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REVIEW ARTICLE

Laryngomalacia: is there an evidence base for management?

C MCCAFFER, K BLACKMORE, L M FLOOD

ENT Department, James Cook University Hospital, Middlesbrough, UK

Abstract

Background: The advent of supraglottoplasty clearly has transformed the surgical management of severe laryngomalacia. The condition, however, generally runs a milder course, with spontaneous resolution the norm.

Objectives: To identify gaps in the knowledge and identify topics for future study.

Method: Systematic review of the literature.

Results: The literature suggests that there is a range of abnormalities leading to the typical collapsing upper airway, and that neurological disease, other airway abnormalities, syndromes and gastroesophageal reflux all contribute to disease severity and influence outcomes. The procedures involved in supraglottoplasty are rarely specified, the indications for surgery are vaguely defined and the role of medical therapy is unclear.

Conclusion: Every review article or survey of opinion suggests that there is still a marked variation in individual practice and a lack of consensus.

Key words: Laryngomalacia; Diagnosis; Surgery; Review, Systematic

Introduction

Surgical procedures are rarely supported by a sound evidence base, but it is human nature to be influenced by personal experience and make assumptions as to efficacy and safety. Systematic reviews in surgery, however flawless the methodology, usually conclude that the evidence sought is sorely lacking and call for further research. However, repeating the exercise after a long interval rarely shows that this call has been heeded.

Common sense may well triumph over the demands of evidence-based medicine (EBM), especially with the ethical and administrative challenges of creating a control group for any surgical intervention. This was memorably illustrated in a humorous and iconoclastic systematic review lamenting the lack of randomised controlled trials to confirm the efficacy of a parachute in preventing death or major trauma in a 'gravitational challenge'.[1] This article concluded that, in such a situation, observational data are surely sufficient, whilst amusingly calling for the protagonists of EBM to participate in a placebo controlled trial. However valid this sensible approach might be, it should not prevent further research into efficacy. Even here, there is still persisting uncertainty about the risks and benefits of: canopy design, the provision of parachutes in passenger airliners, a reserve in military low-altitude combat drops and automatic opening devices.

Advances in technology and understanding of disease have surely transformed the management of many challenging conditions, and it may seem that all questions are answered and there is no scope for further research. Typical is the place of sphenopalatine artery ligation as standard practice in the control of refractory epistaxis. Systematic review of the literature, however, highlights many persisting uncertainties.[2]

Reviews of laryngomalacia generally open by reminding us that it is the commonest cause of congenital stridor; they go on to describe the characteristic appearance of the collapsing laryngeal inlet, and stress that the clinical course is relatively benign with spontaneous resolution the norm. The advent of supraglottoplasty, however ill-defined, led to many a case series or cohort study reporting success in the majority of the few patients deemed to require it, and a perception that this clinical problem is largely solved.

The term 'laryngomalacia' was probably first used by Jackson and Jackson in 1942[3] and does not appear in the Archives of *The Journal of Laryngology & Otology* until 1991.[4] The condition was clearly recognised, however, in the late nineteenth century. Typical clinical findings were nicely described, for the first time in this journal, by Dan Mckenzie in 1919, as 'those seen in congenital laryngeal stridor, in which it is the aryepiglottic folds and lateral walls of the larynx that are sucked inwards'.[5]

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The progressive adoption of endoscopic surgery and especially aryepiglottoplasty has clearly transformed management. The earliest report in this journal (in 1991), of 12 procedures,[4] was followed 10 years later by the same group's results in 100 consecutive patients.[6] Indeed, many systematic reviews attest to efficacy, although based solely on case series, and they, universally, call for further research into gaps in knowledge.

The literature was systematically reviewed to establish an evidence base for our understanding of laryngomalacia and its management, and to identify where further work is needed. The topics addressed include: definition and classification; diagnostic criteria; the overlap with obstructive sleep apnoea (OSA); associated abnormalities and the role of medical therapy; staging of severity and indications for surgical intervention; the natural history of the condition; choice of surgical technique; surgical outcomes and efficacy; and complications of treatment.

Materials and methods

In the preparation of this systematic review, we have followed the guidelines of the Preferred Reporting Items for Systematic reviews and Meta-Analyses for Protocols ('PRISMA-P') 2015.[7]

We assessed the quality of papers using the National Institute for Health and Care Excellence quality assessment tool, as it allows some analysis of case reports and series (lower level evidence).[8] We sought high-quality prospective clinical studies, reviews or laboratory work relevant to the diagnosis, classification, management and prognosis of laryngomalacia.

Medline, Embase and Cochrane Library databases were searched from inception up to March 2017. The following keywords or combinations thereof were used: 'congenital laryngomalacia', 'supraglottoplasty', 'review', 'controlled trial', 'classification' and 'reflux'.

Abstracts, identified from a review of article titles, were evaluated for inclusion by two authors (CM and LMF) working independently, with consensus if opinions differed. Papers were chosen if the abstracts suggested systematic reviews or meta-analyses, prospective controlled studies, or original basic science findings from laboratory studies. Audits and larger case series or cohort studies, especially those offering any comparative study between groups or before and after intervention, provided a lower level of evidence. Papers suggesting algorithms and consensus views for treatment, case reports suggesting complications, and the earliest reports of the procedure were also included.

Abstracts were excluded if they suggested isolated case reports or small, uncontrolled series that presented no new insight. No language restrictions were applied.

Results

We selected and have made reference in the text to the following: 9 systematic reviews;[9–17] 0 randomised controlled trials; 7 non-randomised controlled or comparative studies;[18–24] 33 case series or cohort studies;[25–57] 4 surveys, consensus documents or questionnaires;[58–61] 4 historical articles;[3–6] and 0 case reports.

