Clinical Neurology and Neurosurgery 185 (2019) 105486

Contents lists available at ScienceDirect

Clinical Neurology and Neurosurgery

journal homepage: www.elsevier.com/locate/clineuro

Surgical management of lumbar disc herniation in children and adolescents

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ARTICLE INFO

Keywords:
Lumbar disc herniation
Surgery
Minimally invasive
Pediatric
Spine
Review

ABSTRACT

Lumbar disc herniation (LDH) is a rare cause of morbidity in the paediatric population that can result in disruption to education and participation in social and athletic activities. Modern minimally invasive techniques have increasingly been adopted in paediatric spine surgery. The purpose of this review was to assess characteristics of paediatric LDH, evaluate current surgical techniques and their outcomes in recent literature, and compare paediatric outcomes with adults. A literature search was carried out identifying articles published from 2008 to 2018 relating to surgical treatment of LDH in children and adolescents. Original articles were scrutinised for outcome data and complications then compared by surgical approach. Over the last decade 1094 surgical cases have been published, mostly L4/L5 (52%) and L5/S1 (41%) intervertebral discs. These were predominantly operated with microdiscectomy and minimally invasive techniques: percutaneous endoscopic and tubular approaches to discectomy. Cystic fibrosis, trauma, extensive athletic activity, facet joint asymmetries and lumbosacral transition vertebrae may be risk factors for LDH. 55% had total resolution of pain after surgery, complications are rare and unsatisfactory resolution of pain and re-operation uncommon. In the short and medium-term, overall, paediatric patients do not have worse surgical outcomes than adult patients; they may recover faster and improve more. Minimally invasive approaches for LDH in adolescents are safe and efficacious. No technique has yet demonstrated clear superiority. Delaying surgery for conservative treatment is warranted, but for how long remains unclear.

1. Introduction

Lumbar disc herniation (LDH) is a rare cause of morbidity in paediatric patients. The pathogenesis is unclear, but trauma, genetics and dysfunctional biomechanical conditions are likely contributory [1]. Adult LDH is common and typically features dehydrated, degenerative discs occurring in line with a spinal degenerative process. Disease occurring up to 21 years of age is usually termed ‘adolescent’. The practice at our institution is to consider herniation presenting below 17 years as paediatric, at which age the estimated cumulative incidence is 4 in 10,000 [2]. These cases typically feature a well-hydrated disc and are more commonly associated with ring apophysis avulsion fracture (RAF) and trauma [3,4]. As such, paediatric LDH cannot be assumed to be the same disease as in adults, but a related phenomenon with potentially different natural and clinical histories. At what age there is a relevant distinction from adult disease is unclear.

Due to the low incidence of paediatric LHD, these patients are commonly misdiagnosed initially and experience a prolonged length of time from onset of symptoms to diagnosis [4]. Before surgery, a trial of conservative management is widely considered the appropriate initial management in the absence of neurological compromise.

Surgical approaches have developed since the first reported surgical treatment of paediatric LDH in 1960 [5]. Open discectomy, widely used in the 1970s and 1980s, was increasingly replaced by modern microdiscectomy with the advantages of reduced damage to connective tissue and improved recovery time. The first paediatric series was published in 1994 [6], and over the last 20 years, more minimally invasive approaches have been introduced as alternatives, including the use of a tubular retractor system and percutaneous endoscopic transforaminal and interlaminar approaches. However, conventional microdiscectomy is still preferred by many surgeons. Despite a systematic review of the literature covering 1945–2008 [7], there are continuing questions over how surgical outcomes compare between paediatrics and adults, and whether any minimally invasive technique delivers better surgical outcomes in paediatric patients. Only two endoscopic series were published at that time.

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https://doi.org/10.1016/j.clineuro.2019.105486
Received 27 March 2019; Received in revised form 15 May 2019; Accepted 8 August 2019
Available online 09 August 2019

In this article, we review the literature published between 2008 and 2018 to assess 1) clinical characteristics of paediatric LDH, 2) outcomes of different surgical techniques, 3) comparison of paediatric and adult outcomes, 4) developments in the understanding of paediatric LDH.

2. Methods

2.1. Search strategy

Literature searching was performed on MEDLINE and EMBASE with MeSH/Emtree terminologies (child, adolescent, pediatrics, intervertebral disc displacement/disk hernia, lumbar disk hernia), along with synonymic key words and alternative spellings. Journal articles were limited to publication between 2008 and 2018, and in the English language. Additional articles were identified from reference lists of these publications. Articles were deemed relevant by title and abstract.

2.2. Inclusion and exclusion criteria

Original research articles were included that reported surgical management of LDH in children and/or adolescents (Age ≤ 21 years). Reports including patients aged both over and under 21 years were excluded if the results for younger patients were not separable. Reports of cervical and thoracic discs were excluded, as were conference abstracts and reviews. Mechanistic LDH research that was specifically paediatric was included. Data duplicated in different articles were identified and one article arbitrarily selected for inclusion. References to discectomy without mention of microscopic assistance or minimally invasive techniques were interpreted as open procedures.

3. Results

The search identified 43 publications of which 8 were non-surgical. Among the 35 surgical articles there were 5 prospective cohort studies, 3 comparing adolescent to adult surgical outcomes [8–10], and 2 evaluating risk-factors for poor surgical outcomes [11,12]. Three of these were generated from the same registry (SweSpine) with different age and time selection criteria [9,11,12]. Including the larger of these three cohorts, overall the reports comprised 1094 surgical patients aged 1 to 21, with a mean age of 17. Surgical techniques included open discectomy +/- arthrodesis, posterior lumbar interbody fusion (PLIF) +/- pedicle screw fixation, transforaminal lumbar interbody fusion (TLIF), microdiscectomy, tubular discectomy, and percutaneous interlaminar and transforaminal endoscopic approaches.

4. Discussion

4.1. Clinical characteristics

It is rare for herniation to occur in children age 12 years or below. The largest recent series measuring this found 51% of patients 17–18 years of age, 46.5% 13–16 years and 2.5% 12 years or younger [4]. To our knowledge, there have been only 8 published surgical cases of children below 10 years old in the last 30 years [13–15,41–44]. Recent reports have highlighted a link between paediatric LDH and cystic fibrosis (see Table 1), which is likely mediated by chronic cough [15,45].

Paediatric LDH is predominantly a L4/L5 and L5/S1 disease (93%), with other levels and multi-level disease recognised, but uncommon. L4/L5 disease appears to be more common in paediatrics (n = 1064, 52 vs. 41%) (see Table 2) and L5/S1 disease more common in adults (n = 3148, 39 vs. 58%) [10]. Patients present with lower back pain (LBP), sciatica and straight leg raising is a sensitive test (86%). It appears that this test is more sensitive in young patients [46], contrary to what might be expected. Older patients have less mobile sciatic nerves [47], related to peri-dural fibrotic adhesions which are thought to be important for pain generation on straight leg raising [48]. A large minority of patients have motor weakness or compromise of deep tendon reflexes; frank compromise of autonomic lumbosacral function is rare. Presentation with painful scoliosis is recognised, where the herniated disc is typically (87%) the same side as the convexity of the scoliosis [4,23,26,37]. Surgery is most effective at resolving radicular pain and motor deficit, but also usually resolves or improves LBP. Analysis of the Swedish spine register (SweSpine) found lower patient-reported outcome measures at 1 year were predicted by severe pre-operative pain, disability, and poor mental health [11]. Interestingly pre-operative duration of leg pain was not associated with lower scores. These findings are particularly important, regarding confounding, for the design of future trials to assess superiority of different surgical approaches.

