid granulations gives rise to cyst formation as a result of CSF production and sequestration along the path of least resistance [2,13]. As a consequence of more recent work on the classification of arachnoid cysts [1,4] the role of this hypothesis, although credible is less likely to be as significant as that proposed by Perret et al. [12].

4.2. Location

In our case series all 17 primary SAC were located within the dorsal aspect of the thoracic spine. The existing literature reports a total of 85 primary SAC, of those 82% ($n = 70$) were primarily within the thoracic spine and 93% ($n = 65$) of those were located within the dorsal aspect (see Table 3). The largest reported case series ($n = 59$) to date on arachnoid cysts did not observe a single SAC outside of the dorsal subarachnoid space, indeed 94% of cases were within the thoracic spine, however no differentiation between primary and secondary SAC was documented within the tablature of the report [4]. The propensity of primary SAC to be located within this region is consistent with the early cadaveric and myelographic studies [14,16]. These findings support the hypothesis that primary SAC arise from within the septum

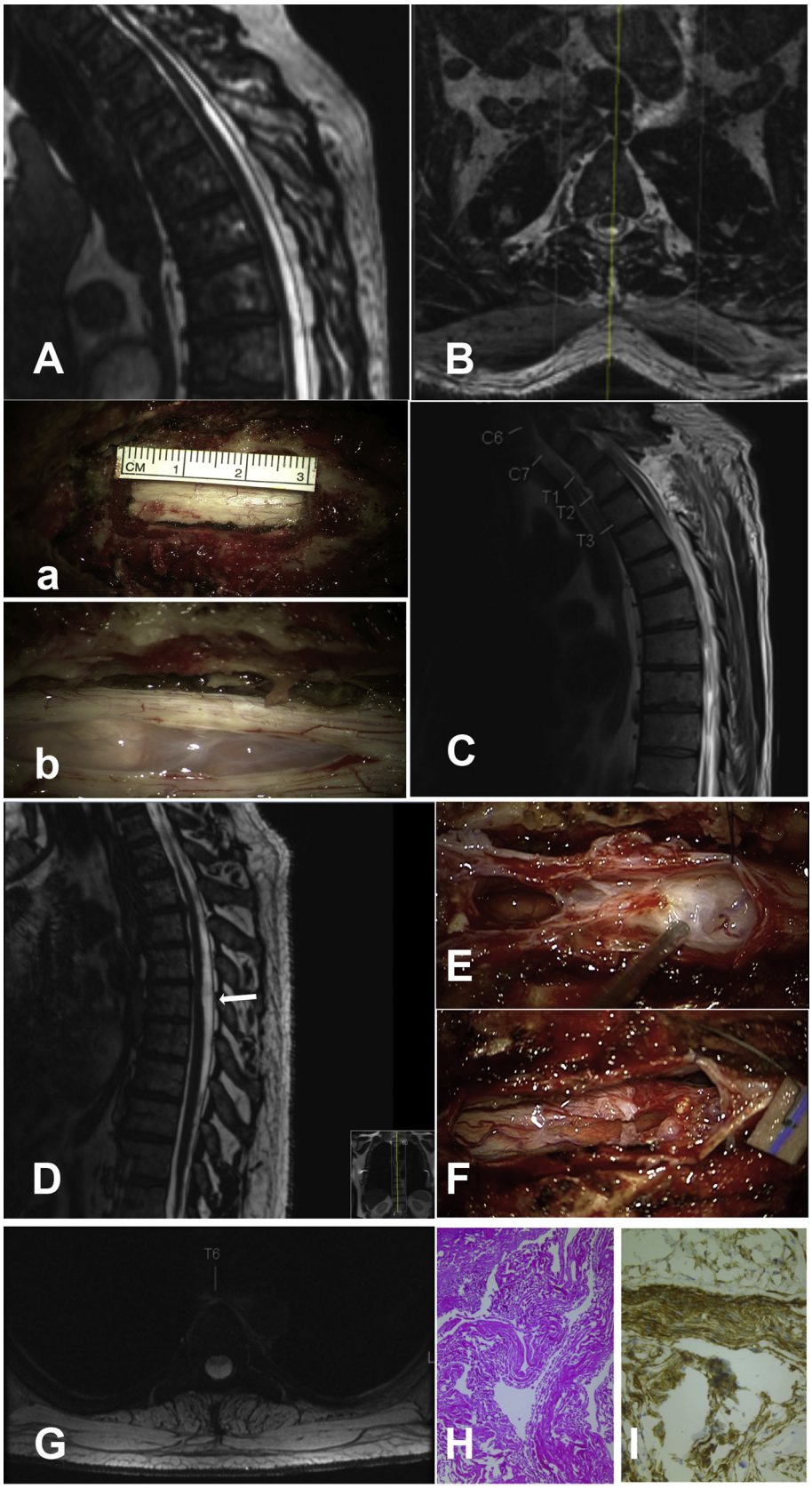

Fig. 3. Orientation of SAC. *Cranial SAC*. Sagittal (A) and axial (B) T2-weighted MRI images demonstrating a cranially orientated high thoracic SAC with focal cord compression. A laminectomy was performed (a) and following durotomy a contained turgid arachnoid cyst is observed (b). Subsequent post-operative saggital MRI demonstrates no recurrence of SAC at 6 months (C). *Caudal SAC*. Sagittal (D) and axial (B) T2-weighted MRI images demonstrating a caudally orientated upper thoracic SAC with focal cord compression. Intra-operative imaging demonstrates dense arachnoid member at polar cap (E). Marsupialisation of the cyst is performed (F). Histological examination of the tissue demonstrates on haematoxylin and eosin staining a collapsed cystic structure (E) with epithelial membrane antigen staining (F) demonstrating that the cells lining the cyst are arachnoidal.

posticum, which is primarily located with the dorsal thoracic spine. Indeed several SAC are reported at the cervicothoracic junction, which is where the membrane starts becoming more evident [11,14,16]. The sparcity of cervical SAC (5%, $n = 4$) and absence of sacral SAC (where the septum posticum is absent) further supports the theory that these lesions arise from the septum posticum.

Although rarer, primary ventral SAC have also been reported and managed surgically. Intra-operatively these lesions have been observed

Table 3
