The addition of duraplasty to posterior fossa decompression in the surgical treatment of pediatric Chiari malformation Type I: a systematic review and meta-analysis of surgical and performance outcomes

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OBJECTIVE Surgery is the definitive treatment of Chiari malformation Type I (CM-I). It involves posterior fossa decompression, which can be performed along with C-1 laminectomy, reconstructive duraplasty, or tonsil shrinkage. The aim of this study was to provide an updated systematic review and meta-analysis of the latest available evidence regarding posterior fossa decompression only (PFDO) versus posterior fossa decompression with duraplasty (PFDD) in the treatment of CM-I in children.

METHODS A literature search was performed in compliance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines for article identification, screening, eligibility, and inclusion. Relevant articles were identified from 6 electronic databases from their inception to April 2016. These articles were screened against established criteria for inclusion into this study.

RESULTS From 12 relevant studies identified, 1492 pediatric patients treated via PFDD were compared with 1963 pediatric patients treated by PFDO for CM-I. PFDD was associated with greater overall clinical improvement ($p = 0.009$), along with longer length of stay ($p < 0.0001$) and more postoperative complications ($p = 0.0001$) compared with PFDO. No difference was observed between PFDD and PFDO in terms of revision surgery incidence ($p = 0.13$), estimated blood loss ($p = 0.14$), syrinx improvement ($p = 0.09$), or scoliosis improvement ($p = 0.95$).

CONCLUSIONS It appears that the addition of duraplasty to posterior decompression in the definitive treatment of CM-I in children may alter surgical and performance outcomes. In particular, parameters of overall clinical improvement, length of stay, and postoperative complication may differ between children undergoing PFDD and those undergoing PFDO. Current evidence in the literature is of low to very low quality that, as of yet, has not been able to completely control for inherent selection bias both in study design and surgeon preference. Future, large prospective registries and randomized controlled trials are warranted to validate the findings of this study.

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KEY WORDS Chiari malformation; pediatrics; surgery; duraplasty; dural graft; decompression; systematic review; meta-analysis

CHIARI malformation Type I (CM-I) is characterized by caudal displacement of the cerebellar tonsils below the level of the foramen magnum at the craniovertebral junction.⁵³ Surgery remains the definitive treatment to ameliorate any disruption to the CSF circulation and compressive impact of local neural structures caused by CM-I.^{38,46} The prevalence of CM-I is potentially as high as 1% in both the general population⁶¹ and in children alone.¹ To date, many case series in the literature have de-

scribed satisfactory outcomes for the 2 main surgical approaches used to treat CM-I in pediatric patients: posterior fossa decompression only (PFDO)^{1,8,9,12,15,17,21,27,31,54,55,63} and posterior fossa decompression with duraplasty (PFDD).^{2,6,7,11,13,18,19,22,23,26,28,32,35,43,47,48,57,59,62}

Posterior fossa decompression involves resection of suboccipital bone and the C-1 lamina.^{7,21,31,51} Thus, the PFDO approach does not involve entry into the intradural space. PFDD, on the other hand, involves dural invasion

ABBREVIATIONS CM-I = Chiari malformation Type I; GRADE = Grades of Recommendation, Assessment, Development and Evaluation; LOS = length of stay; MD = mean difference; PFDD = posterior fossa decompression with duraplasty; PFDO = posterior fossa decompression only.

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and intradural manipulation at the craniovertebral junction.^{5,32,51,57} This approach has the ability to address intradural pathology, such as fourth ventricular outlet obstruction by gross tonsillar herniation and arachnoid veils and webs, if present.^{47,58} As PFDO is an extradural procedure only, it can be considered to be less invasive than PFDD. In theory, PFDO would involve shorter operative times, fewer complications, and shorter hospital lengths of stay (LOS);⁵⁷ however, this has not been conclusively demonstrated. Currently, no clear consensus or evidence exists on which surgical approach is more appropriate for children with CM-I.^{4,7,16,25}

Few systematic studies have focused on the surgical treatment of CM-I in the pediatric population.^{16,25} It is important to distinguish between pediatric and adult populations, as the postoperative course after posterior fossa decompression seems to differ between the 2 populations.⁵⁹ In recent years, studies of relatively significant size^{33,37} and a national registry analysis⁵⁶ have been published in the United States in which PFDD and PFDO outcome measures in children with CM-I are compared. The aim of this study was to incorporate these new findings into a systematic review and meta-analysis to provide an up-to-date comparison of PFDD versus PFDO in the surgical treatment of pediatric CM-I.