There were more male than female patients with LDH (3:2). El-Kader et al. [30] report a series comprising 72% men, which they attribute to employment in agricultural labour. Dividing the publications into high and low '% of employed population in agricultural labour' [49], there is a major male dominance (72%) and a minor female dominance (52%) respectively. Manual labour is a plausible mechanism for adolescent LDH and is implicated in other male dominant series [50]. It is unclear why recent studies in the US are female predominant, or if this is significant (see Table 2). It could reflect more avid participation in certain activities; some of these authors note a high proportion of competitive athletes (64–67%) [4,35]. A retrospective review of paediatric patients presenting with symptomatic LBP found athletes (exercising 5 days or 20 h or more a week) were more likely to have spondylosis with or without a slip (32 vs. 2%) [51]. Young athletes, for example child and adolescent weightlifters and tennis players, have spondylosis and disc disease far in excess of population prevalence [52–54]. It is difficult to establish whether trauma or athletic activity is implicated in an individual presentation of LDH. It may be obvious, for example following a cheerleading stunt [55] or somersault [18], but there may be a question over plausibility of the mechanism and the timing with onset of symptoms [13]. Nevertheless, many authors report a history of trauma in their patients (33–100%) [25,31,35,40]. Differences in sex ratios between publications may represent cultural and lifestyle differences between regions, relevant for exposure to trauma and lumbosacral stress. The relationship between childhood obesity and paediatric LDH remains unclear, although obesity is strongly associated with paediatric disc degeneration.

4.2. Surgical technique

Reports of open discectomy were uncommon over the last decade. Dang et al. [32] retrospectively examined whether arthrodesis resulted in improved outcomes relative to discectomy alone; outcomes were not different between groups at a mean follow-up of 39.1 months. The study indications for arthrodesis imply these populations are different, but equally these indications may be irrelevant to outcomes. Comparison with the Norwegian spine registry (NORspine) fails to show any superiority of microdiscectomy over open discectomy by the same outcome metrics (see Table 4). Kwon et al. [28] report a PLIF series with or without pedicle screw fixation as well as one minimally invasive TLIF case. Pain following surgery decreased from 7.7 ± 1.4 to 2.3 ± 1.0 on a visual analogue scale (VAS). The indications for fusion in this study were ostensibly the same as investigated by Dang et al. [32] suggesting that fusion may have been an unnecessarily extensive approach in these patients.

Minimally invasive techniques are an attractive alternative to microdiscectomy with a view to improving management of paediatric LDH patients. For example, over the last decade the efficacy and safety of the tubular approach has been demonstrated in four series with 136 patients [27,29,35,39]. For most patients, the best surgical outcome is to have no pain; an excellent Macnab score denotes this. Due to its simplicity, the score can be estimated in most studies which do not record it explicitly. Such a comparison between surgical techniques fails to

Table 1
Surgical LDH case reports*.

Year	Authors	Age	Sex	Features	Surgical outcome
2008	Benifla et al. [13]	1 year	M	Youngest ever reported	Resolution
2011	Cahill et al. [14]	18 months	F	Following a fall	Resolution
2014	Alexiou et al. [15]	8 years	M	Cystic fibrosis	Resolution
2010	Jiang and Jiang [16]	12 years	M	Extreme lateral herniation	Resolution
2011	Chang et al. [17]	12 years	M	Cauda equina syndrome	Resolution
2015	Yuceer and Arda [18]	12 years	F	Somersault	Resolution
2016	Farrokhi et al. [19]	13 years	M	Ring apophysis fracture	Resolution
		14 years	M	Ring apophysis fracture	Resolution
2017	Kadam et al. [20]	15 years	M	Ring apophysis fracture (fall)	Resolution
2013	Fridley et al. [21]	16 years	F	US-guided epidural blood patch	Resolution
		17 years	F	US-guided epidural blood patch	Resolution
2015	Grudkova et al. [22]	17 years	F	Femoral head osteoid osteoma	No improvement (hip pain)
2012	Hsu et al. [23]	14 years	M	Painful scoliosis	Resolution
		14 years	M	Painful scoliosis	Resolution
		16 years	F	Painful scoliosis	Resolution
		21 years	M	Painful scoliosis	Resolution

* Reports of 4 paediatric cases or less.

robustly support the superiority of any particular surgical technique (see Table 3). This comparison may be limited by varying follow-up times, but in our experience if total pain relief is achieved it is usually within days of treatment.

There was inconsistency between authors on Macnab outcomes for percutaneous endoscopic discectomy (PED) procedures. Prior to 2008 46 of 50 published PED procedures in adolescents were reported by Lee et al. [56] and only 22% achieved excellent Macnab criteria. Since 2008 this has ranged from 43 to 83%. This discrepancy in outcomes is less apparent with other outcome criteria (see Table 4). Among those where the specific PED approach was specified, transforaminal procedures were carried out in 70 patients, and interlaminar procedures in a further 96 patients [31,34,39]. Surgical outcomes overall for both approaches were similar, although Macnab outcomes appeared to be better for the interlaminar approach (see Tables 3 and 5).

Fakouri et al. [25] report a microdiscectomy series of 6 patients where they used the Japanese Orthopaedic Association (JOA) score for LBP to measure outcomes. They showed a median improvement from 4 to 8 at 13 months mean follow-up. 33% scored 9 (no symptoms), however they also report that 100% had their pain disappear by last follow-up and none were taking pain medication. 77 microdiscectomy patients from a multicenter Norwegian registry study reported Oswestry Disability Index (ODI) scores which were similar to results from PED (see Table 4) [10]. The majority of recent publications report endoscopic approaches and there is a need for more modern outcome data of microdiscectomy, and research designed specifically to establish the place of microdiscectomy alongside minimally invasive techniques. Comparing tubular to PED, a retrospective study found no difference in ODI or leg pain at final follow-up [39]. PED, however, resulted in a greater decrease in LBP at final follow-up and a faster improvement in

Table 2
Patient and clinical characteristics of surgically managed paediatric LDH cases 2008-2018.