Review of the existing literature on the presentation and outcomes associated with surgically managed adult primary SAC.

Authors	No. of surgically managed 1[a] SAC	Gender distribution	Mean age (years)	Cyst location		Cyst length (no. of vertebrae)	Presence of syrinx (%)	Mean length of F/U (months)	Presenting symptoms				Surgical outcomes	
				Ventral/ Dorsal	Vertebrae				Paraesthesia	Neuropathic pain	Weakness	Gait disturbance	Sensory improvement	Motor improvement
Sadek et al. (present study) 2018.	17	1.8M:1F	58.2	All dorsal	T = 17	2.1	29%	17	76%	76%	47%	76%	All had some improvement. Complete resolution in 27%.	All experienced improvement- 1 point increase in MRC grade.
Klekamp 2017 (Klekamp, 2017)	59	Unknown	51.9	All dorsal	94% of all cases (n = 109) thoracic[a]	~3	46%	57	55%	69%	45%	69%	Progression free survival at 1 year 87% following surgery	
Viswanathan et al., 2017 (Viswanathan et al., 2017)	14	1.8M:F	52.1	All dorsal	C-T = 1, T-L = 1, T = 12	3.7	57%	21.8	85.7%	100%	78.6%	100%	Improvement in mJOA scores in 79% (11/14).	
Srinivasan et al., 2016 (Srinivasan et al., 2016)	7	6M:1F	59.4	All dorsal	T = 7	~2	100%[b]	3	29%	43%	71%	71%	57% resolution gait abnormality. All had improvement in muscle weakness. Sensory improvement not documented	
Griessenauer et al., 2014 (Griessenauer et al., 2014)	5	1M:1.5F	42	All dorsal	T = 5	2.8	Unknown	112.8	All had combination of symptoms with mean MJOA scores of 6. Nb upper limbs not scored.				Improvement in symptoms in all but 1 case. Mean MJOA improvement of 2.	
Mohindra et al., 2010 (Mohindra et al., 2010)	10	9M:1F	25	D = 5, V = 4, Lateral = 1	C = 4, T = 3. L = 1, S = 2	2.8	Unknown	Unknown	Unknown	30%	Spastic paraparesis 70%		Improvement in all cases.	
Endo et al., 2010 (Endo et al., 2010)	8	1M:1.7F	42.3	All dorsal	C-T = 2, T = 6	4.3	Unknown	118.6	82%	64%	73%	Unknown	Unknown, no cyst recurrences.	
Holly et al., 2006 (Holly and Batzdorf, 2006)	8	All M	49.5	All dorsal	T = 8	1.9	100%	19	75%	25%	50%	100%	Neuropathic pain only improved in 30%, Motor improvement in all cases.	
Bassiouni et al., 2004 (Bassiouni et al., 2004)	11	1M:1.75F	49.3	All dorsal	CT = 3, T = 9	3.6	None	38.4	9 myelopathic patients and 3 with primarily radicular symptoms.			100%	Complete remission = 5, Incomplete remission = 1, substantial amelioration = 4, no change = 1.	
Wang et al., 2003 (Wang et al., 2003)	21	13M:8F	47.7	D = 15, V6	CT = 4, T = 13, TL = 1, L = 1, LS = 2	3.3	33%	17	Dorsal cysts; 60% paraesthesia, 93% neuropathic pain. ventral cysts; 83% myelopathy, 50% weakness				Improvement in; weakness (100%, hyperreflexia (91%), incontinence (80%). Neuropathic pain (44%), parathesia (33%).	