Methods

Literature Search Strategy

This systematic review and meta-analysis was conducted according to PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines and recommendations.^{39,49} Electronic searches were performed independently by 2 reviewers (V.M.L. and K.P.) using Ovid Medline, PubMed, EMBASE, CCTR (Cochrane Central Register of Controlled Trials), CDSR (Cochrane Database of Systematic Reviews), American College of Physicians Journal Club, and CARE (Database of Abstracts of Review of Effectiveness) from their dates of inception to April 2016. To achieve maximal sensitivity of the search strategy and identify all studies, we combined the terms “pediatric/paediatric,” “children,” “Chiari malformation/Chiari I,” “duraplasty/dural graft,” and “surgery” as either keywords or MeSH terms. The reference lists of all retrieved articles were reviewed for further identification of potentially relevant studies.

Selection Criteria

Eligible studies were systematically assessed using the inclusion and exclusion criteria. The inclusion criteria were 1) diagnosis of CM-I confirmed by MRI; 2) a discernible cohort with a maximum age of 18 years at surgery; and 3) treatment via either a PFDO or PFDD. We included patients with symptomatic or asymptomatic CM-I. PFDD could include tonsil shrinkage. Studies that did not include death or complications as end points were excluded. When institutions published duplicate studies with accumulating numbers of patients or increased durations of follow-up, only the most complete reports were included for quantitative assessment at each time interval. All publications were limited to those involving human subjects

and those written in the English language. Editorials and expert opinions were excluded. Review articles were omitted because of potential publication bias and duplication of results.

Data Extraction and Critical Appraisal

All data were extracted from article texts, tables, and figures with any estimates made based on the presented data and figures. All attempts were made to contact study authors for any clarification. Two investigators independently reviewed each retrieved article (V.M.L. and S.P.C.). Primary outcome measures included 1) surgical parameters such as LOS and estimated blood loss; and 2) performance parameters, such as postoperative complications; revision surgery; and improvements in syrinx, scoliosis, and overall clinical status. Definition of improvement was defined or implied on a study-to-study basis and included complete resolution. Examples of improvement in overall clinical status included complete remission of symptoms,⁴⁰ notable improvement in preoperative symptoms and no need of further treatment,⁶⁴ and clinical and radiological improvements.⁶⁰ Assessment of risk of bias for each selected study was performed according to the most updated Cochrane statement. Quality of evidence was assessed using the Grades of Recommendation, Assessment, Development and Evaluation (GRADE) Working Group system⁵ for limitations in study design and methodology, evidence directedness, consistency, and precision in results as well as publication bias risk. Any discrepancies between the 2 reviewers were resolved by discussion and consensus.

Statistical Analysis

The odds ratio (OR) and mean difference (MD) were used as summary statistics. Meta-analysis of each outcome was presented as a forest plot; its summary statistical estimate, 95% confidence interval, and relative weighting were represented by the middle of the square, the horizontal line, and the relative size of the square, respectively. For the overall summary statistic, the mean and 95% confidence interval were represented by the middle and width of the diamond, respectively. In the present study, both fixed- and random-effect models were tested. In the fixed-effects model, it was assumed that treatment effect in each study was the same, whereas in a random-effects model, it was assumed that there were variations between studies. Chi-square tests were used to study heterogeneity between trials. The I^2 statistic was used to estimate the percentage of total variation across studies, owing to heterogeneity rather than chance, with values greater than 50% considered as substantial heterogeneity. I^2 can be calculated as $I^2 = 100\% \times (Q - df)/Q$, with Q defined as Cochrane's heterogeneity statistics and df defined as degrees of freedom. If there was substantial heterogeneity, the possible clinical and methodological reasons for this were explored qualitatively and quantitatively using leave-one-out sensitivity analysis. In the present meta-analysis, the results using the random-effects model were presented to take into account the possible clinical diversity and methodological variation between studies. Specific analyses considering