Authors	Country	No.	L4/L5	L5/S1	Other	M	F	Motor	SLR -(FNS)	DTR	B-B	Sx
Case reports	Mixed	16	8	5	3	13	3	4	12	3	1	O, M
2008 Chang et al. [24]	Taiwan	32	20	10	2	–	–	–	–	–	–	O
2009 Fakouri et al. [25]	UK	6	4	2	0	4	2	2	6	–	0	M
2009 Cahill et al. [4]	US	87	39	31	17	35	52	22	81	19	2	M
2011 Zhu et al. [26]	China	26	14	6	6	18	8	4	18	–	0	M
2011 Thomas et al. [27]	US	6	3	3	0	2	4	2	6	0	0	T
2011 Çelik et al. [8]	Turkey	32	16	16	0	14	18	–	–	–	–	M
2013 Kwon et al. [28]	S.Korea	18	13	2	3	16	2	–	–	–	–	PLIF, TLIF
2013 Singhal et al. [3]	Canada	30	–	–	–	–	–	–	–	–	–	M
2013 Wang et al. [29]	China	121	61	42	18	95	26	69	109	40	0	O, T, E
2014 El-Kader et al. [30]	Egypt	25	14	8	3	18	7	2	–	–	0	O, M, E
2014 Wang et al. [31]	China	29	9	20	0	21	8	13	18	–	0	E
2015 Dang et al. [32]	China	63	37	26	0	37	26	–	–	–	–	O ± A
2015 Lägerback et al. [9]	Sweden* a)	151	70	72	9	75	76	–	–	–	–	O, M
2016 Strömqvist et al. [12]	Sweden* b)	74	38	36	2	31	43	–	–	–	–	O, M
2016 Strömqvist et al. [11]	Sweden* c)	180	94	84	2	89	91	–	–	–	–	O, M
2016 Sarma et al. [33]	India	28	18	4	6	–	–	16	26	–	2	O
2016 Zheng et al. [34]	China	12	5	4	3	7	5	12	4, (8)	8	0	E
2017 Montejo et al. [35]	US	12	3	9	0	5	7	8	10	–	0	T
2017 Gulati et al. [10]	Norway	97	55	39	3	49	48	–	–	–	–	M
2017 Zhang et al. [36]	China	80	44	36	0	62	18	–	–	–	–	–
2018 Tu et al. [37]	China	74	51	22	1	55	19	–	–	–	–	E
2018 Xu et al. [38]	China	23	0	23	0	13	10	14	18	–	0	E
2018 Li et al. [39]	China	78	40	30	8	50	28	–	–	–	–	T, E
2018 Chen et al. [40]	China	19	7	12	0	17	2	5	19	5	0	E
TOTAL†		1094	555	434	75	620	384	173	335	75	5	
%			52	41	7	62	38	43	88	31	1	

Other = other level or multilevel, SLR = straight leg raising test, FNS = femoral nerve stretch test, DTR = deep tendon reflex, B-B = bladder or bowel symptoms, Sx = surgery, O = open, M = microdiscectomy, T = tubular, E = endoscopic, A = arthrodesis, P/TLIF = posterior/transforaminal interbody fusion.

* All derived from SweSpine. a) ≤18, b) ≤17, c) ≤20 years old. †Only including [11] from SweSpine.

Table 3
Comparison of surgical techniques by Macnab outcomes and post-operative length of stay.

Authors	Surgical technique (patients)	Post-operative length of stay	Mean follow-up (months)	Macnab excellent %
2009 Fakouri et al. [25]	Microdiscectomy (6)	Within 2 days	13	≥50 (estimated)
2009 Cahill et al. [4]	Microdiscectomy (87)	Mean 1.3 days	12.5	–
2011 Thomas et al. [27]	Tubular (6)	Mean 1.3 days	10.2	≥50 (estimated)
2013 Wang et al. [29]	Open (16)	Mean 10.6 days	At discharge	48
	Tubular (80)	Mean 7.3 days		
	Endoscopic (25)	Mean 4.4 days		
2013 Singhal et al. [3]	Microdiscectomy (30)	–	–	68
2014 Wang et al. [31]	Endoscopic (29)	Within 24 hours	19.7	83
2016 Zheng et al. [34]	Endoscopic (12)	Same day	Minimum of 12	50
2017 Montejo et al. [35]	Tubular (12)	Median 1 day	24.6	64
2018 Tu et al. [37]	Endoscopic (42)	–	39.0	43
2018 Xu et al. [38]	Endoscopic (23)	–	19.7	78
2018 Li et al. [39]	Tubular (38)	Mean 4.8 days	67.1	–
	Endoscopic (40)	Mean 3.8 days	68.9	–
2018 Chen et al. [40]	Endoscopic (20)	–	41.7	53
AVERAGE				55

leg pain and ODI.

The tubular approach does not appear to allow patients to return home earlier than with microdiscectomy, although with PED they may do. Li et al. [39] and Wang et al. [29] found most of their tubular and PED patients went home more than 72 h after surgery, many much longer. However, other authors report all their patients leaving hospital in under 24 h when managed with PED (see Table 3). Clearly this is beneficial in terms of hospital economy and exposure to nosocomial risk, but has not obviously translated to a reduction in complications. Post-operative stay is highly dependent on patient preparation, and adult microdiscectomy cases commonly go home the same day. Paediatric microdiscectomy may also have the potential to mostly be a day-case procedure.

Peri-operative and post-operative complications with microdiscectomy are rare (1.0%, 2.6%, n = 192) [4,10,13,14,25]. There is no conclusive difference in the complication rates between the surgical techniques (see Table 5), although variability in reporting makes quantitative comparison challenging. Rates of deep and superficial infection in paediatric degenerative spine surgery are low (< 1%), and minimally invasive techniques are clearly associated with lower rates of infection than open surgery [57].

4.3. Paediatric vs. Adult outcomes

At 1–2 years following surgical treatment of LDH, 4.5–14% of adolescent patients are unsatisfied with the surgical outcome [9,11]. The comparative surgical success of paediatric and adult LDH patients continues to be unresolved. Two prospective observational registry-based studies from Scandanavia (SweSpine, NORspine) have found contradictory results [9,10]. The Swedish study, the larger of the two, found that a greater proportion of adolescents (12–18 years) had significantly decreased leg and back pain after surgery at 1 or 2-year follow-up (mean = 1.7 years) compared to adults. Although the discectomy techniques were unspecified the registry is known to include a mix of open and microdiscectomy. The Norwegian study included microdiscectomy cases only and found no difference in ODI, leg or back pain between adolescents (13–19 years) and adults at 1-year follow-up. In addition, a smaller prospective Turkish microdiscectomy study found greater short and long-term improvement in pain for adolescents (≤18 years) [8]. The adult group also demonstrated higher reherniation rates and post-operative peri-dural fibrotic change. As such, the notion that adolescents do poorer with microdiscectomy than adults is unsubstantiated by the literature. Regarding the PED approach, a Chinese study with 3–5 years follow-up found adolescents (13–18 years) improved faster after surgery and overall did better than adults measured by both JOA score and severity of persisting leg pain [40].