[a] Complete dataset did not differentiate between location of primary and secondary SAC.
[b] Case series primarily looking at SAC associated with syrinx.

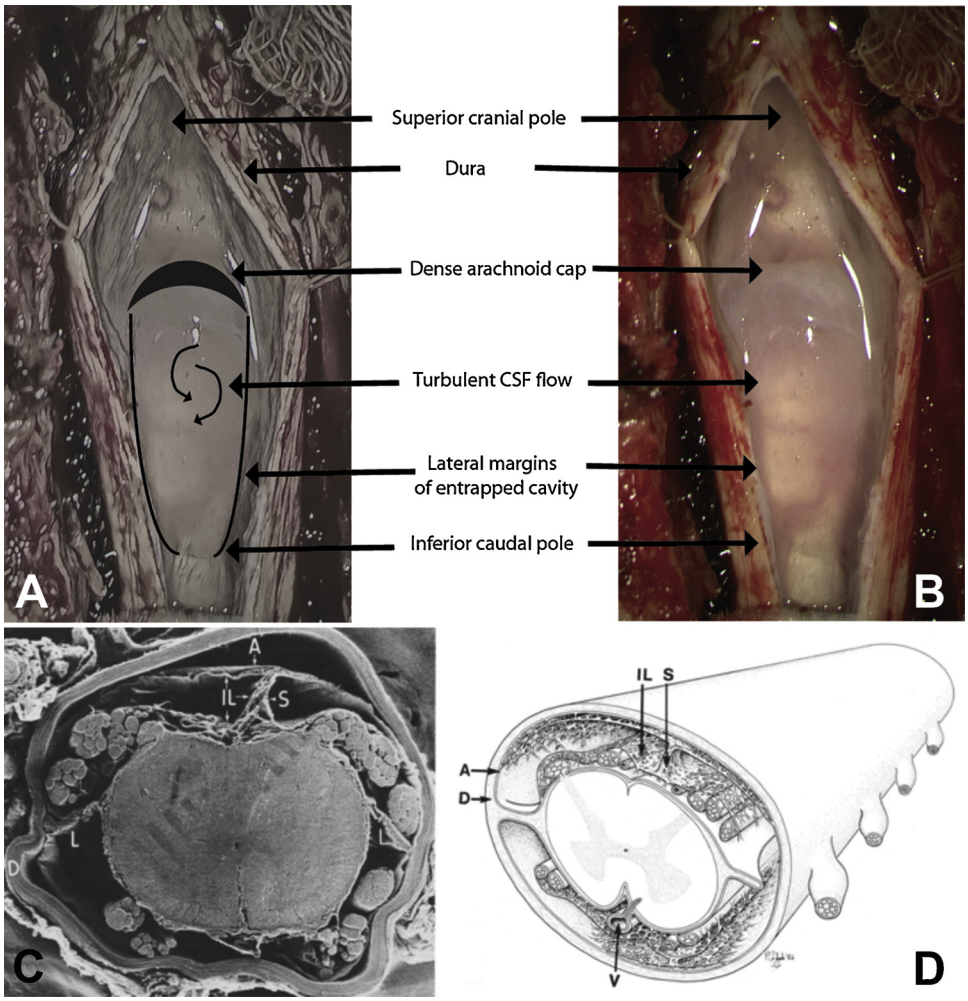

Fig. 4. Anatomy of spinal arachnoid cysts. *Macroscopic anatomy*. Pictorial (A) and intra-operative (B) demonstration of the anatomy of SACs. Following meticulous dural opening SACs were observed to be well defined and distinct structures. All possess a dense polar arachnoid cap. Cysts had defined lateral margins and poorly defined inferior poles, often observed as a tapering of the cyst conal structure. Turbulent CSF flow was observed within the cyst intra-operatively. *Microscopic anatomy.* C. Scanning electron micrograph of the spinal cord demonstrating the midline septum posticum (S), intermediate leptomeningeal layer (IL) which is closely applied to the inner aspect of the arachnoid (A). The septum posticum spans the space between in the intermediate leptomeningeal layer and the inner aspect of the arachnoid layer. The dentate ligaments are observed at the lateral margins of the spinal cord (L) and the dura (D) is observed in the periphery of the electron micrograph. B. Digrammatic representation of the human spinal cord with surrounding meninges. The arachnoid (A) is in close proximity to the thick outer dura (D). An intermediate leptomeningeal layer (IL) lies between the arachnoid mater and the pia mater. This layer is reflected in the midline to form the dorsal midline septum posticum (S). Blood vessels (V) within the subarachnoid space are coated by the leptomeningeal sheath continuous with the pia mater. Images and legends courtesy of Dr. R. Weller [11].

to have tough fibrous septae, unlike their dorsal counterparts, leading the authors to suggest that a preceding unidentified history of trauma or episode of traumatic subarachnoid haemorrhage and ensuing adhesive arachnoiditis was the likely pathological driver for cyst formation [17]. These lesions are therefore not true primary idiopathic SAC and this may highlight the difficulty in differentiating between primary and secondary SAC on the basis of history and radiographic imaging alone. In our experience, intra-operatively, SAC were translucent and thin walled with absence of bands and loculations. Apart from a thickened dome the remainder of the cyst was uniformly thin and collapsed following marsupialisation.