confounding factors were not possible because raw data were not available. Leave-one-out sensitivity analysis was conducted for each outcome involving 3 or more studies to assess for cohort size bias. Each study was sequentially removed, and the overall outcome trend was reassessed for any significant change. All *p* values were 2-sided. All statistical analyses were conducted using Review Manager (version 5.3.3, Cochrane Collaboration, Software Update).

Results

Literature Search

The search strategy identified a total of 804 studies (Fig. 1). After removal of 361 duplicate studies, inclusion/exclusion criteria were applied to the titles of the 443 articles. This yielded 21 studies that underwent full-text analysis. Ten articles and 2 abstracts are included in this current review for both qualitative and quantitative analyses. Comparative features and primary outcomes from each study are described in Tables 1 and 2, respectively.

Cohort Description

The cohort size of this review was 3455, with 1492 (43%) children undergoing PFDD and 1963 (57%) chil-

dren undergoing PFDO for the treatment of CM-I. In terms of the PFDD grafts, natural grafts included pericranial autograft, cadaveric dura, bovine pericardium, and fascia lata while synthetic grafts included Durepair (Medtronic), Gore-Tex, AlloDerm (LifeCell Corp.), and Dura-Guard (Synovis Life Technologies, Inc.). The majority of PFDD approaches involved complete dural incision only; however, additional arachnoid dissection^{20,33,40,44,64} was also used selectively. The majority of PFDO approaches involved bone decompression only; however, additional durotomy^{40,44} was also used selectively. The mean of the ages reported at the time of PFDD and PFDO were 10.9 and 9.7 years, respectively. The proportion of male patients in the studies treated by PFDD and PFDO ranged from 44% to 56% and 0% to 63%, respectively. The mean follow-up ranged from immediate evaluation only to 55 months. There was no statistically significant difference in the aforementioned features between the PFDD and PFDO cohorts.

Surgical Outcomes

Length of Stay

PFDD was associated with a significantly longer hos-

FIG. 1. Results of the literature search. Data added to the PRISMA template (from Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group: Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. *PLoS Med* 6(7):e1000097, 2009) under the terms of the Creative Commons Attribution License. Figure is available in color online only.

TABLE 1. Study characteristics and basic demographics

Authors & Year	Country	GRADE Rating	Study Design*	No. of Pts	No. of Pts Treated (%)		Dural Graft	Mean Age (yrs)		% Male		Mean Follow-Up (mos)	
					PFDD	PFDO		PFDD	PFDO	PFDD	PFDO	PFDD	PFDO
Duddy et al., 2013	Ireland	Very low	R, OS (2)	21	9 (43)	12 (57)	NR	10.9†		48†		NR	NR
Galarza et al., 2007	US	Very low	R, OS (1)	41	21 (51)	20 (49)	Natural	10†		NR	NR	21†	
Keating et al., 2011	US	Very low	R, OS (1)	55	39 (71)	16 (29)	NR	9.06	11.4	49	63	35	11.1
Lee et al., 2014	US	Very low	R, OS (1)	65	36 (55)	29 (45)	Natural, synthetic	9.9	8.9	44	52	23.5	23.7
Limonadi & Selden, 2004	US	Low	P, OS (1)	24	12 (50)	12 (50)	Natural	10.8	7.6	50	42	14.8	15.7
McGirt et al., 2008	US	Low	P, OS (1)	256	140 (55)	116 (45)	Natural, synthetic	12	5	44	52	29	25
Mottollese et al., 2011	France	Very low	R, OS (1)	82	39 (48)	43 (52)	Synthetic	NR	NR	NR	NR	NR	NR
Munshi et al., 2000	US	Very low	R, OS (1)	12	9 (75)	3 (25)	Natural	10.2	15.7	56	0	NR	NR
Navarro et al., 2004	US	Very low	R, OS (1)	109	38 (35)	71 (65)	Natural, synthetic	8.2†		NR	NR	55†	
Shweikeh et al., 2015	US	Very low	R, OS (4121)	2649	1056 (40)	1593 (60)	NR	10.9	9.8	45	48	NR	NR
Ventureyra et al., 2003	Canada	Very low	R, OS (1)	16	8 (50)	8 (50)	NR	NR	NR	38†		NR	NR
Yeh et al., 2006	US	Low	P, OS (1)	125	85 (68)	40 (32)	Natural	NR	NR	NR	NR	20†	
Total				3455	1492 (43)	1963 (57)							