The standard adult trial of conservative management is 6–12 weeks before proceeding to surgery [58]. Fakouri et al. [25] emulated this in adolescents (mean = 10.5 weeks) and propose that this period should be brief given the safety and efficacy of the modern surgical approaches as well as the disruption to the patient's life. These patients are at an age of crucial social, athletic and educational development, and lumbar disc herniation can result in disengagement from these activities and impact on them claiming their potential. Numerous authors have highlighted the importance of conservative management prior to LDH surgery. While some surgeons believe that the majority of such cases are satisfactorily resolved with conservative management [4], published long-term success rates vary between 25–50% [59–61]. There are contradictory results concerning the superiority of surgery to conservative treatment in long-term outcomes [60,61]. However,

Table 4
Comparison of surgical approaches to discectomy by pre- and post-operative outcome metrics.

		Leg-VAS		Back-VAS		ODI		JOA	
Authors	Surgical technique (No. of patients)	Pre-op	Post-op	Pre-op	Post-op	Pre-op	Post-op	Pre-op	Post-op
Dang et al. [32]	Open (36)	6.3	1.1	4.3	1.8	39.2	7.9	–	–
	Open + arthrodesis (27)	5.5	1.4	4.6	2.0	41.5	12.1	–	–
Gulati et al. [10]	Microdiscectomy (77)	6.4	1.3	5.5	2.0	33.7	8.3	–	–
Li et al. [39]	Tubular (38)	6.2 ± 2.5	0.7 ± 1.1	4.7 ± 3.5	1.9 ± 1.5	72.2 ± 26.1	8.0 ± 8.8	–	–
	Transforaminal PED (40)	6.3 ± 2.3	0.6 ± 1.2	4.8 ± 2.9	0.7 ± 0.9	63.0 ± 22.2	6.8 ± 13.1	–	–
Wang et al. [31]	Interlaminar PED (29)	8.5 ± 0.8	0.5 ± 0.5	5.1 ± 1.5	0.5 ± 0.6	46.0 ± 10.5	5.3 ± 3.3	–	–
Tu et al. [37]	Interlaminar PED (42)	7.0 ± 1.5	1.4 ± 1.0	3.7 ± 1.7	1.2 ± 1.0	73.9 ± 11.8	15.2 ± 5.3	–	–
Xu et al. [38]	Interlaminar PED (23)	6.2 ± 1.3	1.2 ± 0.6	–	–	–	–	12.5 ± 3.8	27.6 ± 1.3
Zheng et al. [34]	Transforaminal PED (12)	8.6 ± 1.6	2.1 ± 0.4	–	–	–	–	–	–
Chen et al. [40]	Transforaminal (18) + interlaminar (2)	6.8	0.1	2.9	0.3	–	–	13.4	28

VAS = visual analogue scale, ODI = Oswestry disability index, JOA = Japanese Orthopaedic Association score.

Table 5
Complications of intervertebral disc surgery.

Authors	No.	Peri- and post-operative complications	Long-term complications	Unsatisfactory outcomes
Mixed				
Under 10 years old [13,14,15]	3	None reported	None reported	None reported
Wang et al. [29]	121	1 dysaesthesia 1 CSF leak 1 haematoma elimination	2 recurrence	3 Macnab poor score
Strömqvist et al. [11]	180	1 ganglion injury 6 durotomy	–	8 unsatisfied with surgery
Li et al. [39]	78	1 recurrent herniation	2 same level operation	–
El-Kader et al. [30]	25	1 infection 2 CSF leaks	None reported	3 persistent pain
Open				
Dang et al. [32]	63	–	2 recurrence	–
P/TLIF				
Kwon et al. [28]	18	None reported	1 revision adjacent level	
Microdiscectomy				
Fakouri et al. [25]	6	None reported	None reported	1 persistent numbness
Cahill et al. [4]	87	1 infection + CSF leak + meningitis 3 CSF leak 1 transient neurological deficit 1 residual disc reoperation	4 same level operation 1 adjacent level operation 1 L3-sacral fusion	–
Gulati et al. [10]	97	1 micturition problem	–	–
Tubular				
Thomas et al. [27]	6	None reported	None reported	None reported
Montejo et al. [35]	12	None reported	1 same level operation	1 no improvement
Endoscopic				
Wang et al. [31]	29	1 neurological deficit 2 transient worsening of pain	None reported	2 Macnab fair scores
Zheng et al. [34]	12	1 neurological deficit 1 ganglion injury	None reported	1 persistent numbness 1 Macnab fair score
Tu et al. [37]	74	1 durotomy 2 dysesthesias	2 recurrence	2 Macnab fair 1 Macnab poor score
Xu et al. [38]	23	2 leg numbness	1 same level operation	3 Macnab fair scores
Chen et al. [40]	19	1 same level operation	None reported	None reported

Post-operative: less than 3 months, long-term: continuing beyond or occurring at more than 3 months.

consensus opinion is that paediatric discs respond less well to conservative management than adults [7]. In adults non-contained herniation responds better to conservative management than contained herniation [62]. Predominance of contained herniation could partly explain poorer response to conservative management in adolescents [37,4].

Receiving spinal surgery at such a young age raises important concerns regarding the prognosis for these patients decades in the future. Prior to the practice of microdiscectomy and minimally invasive surgery, at 20-years follow-up from discectomy about 25% of patients had undergone another discectomy, with 5% also undergoing arthrodesis [63]. For modern spinal surgery such data are unavailable, as are the likelihoods for having lower back pain, disc herniation and surgery even later in life. Importantly, it is unknown whether adolescents with disc herniation increase their risk for having spinal surgery decades in the future by opting for surgical intervention rather than conservative management.

4.4. Clinical mechanistic research

TNF-α has previously been implicated in the production of radicular pain in adults [64–67], where the pain can be thought of as a function of nerve compression and TNF-α mediated inflammation. Evidence of this has now been demonstrated in adolescents, through finding more TNF-α immunoreactive cells of the nucleus pulposus in painful LDH than non-painful scoliosis specimen controls [68]. Some success has been reported with epidural steroid injections in conservative treatment [69]. This lends theoretical support to that strategy, and may well be an important avenue of conservative treatment in adolescents. This is a safe intervention in paediatrics, and as many as 58% of patients managed this way do not progress to surgery [70]. The true benefit of steroid injections, however, and the comparative pain/disability outcomes of conservatively vs. surgically managed patients are not well defined.

RAF can be found in association with LDH and is best identified by CT [1,24]. It is unknown whether RAF is a cause or consequence of LDH; conceivably it could both reduce the integrity of the intervertebral space and be the result of trauma [71]. Chang et al. [24] found RAF in 28% of cases (34% of males, 14% of females), in comparison with 5% in adult reports [72]. The rate of surgery was higher in RAF cases, and among conservatively managed patients those with large apophyseal fragments had a higher rate of chronic back pain at follow-up. Singhal et al. [3] found RAF in 38% of paediatric cases (55% of males, 20% of females). Prior to ring apophyseal fusion at around 17 years of age, osteocartilaginous junctions represent structural weak points. The male skeleton has a longer period of immaturity, which may explain the male RAF proclivity. Emergence of the ring apophysis ossification centre is later in males, and most cases of greatly delayed ossification could conceivably be male [73]. History of trauma is common in paediatric LDH series (15–56%) [3,31,35,40,74]. Although trauma is an obvious mechanism for fracture, Singhal et al. [3] did not find RAF associated with history of trauma. Central disc herniation was associated with RAF, indicating RAF might promote herniation specifically at this orientation. Alternatively, central herniation could be a critical disc orientation for causing RAF, through intervertebral ligaments inserting on the apophysis experiencing particularly high tension, generating shearing forces and apophyseal fracture [3].