Review of the 143 described cases of SAC suggests that cysts span a mean of 3 vertebra with an associated syrinx in over two-thirds of cases (Table 3). We observed cysts to span a mean of 2.1 vertebrae with a preponderance of cysts between T3 to T6 with less than one-third of cases being associated with a syrinx.

4.3. Novel hypothesis of pathogenesis

We believe the complex interplay between CSF flow-dynamics within the thoracic spine and septum posticum gives rise to SAC through a previously undescribed hypothesis. It is recognised CSF flow, direction and speed is closely related to systole and diastole [18]. Systolic velocities of CSF in a cranio-caudal direction are largest in the thoracic region (25–50 mm/s), almost 4 times greater than in the cervical spine (8–12 mm/s) and double that within the lumbar spine (0–20 mm/s)[18]. In diastole reversal of flow, in a cadual to cranial direction, starts primarily in the ventral CSF space in the thoracic spine, anterior to the spinal cord, unlike in the cervical and lumbar spine where it is primarily initially in the dorsal CSF space. We postulate that the fast systolic CSF- velocities within the dorsal CSF space within the thoracic spine can result in a “dissection” within the septum posticum. This gives rise to a focal contained region of turbulent CSF flow that forms the appearance of a cyst with a ball-valve inlet (Fig. 5). The walls of the cyst, not strictly walls per se but boundaries, are as we have observed intra-operatively; lateral walls being the dissected arachnoid layers of the septum posticum and ventrally the pia overlying the cord parenchyma (Fig. 32). The polar cap of the SAC we postulate is defined by the overall difference in turbulent CSF velocities within the SAC. With the thickened arachnoid polar cap noted to point upwards in the cranial direction (often described in the literature as the scalpel sign radiographically [19]) when the greatest CSF pressure-flow differential is upwards and downwards with the converse (Figs. 2 and 5). We observed that the cysts never collapsed but appeared to reduce in turgidity in diastole this can be explained by the presence of phase shift in flow from a dorsal to ventral direction facilitating cross-sectional flow, to a limited extent, around the cord [18,20]. This in addition to a possible ball-valve effect explains why the SAC never collapse. We believe it is a combination of constant and dynamic focal compression on the cord parenchyma due to the alternating intra-cystic CSF pressures relating to the cardiac cycle that give rise to cord damage.