NR = not recorded; OS = observational study; P = prospective; pts = patients; R = retrospective.

* Values in parentheses indicate the number of institutions.

† Authors reported the value for the entire cohort only.

TABLE 2. Postoperative outcomes of studies with rates expressed as patient number/available cohort

Authors & Year	Postop Complications		CSF-Related Complications (n)		Infection-Related Complications (n)		Revision Op		Syrinx Improvement		Overall Clinical Improvement	
	PFDD	PFDO	PFDD	PFDO	PFDD	PFDO	PFDD	PFDO	PFDD	PFDO	PFDD	PFDO
Duddy et al., 2013	4/9	0/12	3	0	1	0	0/9	0/12	NR	NR	NR	NR
Galarza et al., 2007	5/41*		3*		0*		NR	NR	4/7	5/7	11/15	4/12
Keating et al., 2011	11/55	0/39	11	0	0	0	11/39	0/16	25/37	10/16	NR	NR
Lee et al., 2014	8/36	3/29	7	0	3	1	1/36	2/29	10/13	8/8	NR	NR
Limonadi & Selden, 2004	1/12	0/12	0	0	1	0	0/12	0/12	10/10	0	NR	NR
McGirt et al., 2008	7/140	1/116	2	0	5	1	10/140	9/116	NR	NR	200/256*	
Mottollese et al., 2011*	0/39	7/43	0	3	0	3	0/39	2/43	2/7	0/6	35/39	30/43
Munshi et al., 2000	NR	NR	NR	NR	NR	NR	NR	NR	3/4	1/1	9/9	2/3
Navarro et al., 2004*	18/38	4/71	8	2	5	1	5/38	8/71	NR	NR	20/38	51/71
Shweikeh et al., 2015	169/1056	217/1593	141	191	0	0	22/1056	12/1593	NR	NR	NR	NR
Ventureyra et al., 2003	0/8	0/8	0	0	0	0	0/8	2/8	5/5	0/2	8/8	5/8
Yeh et al., 2006*	12/85	0/40	9	0	2	0	2/85	4/40	17/20	4/6	83/85	36/40
Overall (%)	230/1478 (15.6)	232/1963 (11.8)	181/1478 (12.2)	196/1963 (10.0)	171/1478 (1.2)	6/1963 (0.3)	51/1462 (3.5)	39/1940 (2.0)	76/103 (73.7)	28/46 (60.9)	166/194 (85.5)	128/177 (72.3)

* Reported value for overall cohort only.

† Scoliosis improvement rates were reported by Mottollese et al. (PFDD, 3/7; PFDO, 4/8), Navarro et al. (overall, 7/14), and Yeh et al. (PFDD, 4/9; PFDO, 0/1).

FIG. 2. Forest plots comparing surgical outcomes of PFDD versus PFDO in the treatment of pediatric CM-I for LOS (days, **A**), estimated blood loss (ml, **B**), and revision surgery (**C**) complications. IV = inverse variance; M-H = Mantel-Haenszel. Figure is available in color online only.

pital LOS compared with PFDO (MD 0.60 days; 95% CI 0.59–0.61 days; $p < 0.00001$) based on 4 studies, with pooled means of 4.46 and 3.79 days, respectively (Fig. 2A).