Spinal anatomic variants are associated with paediatric LDH [35,63,75,76]. Lumbosacral transitional vertebra are present in up to 30% of cases, relative to 8% in controls. Sacralisation and lumbarisation may specifically dispose to L4/L5 and L5/S1 herniation respectively [32,36]. Likewise, spino-pelvic radiographic parameters are associated with paediatric LDH: decreased pelvic incidence, sacral slope, lumbar lordosis, and increased pelvic tilt [77]. Although these may well be a consequence of LDH, and not predisposing to it. Dang et al. [32] reason that biomechanical stability of lumbosacral segment is related to paediatric LDH, and relies on appropriate function of the iliolumbar ligament. Investigating insertion points of the ligament, long L5 transverse processes and abnormally high or low iliac crests were associated with LDH. Furthermore, the associated level of disc herniation was concordant with biomechanical predictions of instability resulting from the anatomical variant. In all, 95% of patients had such an abnormality and/or a transition vertebra. These findings suggest that some patients are anatomically predisposed to herniation, and that risk is focused at a specific vertebral level.

Intervertebral facet joints carry a component of the vertical spinal load, and anatomic variants have the potential to jeopardise biomechanical stability of the lumbosacral segment [78]. Facet joint asymmetry is a recognised radiographic feature of LDH, and is 5-times more common in paediatric LDH than in adult LDH [79]. Wang et al. [80,81] investigated facet angle asymmetry at the herniated disc level and facet angle progression in sequential lumbar segments (L3-S1). There was significantly more facet abnormality in both forms compared to 'non-herniated' controls. However, the control group was an adult sample, so the findings should be treated with some caution. Although these findings support the notion that lumbosacral facet joint asymmetries are a particular feature of paediatric LDH, they do not help resolve whether abnormal facet anatomy is a predisposing factor to LDH, or conversely, if it is caused by the LDH.

5. Conclusion

LDH can occur at any age but is very rare in patients younger than 12 years old. In contrast to adult disease, L4/L5 disc herniation is more common than L5/S1 herniation in children and adolescents. Activities involving lumbosacral stress likely promote paediatric LDH, be it manual labour, sport or dancing. Lumbosacral anatomical variants, including transition vertebrae, also likely increase risk.

The literature does not support the notion that surgical outcomes are worse in adolescents than in adults; they are either equivalent or better. Endoscopic, tubular access, and classic microdiscectomy have all been shown to be safe and efficacious techniques. There may be minimal superiority of outcome with PED over the tubular approach in management of paediatric LDH. Current evidence has failed to demonstrate superiority of minimally invasive techniques over microdiscectomy. Future publications would benefit from recording Macnab criteria, pre- and post-operative ODI and back/leg VAS for best comparability to pre-existing literature.

Disclosure statement

The authors report no conflict of interest

References

[1] W.F. Lavelle, A. Bianco, R. Mason, R.R. Betz, S.A. Albanese, Pediatric disk herniation, Am. Acad. Orthop. Surg. 19 (2011) 649–656, https://doi.org/10.5435/00124635-201111000-00001.

[2] P. Zitting, P. Rantakallio, H. Vanharanta, Cumulative incidence of lumbar disc diseases leading to hospitalization up to the age of 28 years, Spine 23 (1998) 2337–2343.

[3] A. Singhal, A. Mitra, D. Cochrane, P. Steinbok, Ring apophysis fracture in pediatric lumbar disc herniation: a common entity, Pediatr. Neurosurg. 49 (2013) 16–20, https://doi.org/10.1159/000355127.

[4] K.S. Cahill, I. Dunn, T. Gunnarsson, M.R. Proctor, Lumbar microdiscectomy in pediatric patients: a large single-institution series, J. Neurosurg. Spine 12 (2010) 165–170, https://doi.org/10.3171/2009.9.SPINE09756.

[5] J.E. O'Connell, Intervertebral disk protrusions in childhood and adolescence, Br. J. Surg. 47 (1960) 611–616.

[6] H.R. Silvers, P.J. Lewis, D.E. Clabeaux, H.L. Asch, Lumbar disc excisions in patients under the age of 21 years, Spine 19 (1994) 2387–2391.

[7] L. Dang, Z. Liu, A review of current treatment for lumbar disc herniation in children and adolescents, Eur. Spine J. 19 (2010) 205–214, https://doi.org/10.1007/s00586-009-1202-7.

[8] S. Çelik, K. Göksu, S.E. Çelik, C.B. Emir, Benign neurological recovery with low recurrence and low peridural fibrosis rate in pediatric disc herniations after lumbar microdiscectomy, Pediatr. Neurosurg. 47 (2011) 417–422, https://doi.org/10.1159/000338982.

[9] T. Lagerbäck, P. Elkan, H. Möller, A. Grauers, E. Diarbakerli, P. Gerdhem, An observational study on the outcome after surgery for lumbar disc herniation in adolescents compared with adults based on the Swedish Spine Register, Spine J. 15 (2015) 1241–1247, https://doi.org/10.1016/j.spinee.2015.02.024.

[10] S. Gulati, M.A. Madsbu, T.K. Solberg, A. Sørlie, C. Giannadakis, M.K. Skram, Ø.P. Nygaard, A.S. Jakola, Lumbar microdiscectomy for sciatica in adolescents: a multicentre observational registry-based study, Acta Neurochir. (Wien). 159 (2017) 509–516, https://doi.org/10.1007/s00701-017-3077-4.

[11] F. Strömqvist, B. Strömqvist, B. Jönsson, P. Gerdhem, M.K. Karlsson, Predictive outcome factors in the young patient treated with lumbar disc herniation surgery, J. Neurosurg. Spine 25 (2016) 421–544, https://doi.org/10.3171/2016.2.SPINE16136.

[12] F. Strömqvist, B. Strömqvist, B. Jönsson, P. Gerdhem, M.K. Karlsson, Lumbar disc herniation surgery in children: outcome and gender differences, Eur. Spine J. 25 (2016) 657–663, https://doi.org/10.1007/s00586-015-4149-x.

[13] M. Benifla, I. Melamed, R. Barrelly, A. Aloushin, I. Shelef, Unilateral partial hemilaminectomy for disc removal in a 1-year-old child, J. Neurosurg. Pediatr. 2 (2008) 133–135, https://doi.org/10.3171/PED/2008/2/8/133.