Our hypothesis is consistent with Oldfields own findings and postulations with respect to the formation of primary spinal syrinxes [21]. It has been proposed that a spinal subarachnoid block increases spinal subarachnoid pulse pressure above the block [22]. We have observed intraoperatively (refer to Movie 1) that the SAC gives rise to a focal

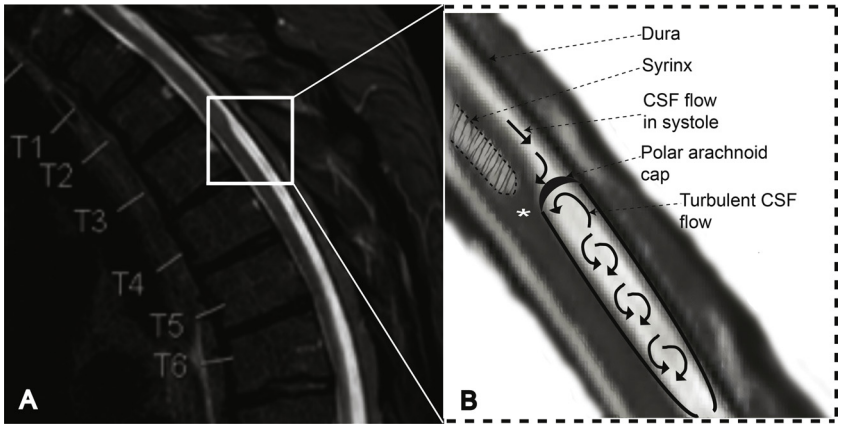

Fig. 5. Pictorial demonstrating putative hypothesis for syrinx formation in SAC. A. T2 weight sagittal MRI demonstrating a cranial orientated SAC with the classical "scalpel sign" being observed (*inset*). B. Pictorial demonstrating a SAC causing both focal cord compression and obstruction to CSF flow within the subarachnoid space. We propose that this obstruction in subarachnoid CSF flow increases the spinal subarachnoid pulse pressure above the SAC and in conjunction with the loss of cord compliance can herald both syrinx formation (*asterix*) and progression.

obstruction to CSF flow in the posterior spinal subarachnoid space and hence above the blockade there is potentially a resulting pressure differential across the obstructed subarachnoid space which can in combination of reduced cord compliance [secondary to compression] can herald both syrinx formation and progression.

4.4. Presentation

Typically patients are in their fifth decade of life when they present (Table 3). The mean age of our cohort was observed to be 58.2 years of age with a range of 25 to 77 years. This is consistent with the reported literature when paediatric cases are excluded (Table 3). Early cadaveric studies have observed that the septum posticum thickens with age [14] which may explain the predilection of SACs with increasing age. The preponderance of SAC in males has also been documented previously with an identical 1.8 M:1F ratio reported [23]. However due to inconsistencies in identifying primary and secondary SAC in the published literature it is difficult to concluded that this is primarily a male pathology. Indeed several studies have observed a reverse of the male to female ratio [17,24]. Strikingly we observed that male cases tended to be on average at least 10 years older than their female counterparts, a finding also previously reported [23].

Patients with SACs typically present with gait disturbance (85%), paraesthesia (65.4%), weakness (63%) and neuropathic pain (55%) (see Table 3). We observed that neuropathic pain (69%) and gait disturbance (69%) the predominant symptoms with parathesia in just over half of patients (55%) and motor weakness in under half of patients (45%). Bowel and bladder dysfunction were not observed in our cohort, unlike previously reported rates of between 36–50% [2,25,26]. The combination of both intra and extra-dural arachnoid cysts, were the extra-dural type are the majority within these studies makes it difficult to extrapolate whether the observed incidence of sphincteric dysfunction is representative of intradural SAC [2,25]. Patients presented with a mean period of 19-months prior to receiving a diagnosis a figure not dissimilar to the existing literature [2].