Estimated Blood Loss

PFDD was not associated with significantly different estimated blood loss compared with PFDO ($p = 0.14$) based on 2 studies (Fig. 2B).

Revision Surgery

Incidences of revision surgery after PFDD and PFDO were 51 of 1462 (3.5%) and 39 of 1940 (2.0%), respectively. PFDD was not associated with significantly different likelihood of revision surgery compared with PFDO ($p = 0.13$) based on 8 studies (Fig. 2C).

Postoperative Complications

Incidences of postoperative complications after PFDD and PFDO were 230 of 1478 (15.6%) and 232 of 1963

(11.8%), respectively. PFDD was associated with a significantly greater incidence of any postoperative complication compared with PFDO (OR 1.47, 95% CI 1.21–1.80; $p = 0.0001$) based on 9 studies (Fig. 3A). Furthermore, PFDD was associated with significantly greater incidences of CSF-related (OR 1.36, 95% CI 1.09–1.68; $p = 0.006$ [Fig. 3B]) and infection-related (OR 4.38, 95% CI 1.54–12.50; $p = 0.006$) postoperative complications compared with PFDO based on 8 studies (Fig. 3B) and 6 studies (Fig. 3C), respectively.

Performance Outcomes

Syrinx Improvement

Incidences of syrinx improvement after PFDD and PFDO were 76 of 103 (73.7%) and 28 of 46 (60.9%), respectively. PFDD was not associated with a significantly different likelihood of syrinx improvement compared with PFDO ($p = 0.40$) based on 7 studies (Fig. 4A).

FIG. 3. Forest plots comparing postoperative complications of PFDD versus PFDO in the treatment of pediatric CM-I for overall (A), CSF-related only (B), and infection-related only (C). Figure is available in color online only.

Scoliosis Improvement

Incidences of scoliosis improvement after PFDD and PFDO were 7 of 16 (43.8%) and 4 of 9 (44.4%), respectively. PFDD was not associated with significantly different likelihood of scoliosis improvement compared with PFDO ($p = 0.95$) based on 2 studies (Fig. 4B).

Overall Clinical Improvement

Incidences of clinical improvement after PFDD and PFDO were 171 of 194 (88.1%) and 128 of 177 (72.3%), respectively. PFDD was associated with significantly greater clinical improvement compared with PFDD (OR 2.09, 95% CI 1.20–3.64; $p = 0.009$) based on 6 studies (Fig. 4C).

FIG. 4. Forest plots comparing improvement of PFDD versus PFDO in treatment of pediatric CM-I for syrinx (A), scoliosis (B), and overall clinical status (C). Figure is available in color online only.

Evaluation of Studies

Quality of Evidence

Based on the GRADE assessment of all studies, the certainty of the evidence and the strength of the data were low in 3 studies^{34,37,64} and very low in the remaining 9 studies.^{14,20,30,33,40,41,44,56,60}

Publication Bias

Funnel plots were generated for each outcome. No significant asymmetry and thus no evidence of publication bias were observed.

Sensitivity Analysis

Leave-one-out sensitivity analyses of all outcomes involving more than 2 studies were performed to assess for cohort size bias (Supplemental Figure). No significant

changes in outcome trend directions were observed after the omission of each study, including the large study by Parker et al.⁴⁸

Discussion

In this meta-analysis, we found that surgical treatment of CM-I in children by PFDD was associated with greater overall clinical improvement, longer hospital LOS, and more postoperative complications (CSF and infection related) compared with PFDO. The likelihood of revision surgery was not significantly different between the 2 approaches. With regard to improvement of syrinx or scoliosis that was present at the time of CM-I diagnosis, PFDD was not inferior to PFDO.