[14] J. Cahill, G. Frost, G.A. Solanki, Paediatric lumbar disc herniation in the very young: a case-based update, Childs Nerv. Syst. 27 (2011) 687–691, https://doi.org/10.1007/s00381-010-1369-6.

[15] G.A. Alexiou, K. Stefanaki, G. Sfakianos, N. Prodromou, Lumbar disc herniation in a child with cystic fibrosis: case report, Arch. Argent. Pediatr. 112 (2014) e43–45, https://doi.org/10.5546/aap.2014.e43.

[16] S.-D. Jiang, L.-S. Jiang, L.-Y. Dai, Extreme lateral lumbar disc herniation in a 12-year child: case report and review of the literature, Eur. Spine J. 19 (2010) 197–199, https://doi.org/10.1007/s00586-010-1354-5.

[17] C.-Y. Chang, P.-H. Lai, S.-S. Hsu, Cauda equina syndrome in a pediatric patient due to lumbar disc herniation, J. Med. Sci. 31 (2011) 275–278, https://doi.org/10.6136/JMS.2011.31(6).275.

[18] N. Yuceer, M. Arda, Acute lumbar intervertebral disc herniation occurring after somersault in a girl, J. Pediatr. Neurol. 6 (2015) 375–376, https://doi.org/10.1055/s-0035-1557475.

[19] M.R. Farrokhi, M.S. Masoudi, Slipped vertebral epiphysis (report of 2 cases), J. Res. Med. Sci. 14 (2009) 63–66.

[20] G. Kadam, K. Narsinghpura, S. Deshmukh, S. Desai, Traumatic lumbar vertebral ring apophysis fracture with disk herniation in an adolescent, Radiol. Case Rep. 12 (2017) 427–430, https://doi.org/10.1016/j.radcr.2016.11.026.

[21] J.S. Fridley, A. Jea, C.D. Glover, K.P. Nguyen, Symptomatic postsurgical cerebrospinal fluid leak treated by aspiration and epidural blood patch under ultrasound guidance in 2 adolescents, J. Neurosurg. Pediatr. 11 (2013) 87–90, https://doi.org/10.3171/2012.9.PEDS12314.

[22] M.V. Grudkova, A.G. Kaprelyan, I.N. Dimitrov, B.D. Ivanov, Femoral head osteoid osteoma and lumbar disc herniation: case report, J. Int. Med. Assoc. Bulg. 21 (2015) 922–925.

[23] K.-L. Hsu, T.-W. Tai, J.-T. Chien, C.-J. Lin, Sciatic scoliosis: an easily misdiagnosed disease in adolescents and young adults, Tzu Chi Med. J. 24 (2012) 196–200, https://doi.org/10.1016/j.tcmj.2012.10.006.

[24] C.-H. Chang, Z.-L. Lee, W.-J. Chen, C.-F. Tan, L.-H. Chen, Clinical significance of ring apophysis fracture in adolescent lumbar disc herniation, Spine 33 (2008) 1750–1754, https://doi.org/10.1097/BRS.0b013e31817d1d12.

[25] B. Fakouri, C. Nnadi, B. Boszczyk, A. Kunsky, F. Cacciola, When is the appropriate time for surgical intervention of the herniated lumbar disc in the adolescent? J. Clin. Neurosci. 16 (2009) 1153–1156, https://doi.org/10.1016/j.jocn.2009.01.023.

[26] Z. Zhu, Q. Zhao, B. Wang, Y. Yu, B. Qian, Y. Ding, Y. Qiu, Scoliotic posture as the initial symptom in adolescents with lumbar disc herniation: its curve pattern and natural history after lumbar discectomy, BMC Musculoskelet. Disord. 12 (2011) 1–8, https://doi.org/10.1186/1471-2474-12-216.

[27] J.G. Thomas, S.W. Hwang, W.E. Whitehead, D.J. Curry, T.G. Luerssen, A. Jea, Minimally invasive lumbar microdiscectomy in pediatric patients: a series of 6 patients, J. Neurosurg. Pediatr. 7 (2011) 616–619, https://doi.org/10.3171/2011.3.PEDS10570.

[28] D.-W. Kwon, K.-H. Kim, J.-Y. Park, D.-K. Chin, K.-S. Kim, Y.-E. Cho, S.-U. Kuh, Clinical outcomes and considerations of the lumbar interbody fusion technique for lumbar disk disease in adolescents, Childs Nerv. Syst. 29 (2013) 1339–1344, https://doi.org/10.1007/s00381-013-2088-6.

[29] H. Wang, J. Cheng, H. Xiao, C. Li, Y. Zhou, Adolescent lumbar disc herniation: experience from a large minimally invasive treatment centre for lumbar degenerative disease in Chongqing, China, Clin. Neurol. Neurosurg. 115 (2013) 1415–1419, https://doi.org/10.1016/j.clineuro.2013.01.019.

[30] H.E.-B.A. El-Kader, Lumbar disc herniation in adolescents. Clinical experience and surgical outcome, Egypt J. Neurosurg. 29 (2014) 45–50.

[31] X. Wang, J. Zeng, H. Nie, G. Chen, Z. Li, H. Jiang, Q. Kong, Y. Song, H. Liu, Percutaneous endoscopic interlaminar discectomy for pediatric lumbar disc herniation, Childs Nerv. Syst. 30 (2014) 897–902, https://doi.org/10.1007/s00381-013-2320-4.

[32] L. Dang, Z. Chen, X. Liu, Z. Guo, Q. Qi, W. Li, Y. Zeng, L. Jiang, F. Wei, C. Sun, Z. Liu, Lumbar disk herniation in children and adolescents: the significance of configurations of the lumbar spine, Neurosurgery 77 (2015) 954–959, https://doi.org/10.1227/NEU.0000000000000983.

[33] P. Sarma, R.T. Thirupathi, D. Srinivas, S. Somanna, Adolescent prolapsed lumbar intervertebral disc: management strategies and outcome, J. Pediatr. Neurosci. 11

(2016) 20–24, https://doi.org/10.4103/1817-1745.181259.

[34] C. Zheng, F. Wu, L. Cai, Transforaminal percutaneous endoscopic discectomy in the treatment of far-lateral lumbar disc herniations in children, Int. Orthop. 40 (2016) 1099–1102, https://doi.org/10.1007/s00264-016-3155-x.

[35] J.D. Montejo, J.Q. Camara-Quintana, D. Duran, J.M. Rockefeller, S.B. Conine, A.M. Blaise, K.T. Kahle, M.L. DiLuna, Tubular approach to minimally invasive microdiscectomy for pediatric lumbar disc herniation, J. Neurosurg. Pediatr. 21 (2018) 449–455, https://doi.org/10.3171/2017.11.PEDS17293.

[36] B. Zhang, L. Wang, H. Wang, Q. Guo, X. Lu, D. Chen, Lumbosacral transitional vertebra: possible role in the pathogenesis of adolescent lumbar disc herniation, World Neurosurg. 107 (2017) 983–989, https://doi.org/10.1016/j.wneu.2017.07.095.