4.5. Surgical outcomes

Following marsupialisation or excision of SAC mJOA scores, gait disturbance and motor weakness were most likely to significantly improve (see Table 3) [23,27–29]. We observed that over a quarter of our surgically managed patients had complete resolution of their symptoms, with all patients experiencing a 1 point increase in MRC power grade when weakness was a presenting symptom a finding consistent with the literature. All patients with paraesthesia experienced an improvement. Resolution of neuropathic pain only occurred in 29% of cases following surgery a finding mirrored in other studies [29]. We observed that 20% of patients re-classified their neuropathic pain from being unpleasant to an area of sensitivity following surgery. Rather interestingly improvement in one or more of the clinically measured domains was also mirrored by a mean 45% re-expansion of previously compressed cord (as a result of the SAC) at 6 months. Reassuringly length of preceding symptoms prior to surgical management was not linked to severity of symptoms or inversely related to likelihood of improvement following surgery. These observations suggest that surgery has a critical role in relieving some of the symptoms resulting from SAC irrespective of how long the patient may have had the SAC or how disabled they are as a result of it. In addition following surgery, cyst recurrence is rare [4,24], with only two cases observed in our cohort.

5. Conclusion

Primary spinal arachnoid cysts are rare lesions that present with a constellation of symptoms and signs as a result of focal cord compression typically within the mid thoracic spine. We postulate that they arise as a result of a dissection within the septum posticum and are propagated secondary to the complex CSF flow dynamics within the thoracic spine. This results in a contained focus of turbulent flow entrapped within a cystic structure that gives rise to both static and dynamic compression of the cord parenchyma. These lesions are often missed on radiographic imaging (up to 40%) [27] and dedicated CSF flow studies and review by a dedicated neuro-radiologist is paramount. Surgical marsupialisation is likely to herald improvement most notably in motor, gait and sensory components of the patients clinical presentation.

Consent for publication

For this type of study formal consent is not required.

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Conflict of interest

All authors certify that they have no affiliations with or involvement in any organisation or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the

online version, at https://doi.org/10.1016/j.clineuro.2019.03.014.

References

[1] M.W. Nabors, T.G. Pait, E.B. Byrd, N.O. Karim, D.O. Davis, A.I. Kobrine, H.V. Rizzoli, Updated assessment and current classification of spinal meningeal cysts, J. Neurosurg. 68 (3) (1988) 366–377.

[2] K. Garg, S.A. Borkar, S.S. Kale, B.S. Sharma, Spinal arachnoid cysts – our experience and review of literature, Br. J. Neurosurg. 31 (2) (2017) 172–178.

[3] K.I. Park, H.S. Park, S.R. Kang, A. Nagappan, D.H. Lee, J.A. Kim, D.Y. Han, G.S. Kim, Korean Scutellaria baicalensis water extract inhibits cell cycle G1/S transition by suppressing cyclin D1 expression and matrix-metalloproteinase-2 activity in human lung cancer cells, J. Ethnopharmacol. 133 (2) (2011) 634–641.

[4] J. Klekamp, A New classification for pathologies of spinal meninges-part 2: primary and secondary intradural arachnoid cysts, Neurosurgery 81 (2) (2017) 217–229.

[5] U.D.o.H.a.H. Services [Online], U.D.o.H.a. Human (Ed.), Common Terminology Criteria for Adverse Events (CTCAe) Version 4.0, 2009 (Online).

[6] B.S. Galer, M.P. Jensen, Development and preliminary validation of a pain measure specific to neuropathic pain: the Neuropathic Pain Scale, Neurology 48 (2) (1997) 332–338.

[7] P.J. Dyck, C.J. Boes, D. Mulder, C. Millikan, A.J. Windebank, P.J. Dyck, R. Espinosa, History of standard scoring, notation, and summation of neuromuscular signs. A current survey and recommendation, J. Peripher. Nerv. Syst. 10 (2) (2005) 158–173.

[8] I.S.S. Izumida, Assessment of treatment for low back pain, J. Jpn. Orthop. Assoc. 60 (1986) 391–394.

[9] K.S.A.R. Sadek, R. Anwar, C.J. Dare, A. Nader-Sepahi, Incidence of vertebral column deformity following multi-level laminectomy for intraspinal tumours in adults; time to reassess the need for “prophylactic” fixation? Br. J. Neurosurg. 31 (2) (2017) 120.

[10] R.M. Key EAH, Studies of the Anatomy of the Nervous System and Connective Tissues, Samson Wallin, 1875.

[11] D.S. Nicholas, R.O. Weller, The fine anatomy of the human spinal meninges. A light and scanning electron microscopy study, J. Neurosurg. 69 (2) (1988) 276–282.

[12] G. Perret, D. Green, J. Keller, Diagnosis and treatment of intradural arachnoid cysts of the thoracic spine, Radiology 79 (1962) 425–429.