Of most interest in the meta-analysis was the observed greater overall clinical improvement after PFDD com-

pared with PFDO. Caution must be exercised prior to embracing this result, as selection bias introduced by an unstandardized definition and uncontrollable CM-I presentation makes interpretation of validity difficult. Overall clinical improvement represents the symptomatic progress from the presurgery state to the postsurgery state. Patients presenting with more severe symptoms may appear to have a greater overall improvement after surgery than patients who present with fewer symptoms, despite the surgical end point of PFDD and PFDO being the same (i.e., resolution of effective CSF circulation).

It has been recognized that children present for CM-I surgery with a wide variation of symptomatology.⁶⁰ Given that symptomatic presentation has been considered a major indication for duraplasty in the treatment of CM-I in children,^{33,64} greater overall clinical improvement in those treated by PFDD may be an artifact of there being more symptoms to improve. This consideration also concerns the greater proportion of syringomyelia improvement observed after PFDD compared with PFDO, although it is not statistically significant. It has been proposed that duraplasty alleviates tonsillar disturbance and CSF dysfunction, which contribute to syringomyelia.⁴⁵ The lack of statistical significance in this study is likely a result of the low numbers currently reported in the literature.

In addition to the suboccipital craniectomy used in PFDO, PFDD also involves both dural incision and, at the discretion of the surgeon, cerebellar tonsil shrinkage by either resection or coagulation.^{6,32,51,57} This being a more intense approach theoretically would be expected to translate to greater surgical parameters, explaining the demonstrated significant longer stay in hospital after PFDD compared with PFDO. Unfortunately there was insufficient data to analyze the parameter of operating time or establish significance with respect to estimated blood loss. However, 2 of the observational studies^{33,34} reported longer operating times and greater blood loss with the PFDD approach than with PFDO in pediatric CM-I treatment.

The fact that there are more postoperative CSF- and infection-related complications after PFDD than PFDO can also be attributed to the more invasive nature of PFDD. A previous meta-analysis showed that CSF-related complications, including hydrocephalus, CSF leakage, and pseudomeningocele, were observed more after PFDD than after PFDO.¹⁶ The extradural manifestations can be attributed to the disruption of dural integrity in the duraplasty process.⁵⁶ Infection-related complications in this study included infections of the wound and meninges, both proven and aseptic. To date, an investigation of the relationship between infection-related complications and surgical approach has not been conducted, perhaps because of the limited breakdown of complications available in the pediatric literature as well as the appreciation of subtler presentations, in particular, aseptic meningitis.

Rates of revision surgery were comparable between PFDD and PFDO. This is in light of contrasting comparative studies that have found PFDD to be associated with higher^{30,56} and lower^{33,40,60,64} revision surgery rates than PFDO. Unfortunately, the timings of each revision surgery were not ascertainable in this review, which makes interpretation of these results difficult. This is because in-

dications for revision surgery include short-term postoperative complications and long-term failure of symptoms to improve.³⁶ Should either the PFDD or PFDO approach be associated with greater short- and/or long-term indications, the different follow-up times of each study introduce a selection bias into these results. A similar consideration should be made for performance outcome parameters as well, including overall clinical improvement.

Strengths and Limitations

Strengths of this study include an extensive search of the current literature, strict adherence to PRISMA guidelines,³⁹ quality of evidence analysis by GRADE protocol, and assessing the publication bias by funnel plots. Currently, there exists no prospective randomized controlled trial comparing the surgical approaches of PFDO and PFDD in the surgical treatment of pediatric CM-I. Ultimately, the findings of this meta-analysis require confirmation by larger, multicenter, prospective studies with significant follow-up. Until then, this study represents the highest level of evidence concerning this topic.