[37] Z. Tu, B. Wang, L. Li, Y. Li, Y. Dai, G. Lv, T. Li, Early experience of full-endoscopic interlaminar discectomy for adolescent lumbar disc herniation with sciatic scoliosis, Pain Physician 21 (2018) e63–70.

[38] Z. Xu, Y. Liu, J. Chen, Percutaneous endoscopic interlaminar discectomy for L5/S1 adolescent lumbar disc herniation, Turk. Neurosurg. 28 (2017) 923–928, https://doi.org/10.5137/1019-5149.JTN.21579-17.3.

[39] H. Li, C. Jiang, X. Mu, W. Lan, Y. Zhou, C. Li, Comparison of MED and PELD in the treatment of adolescent lumbar disc herniation: a 5-Year retrospective follow-up, World Neurosurg. 112 (2018) e255–e260, https://doi.org/10.1016/j.wneu.2018.01.030.

[40] Y. Chen, R. Song, W. Huang, Z. Chang, Percutaneous endoscopic discectomy in adolescent lumbar disc herniation: a 3- to 5-year study, J. Neurosurg. Pediatr. 23 (2018) 135–259, https://doi.org/10.3171/2018.8.PEDS18442.

[41] J.F. Martínez-Lage, V. Fernández Cornejo, F. López, M. Poza, Lumbar disc herniation in early childhood: case report and literature review, Childs Nerv. Syst. 19 (2003) 258–260, https://doi.org/10.1007/s00381-003-0720-6.

[42] P. Bartolozzi, G. Lombardini, G. Floris, Herniated lumbar disc in the child: a description of two cases, Ital. J. Orthop. Traumatol. 15 (1989) 115–120.

[43] R. Revuelta, P.P. De Juambelz, B. Fernandez, J.A. Flores, Lumbar disc herniation in a 27-month-old child, J. Neurosurg. Spine 91 (2000) 98–100, https://doi.org/10.3171/spi.2000.92.1.0098.

[44] H. Ishihara, H. Matsui, N. Hirano, H. Tsuji, Lumbar intervertebral disc herniation in children less than 16 years of age: long-term follow-up study of surgically managed cases, Spine 22 (1997) 2044–2049.

[45] C. Denne, A.E. Vogl-Voswinckel, H. Wurmser, M. Steinborn, M. Spaeth, A. Gruebl, S. Burdach, Lumbar disc herniation in three patients with cystic fibrosis: a case series, J. Med. Case Reports 5 (2011) 1–4, https://doi.org/10.1186/1752-1947-5-440.

[46] H. Tabesh, A. Tabesh, E. Fakharian, M. Fazel, S. Abrishamkar, The effect of age on result of straight leg raising test in patients suffering lumbar disc herniation and sciatica, J. Res. Med. Sci. Off. J. Isfahan Univ. Med. Sci. 20 (2015) 150–153.

[47] M.D. Goddard, J.D. Reid, Movements induced by straight leg raising in the lumbosacral roots, nerves and plexus, and in the intrapelvic section of the sciatic nerve, J. Neurol. Neurosurg. Psychiatry 28 (1965) 12–18, https://doi.org/10.1136/jnnp.28.1.12.

[48] S. Kobayashi, K. Takeno, T. Yayama, K. Awara, T. Miyazaki, A. Guerrero, H. Baba, Pathomechanisms of Sciatica in Lumbar Disc Herniation: Effect of Periradicular Adhesive Tissue on Electrophysiological Values by an Intraoperative Straight Leg Raising Test, Spine 35 (2010) 2004–2014, https://doi.org/10.1097/BRS.0b013e3181d4164d.

[49] World Bank, FAO Statistical Year Book; World Food and Agriculture: Part 1; Map 9: Employment in Agriculture; Share of Total Employment, Food and Agriculture Organization of the United Nations, 2013 (accessed October 8, 2008), http://www.fao.org/docrep/018/i3107e/i3107e01.pdf.

[50] A. Kurihara, O. Kataoka, Lumbar disc herniation in children and adolescents. A review of 70 operated cases and their minimum 5-year follow-up studies, Spine 5 (1980) 443–451.

[51] G.D. Schroeder, C.R. LaBella, M. Mendoza, E.L. Daley, J.W. Savage, A.A. Patel, W.K. Hsu, The role of intense athletic activity on structural lumbar abnormalities in adolescent patients with symptomatic low back pain, Eur. Spine J. 25 (2016) 2842–2848, https://doi.org/10.1007/s00586-016-4647-5.

[52] K. Shimozaki, J. Nakase, K. Yoshioka, Y. Takata, K. Asai, K. Kitaoka, H. Tsuchiya, Incidence rates and characteristics of abnormal lumbar findings and low back pain in child and adolescent weightlifter: A prospective three-year cohort study, PLoS One 13 (2018) e0206125, , https://doi.org/10.1371/journal.pone.0206125.

[53] G. Rajeswaran, M. Turner, C. Gissane, J.C. Healy, MRI findings in the lumbar spines of asymptomatic elite junior tennis players, Skeletal Radiol. 43 (2014) 925–932, https://doi.org/10.1007/s00256-014-1862-1.

[54] J. Urrutia, T. Zamora, C. Prada, The prevalence of degenerative or incidental findings in the lumbar spine of pediatric patients: a study using magnetic resonance imaging as a screening tool, Eur. Spine J. 25 (2016) 596–601, https://doi.org/10.1007/s00586-015-4099-3.

[55] N.A. Jacobson, L.G. Morawa, C.A. Bir, Epidemiology of cheerleading injuries presenting to NEISS hospitals from 2002 to 2007, J. Trauma Acute Care Surg. 72 (2012) 521–526, https://doi.org/10.1097/TA.0b013e31823f5fe3.

[56] D.Y. Lee, Y. Ahn, S.-H. Lee, Percutaneous endoscopic lumbar discectomy for adolescent lumbar disc herniation: surgical outcomes in 46 consecutive patients, Mt. Sinai J. Med. N. Y. 73 (2006) 864–870.

[57] J.S. Smith, C.I. Shaffrey, C.A. Sansur, S.H. Berven, K.-M.G. Fu, P.A. Broadstone, T.J. Choma, M.J. Goytan, H.H. Noordeen, D.R. Knapp, R.A. Hart, W.F. Donaldson, D.W. Polly, J.H. Perra, O. Boachie-Adjei, Rates of infection after spine surgery based on 108,419 procedures: a report from the scoliosis research society morbidity and mortality committee, Spine 36 (2011) 556–563, https://doi.org/10.1097/BRS.0b013e3181eadd41.

[58] W.C.H. Jacobs, M. van Tulder, M. Arts, S.M. Rubinstein, M. van Middelkoop, R. Ostelo, A. Verhagen, B. Koes, W.C. Peul, Surgery versus conservative management of sciatica due to a lumbar herniated disc: a systematic review, Eur. Spine J. 20 (2011) 513–522, https://doi.org/10.1007/s00586-010-1603-7.