[13] A. Fortuna, E. La Torre, P. Ciappetta, Arachnoid diverticula: a unitary approach to spinal cysts communicating with the subarachnoid space, Acta Neurochir. (Wien) 39 (3–4) (1977) 259–268.

[14] G. Di Chiro, E.L. Timins, Supine myelography and the septum posticum, Radiology 111 (2) (1974) 319–327.

[15] M.F, Recherhes physiologiques et cliniques sur le liquides cephalo-rachidien ou cerebrospinal, Paris, (1842).

[16] J. Jirout, J. Fischer, F. Nadvornik, Anatomical and pneumographic studies on the posterior arachnoid space of the normal thoracic spine, Fortschr Geb Rontgenstr Nuklearmed 101 (4) (1964) 395–399.

[17] H. Bassiouni, A. Hunold, S. Asgari, U. Hubschen, H.J. Konig, D. Stolke, Spinal intradural juxtamedullary cysts in the adult: surgical management and outcome, Neurosurgery 55 (6) (2004) 1352–1359 (discussion 1359–60).

[18] D. Greitz, A. Franck, B. Nordell, On the pulsatile nature of intracranial and spinal CSF-circulation demonstrated by MR imaging, Acta Radiol. 34 (4) (1993) 321–328.

[19] R. Schultz Jr., A. Steven, A. Wessell, N. Fischbein, C.A. Sansur, D. Gandhi, D. Ibrahimi, P. Raghavan, Differentiation of idiopathic spinal cord herniation from dorsal arachnoid webs on MRI and CT myelography, J. Neurosurg. Spine 26 (6) (2017) 754–759.

[20] L.M. Levy, G. Di Chiro, MR phase imaging and cerebrospinal fluid flow in the head and spine, Neuroradiology 32 (5) (1990) 399–406.

[21] E.H. Oldfield, Pathogenesis of chiari I – pathophysiology of syringomyelia: implications for therapy: a summary of 3 decades of clinical research, Neurosurgery 64 (CN_suppl_1) (2017) 66–77.

[22] J.D. Heiss, K. Snyder, M.M. Peterson, N.J. Patronas, J.A. Butman, R.K. Smith, H.L. Devroom, C.A. Sansur, E. Eskioglu, W.A. Kammerer, E.H. Oldfield, Pathophysiology of primary spinal syringomyelia, J. Neurosurg. Spine 17 (5) (2012) 367–380.

[23] V.K. Viswanathan, S.R. Manoharan, H. Do, A. Minnema, S.M. Shaddy, J.B. Elder, H.F. Farhadi, Clinical and radiologic outcomes after fenestration and partial wall excision of idiopathic intradural spinal arachnoid cysts presenting with myelopathy, World Neurosurg. 105 (2017) 213–222.

[24] T. Endo, T. Takahashi, H. Jokura, T. Tominaga, Surgical treatment of spinal intradural arachnoid cysts using endoscopy, J. Neurosurg. Spine 12 (6) (2010) 641–646.

[25] H. Funao, M. Nakamura, N. Hosogane, K. Watanabe, T. Tsuji, K. Ishii, M. Kamata, Y. Toyama, K. Chiba, M. Matsumoto, Surgical treatment of spinal extradural arachnoid cysts in the thoracolumbar spine, Neurosurgery 71 (2) (2012) 278–284 (discussion 284).

[26] M.Y. Wang, A.D. Levi, B.A. Green, Intradural spinal arachnoid cysts in adults, Surg. Neurol. 60 (1) (2003) 49–55 (discussion 55–6).

[27] V.M. Srinivasan, J.S. Fridley, J.G. Thomas, I. Omeis, Nuances in localization and surgical treatment of syringomyelia associated with fenestrated and webbed intradural spinal arachnoid cyst: a retrospective analysis, World Neurosurg. 87 (2016) 176–186.

[28] C.J. Griessenauer, D.F. Bauer, T.A. Moore 2nd, P.R. Pritchard, M.N. Hadley, Surgical manifestations of thoracic arachnoid pathology: series of 28 cases, J. Neurosurg. Spine 20 (1) (2014) 30–40.

[29] L.T. Holly, U. Batzdorf, Syringomyelia associated with intradural arachnoid cysts, J. Neurosurg. Spine 5 (2) (2006) 111–116.