This review consisted only of low- and very low quality retrospective and prospective observational study articles and abstracts. The lack of surgical approach randomization (e.g., symptomatic versus asymptomatic presentation, presence of any intradural pathology, preference of individual surgeons, and any shifts in their practice over time) in all studies implicates a selection bias that remains to be clarified. Unfortunately, these aspects are difficult to control for, as what is believed to be in the best interest of the patient varies between surgeons and institutions as demonstrated in the number of different responses to a national survey⁵⁰ by the American Society of Pediatric Neurosurgeons in 2011. Although different management algorithms^{33,34} have been proposed, to date there has been no standardized protocol for management or outcome reporting embraced by the pediatric neurosurgery community. To encourage greater homogeneity in outcomes reporting, a CM-I-specific operative outcome measure could be used, such as the Chicago Chiari Outcome Score which has so far only been applied by Lee et al.³³ to pediatric patients.

This meta-analysis was limited by the small cohort size reported in the literature. There were studies in which the population consisted of both pediatric and adult patients. However, to maintain a high degree of applicability for pediatric patients, a number of studies^{3,10,24,29,42,52,65} in which clinical outcomes could not be discerned between the children and adult groups were not included. Excluding these studies could have diminished the significance of further outcomes, such as syrinx and scoliosis improvement, and introduced a greater degree of heterogeneity between studies observed in the outcomes of this study, despite the lack of publication bias. Although the observed heterogeneity does not invalidate the derived conclusions of this study, it does weaken their significance. This can be overcome with larger cohort sizes in the future.

In addition, improvements in syrinx and scoliosis were study dependent, as no consensus definition of improvement in all studies was employed. Due to the subjective nature of what constitutes improvement, these measures have

the potential to skew overall results, which may not truly reflect what is observed in practice. Although a leave-one-out meta-analysis was used to reduce any inconsistency in study design, clarification and implementation of standardized improvement definitions would greatly improve the validity of these results.

Finally, the direct intra- and interstudy comparability between PFDO and PFDD should be carefully considered, as there were a number of potential dependent variables within the reported surgical methodology of the studies. The extent of initial incision for decompression was often generalized to the upper cervical spine only. Although resection of the cervical laminae was mostly limited to C-1 only, resection at C-2 was performed on a case-by-case basis in some studies^{20,37,40,44,64} as well. Furthermore, variation existed in both PFDO and PFDD approaches in terms of additional manipulations, as well as graft types in PFDD. Mottolose et al.⁴⁰ interestingly observed fewer postoperative complications following PFDD compared with PFDO that involved a durotomy component. This is the only study in which all PFDO approaches have included durotomy and potentially suggests that additional techniques with bone decompression can influence postoperative outcomes.

Four studies explicitly acknowledged tonsil shrinkage as a component of their PFDD approach but did not clarify to what extent.^{20,33,40,64} Only Navarro et al.⁴⁴ presented outcome data for PFDD with and without tonsil shrinkage separately. A consequence of this inherent and undiscernible diversity in surgical approach is that it may weaken the derived implications of the meta-analysis. This will be overcome with larger, prospective, randomized studies comparing PFDD and PFDO outcomes in pediatric CM-I, such as a planned and funded multicenter, prospective, randomized controlled trial (NCT02669836; clinicaltrials.gov) in the United States scheduled to have recently commenced recruiting.

Conclusions

Both PFDD and PFDO achieve satisfactory outcomes in the definitive treatment of CM-I in children. This meta-analysis demonstrated that PFDD was associated with greater overall clinical improvement, longer LOS, and more postoperative complications than PFDO. However, rates of revision surgery and improvement in both syrinx and scoliosis were not statistically different between the 2 approaches. Current evidence in the literature comparing PFDD to PFDO in pediatric CM-I treatment is of low to very low quality, limited by inherent selection bias. Future large, prospective registries and randomized controlled trials are required to validate the findings of this study.

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Disclosures

The authors report no conflict of interest concerning the materi-

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Author Contributions

Conception and design: Lu. Acquisition of data: Lu, Phan, Crowley. Analysis and interpretation of data: Lu, Phan, Crowley. Drafting the article: Lu, Phan. Critically revising the article: Lu, Phan, Daniels. Reviewed submitted version of manuscript: Lu, Phan, Daniels. Approved the final version of the manuscript on behalf of all authors: Lu. Statistical analysis: Lu, Phan. Administrative/technical/material support: Lu.

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