[59] M.H. Zamani, G.D. MacEwen, Herniation of the lumbar disc in children and adolescents, J. Pediatr. Orthop. 2 (1982) 528–533.

[60] P.F. DeLuca, D.E. Mason, R. Weiand, R. Howard, G.S. Bassett, Excision of herniated nucleus pulposus in children and adolescents, J. Pediatr. Orthop. 14 (1994) 318–322.

[61] A.A. Kurth, S. Rau, C. Wang, E. Schmitt, Treatment of lumbar disc herniation in the second decade of life, Eur. Spine J. 5 (1996) 220–224, https://doi.org/10.1007/BF00301323.

[62] T. Ito, Y. Takano, N. Yuasa, Types of lumbar herniated disc and clinical course, Spine 26 (2001) 648–651, https://doi.org/10.1097/00007632-200103150-00017.

[63] P.J. Papagelopoulos, W.J. Shaughnessy, M.J. Ebersold, A.J. Bianco, L.M. Quast, Long-term outcome of lumbar discectomy in children and adolescents sixteen years of age or younger, J. Bone Jt. Surg. 80 (1998) 689–698, https://doi.org/10.2106/00004623-199805000-00009.

[64] H. Takahashi, T. Suguro, Y. Okazima, M. Motegi, Y. Okada, T. Kakiuchi, Inflammatory Cytokines in the Herniated Disc of the Lumbar Spine, Spine 21 (1996) 218–224.

[65] S. Lee, C.S. Moon, D. Sul, J. Lee, M. Bae, Y. Hong, M. Lee, S. Choi, R. Derby, B.-J. Kim, J. Kim, J.-S. Yoon, L. Wolfer, J. Kim, J. Wang, S.-W. Hwang, S.-H. Lee, Comparison of growth factor and cytokine expression in patients with degenerated disc disease and herniated nucleus pulposus, Clin. Biochem. 42 (2009) 1504–1511, https://doi.org/10.1016/j.clinbiochem.2009.06.017.

[66] S. Genevay, A. Finckh, M. Payer, F. Mezin, E. Tessitore, C. Gabay, P.A. Guerne, Elevated levels of tumor necrosis factor-alpha in periradicular fat tissue in patients with radiculopathy from herniated disc, Spine 33 (2008) 2041–2046, https://doi.org/10.1097/BRS.0b013e318183bb86.

[67] D.C. Kraychete, R.K. Sakata, A.M. Issy, O. Bacellar, R. Santos-Jesus, E.M. Carvalho, Serum cytokine levels in patients with chronic low back pain due to herniated disc: analytical cross-sectional study, Sao Paulo Med. J. 128 (2010) 259–262, https://doi.org/10.1590/S1516-31802010000500003.

[68] S. Ohtori, G. Inoue, Y. Eguchi, S. Orita, M. Takaso, N. Ochiai, S. Kishida, K. Kuniyoshi, Y. Aoki, J. Nakamura, T. Ishikawa, G. Arai, M. Miyagi, H. Kamoda, M. Suzuki, Y. Sakuma, Y. Oikawa, G. Kubota, K. Inage, T. Sainoh, T. Toyone, K. Yamauchi, T. Kotani, T. Akazawa, S. Minami, K. Takahashi, Tumor Necrosis Factor-α-Immunoreactive Cells in Nucleus Pulposus in Adolescent Patients With Lumbar Disc Herniation, Spine 38 (2013) 459–462, https://doi.org/10.1097/BRS.0b013e3182739cb4.

[69] J.R. Slotkin, J.M.K. Mislow, A.L. Day, M.R. Proctor, Pediatric disk disease, Pediatr. Spine Surg. Part II. 18 (2007) 659–667, https://doi.org/10.1016/j.nec.2007.08.001.

[70] K.E. Kurgansky, S.T. Rodriguez, M.S. Kralj, J.J. Mooney, P. Dinakar, P.A. d'Hemecourt, D.J. Hedequist, M.R. Proctor, C.B. Berde, Epidural steroid injections for radiculopathy and/or back pain in children and adolescents: a retrospective cohort study with a prospective follow-up, Reg. Anesth. Amp Pain Med. 41 (2016) 86–92, https://doi.org/10.1097/AAP.0000000000000338.

[71] R. Savini, M. Di Silvestre, G. Gargiulo, P. Picci, Posterior lumbar apophyseal fractures, Spine 16 (1991) 1118–1123.

[72] A. Akhaddar, H. Belfquih, M. Oukabli, M. Boucetta, Posterior ring apophysis separation combined with lumbar disc herniation in adults: a 10-year experience in the surgical management of 87 cases, J. Neurosurg. Spine 14 (2011) 475–483, https://doi.org/10.3171/2010.11.SPINE10392.

[73] M. Matsumoto, Radiological and histological studies on the growth of lumbar vertebra, Nihon Seikeigeka Gakkai Zasshi. 62 (1988) 331–343.

[74] Y. Smorgick, Y. Floman, M.A. Millgram, Y. Anekstein, I. Pekarsky, Y. Mirovsky, Mid- to long-term outcome of disc excision in adolescent disc herniation, Spine J. 6 (2006) 380–384, https://doi.org/10.1016/j.spinee.2005.10.015.

[75] P. Parisini, M.D. Silvestre, T. Greggi, A. Miglietta, S. Paderni, Lumbar Disc Excision in Children and Adolescents, Spine. 26 (n.d.) 1997–2000.

[76] M.J. Ebersold, L.M. Quast, A.J. Bianco, Results of lumbar discectomy in the pediatric patient, J. Neurosurg. 67 (1987) 643–647, https://doi.org/10.3171/jns.1987.67.5.0643.

[77] T. Wang, H. Wang, F. Liu, D. Yang, L. Ma, W. Ding, The characteristics of spinopelvic sagittal parameters and obesity factors for adolescents with lumbar disc herniation, Int. J. Clin. Exp. Med. 9 (2016) 14321–14328.

[78] H.F. Farfan, J.D. Sullivan, The relation of facet orientation to intervertebral disc failure, Can. J. Surg. 10 (1967) 179–185.

[79] H. Ishihara, H. Matsui, R. Osada, H. Ohshima, H. Tsuji, Facet joint asymmetry as a radiologic feature of lumbar intervertebral disc herniation in children and adolescents, Spine 22 (1997) 2001–2004.

[80] H. Wang, Z. Zhang, Y. Zhou, Irregular alteration of facet orientation in lumbar segments: possible role in pathology of lumbar disc herniation in adolescents, World Neurosurg. 86 (2016) 321–327, https://doi.org/10.1016/j.wneu.2015.09.029.

[81] H. Wang, Y. Zhou, Facet tropism: possible role in the pathology of lumbar disc herniation in adolescents, J. Neurosurg. Pediatr. 18 (2016) 111–115, https://doi.org/10.3171/2015.7.PEDS15175.