Discussion

Definition and classification

The classical picture of congenital stridor, as due to a contracting laryngeal inlet on inspiration, is well recognised, but there may be different patterns of collapse, each with its own prognosis. There are a number of systems proposed for classification, suggesting this is still unsettled. Without an agreed, reliable classification, there are challenges to diagnosing, judging the severity and staging the disorder, and difficulties in evaluating outcomes and the effect size for surgical treatment.

Described variants from the typical stridor that develops shortly after birth include episodic, exercise-induced, adult and late-onset laryngomalacia and tracheomalacia. The contribution from neurological disorders and other co-morbidities must be recognised. There may even be a secondary form of laryngomalacia, in which a completely normal larynx only collapses because of excessive negative intra-thoracic pressure, in a child struggling against a supra-laryngeal obstruction. This might occur in bilateral choanal atresia, severe OSA or anterior nasal stenosis. Recognition and treatment of the primary disorder may then be fundamental.

The lack of agreed diagnostic criteria was noted two decades ago by Shah and Whetmore, who commented 'While there is a vast literature on the subject, there is neither stratification nor correlation of clinical presentation, endoscopic appearance, treatment and outcome'.[25] They then devised a form to allow classification, but this was based on a validation exercise conducted on only 10 patients.

A decade later, another system was proposed (still based on a study population of only 10 children, however), dividing laryngomalacia into types 1–3.[26] Type 1 showed a foreshortened or tight aryepiglottic fold, type 2 represented excessive redundant soft tissue in the supraglottis, and type 3 comprised all other causes, most notably neurological disease.

Suggested classifications merely increased in complexity. In a study investigating the outcomes of carbon dioxide (CO_2) laser surgery, laryngomalacia was instead subdivided according to the direction of the supraglottic collapse.[27] Type A represented posterolateral inversion, type B reflected complete collapse and type C represented anterior inversion. Unfortunately, most individuals showed mixed patterns and had to be classified as: group I (type A only), group II (type B or B + A) or group III (type C, C + A or C + B + A), resulting in an unwieldy tool.

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In a retrospective case series, published in 2014, which reviewed the morphological types of laryngomalacia and influence on prognosis, the authors could still state 'Further work is required in validating an existing classification scheme for laryngomalacia or developing a new, validated classification system which may be used for future outcomes research'.[28]

Based on a systematic review and a retrospective cohort study of 85 patients, the Groningen Classification System recognises only 3 typical dynamic (as opposed to anatomical, static) airway changes: type 1 – inward collapse of the arytenoid cartilages; type 2 – medial displacement of the aryepiglottic folds; and type 3 – postero-caudal displacement of the epiglottis against the posterior pharyngeal wall.[9]

Diagnostic criteria

Endoscopy remains the method of choice for diagnosis and staging.

The initial assessment of stridor usually involves fibre-optic endoscopy on an awake patient, as reported in this journal in 2001,[29] when a diagnosis could be made confidently in 80 per cent of 20 subjects, with only 4 requiring rigid endoscopy. A literature review reported many techniques attempting to ensure pacification, whilst reporting personal experience with a further modification.[30]

A blinded study asked 3 observers to compare and score videotapes from awake flexible endoscopy and endoscopy employing anaesthesia or sedation, in 42 children with congenital stridor.[18] The recordings were randomly mixed in with a sequence from normal infants and flexible endoscopy under sedation or anaesthesia. The latter showed 100 per cent sensitivity and specificity, compared with 93 per cent and 92 per cent respectively for awake examination. The awake technique missed three cases of laryngomalacia and misdiagnosed one normal individual as a sufferer. The conclusion was that this was best used for screening, for example to exclude the presence of a congenital supraglottic cyst, or for milder typical cases.[18] Flexible endoscopy is frequently combined with rigid bronchoscopy under general anaesthesia, especially seeking sites of multilevel obstruction in those most at risk (see below), but we could find no studies assessing the added benefit.

Airway fluoroscopy certainly did not contribute any added benefit to endoscopy, showing poor sensitivity and specificity, and poor predictive values.[31]

In a typically retrospective study of the airway findings of 130 patients with a laryngomalacia diagnosis, combined posterior and anterior supraglottic collapse was the most common finding (31 per cent).[32] Posterior collapse alone occurred in 25 per cent of patients, anterior collapse in 14 per cent and lateral collapse in 10 per cent. Twelve per cent of patients had all three sites of collapse. Forty-one per cent of patients had a secondary airway lesion, with tracheomalacia being the most common. Prematurity showed a statistically significant increased risk of reflux and multiple sites of collapse.[32]

Obstructive sleep apnoea and laryngomalacia

The relationship of laryngomalacia to OSA has very recently attracted some studies with the highest level of evidence. In that rarity, a prospective cohort study of children with established OSA, polysomnography did not prove of value in determining the severity of laryngomalacia, did not correlate with the clinical impression and, alone, did not predict the need for surgery.[33] Of 25 infants (mean age, 3.9 months), all presented with OSA as determined by polysomnography, but only 80 per cent underwent supraglottoplasty. The apnoea-hypopnea index did not correlate with a high laryngomalacia severity score, nor did it differ between those undergoing surgery and those managed conservatively.[33]

Site of obstruction identification is fundamental in surgical planning for OSA. A systematic review of a much older paediatric population extracted data from 24 articles (960 subjects) and found that most institutes employed drug-induced sleep endoscopy and cine magnetic resonance imaging.[10] It concluded that the evidence for relevance to outcomes was generally extremely limited, but that lingual tonsillectomy and supraglottoplasty were notable exceptions. UK practice would reserve sleep nasendoscopy for refractory OSA; a pre-operative cardiorespiratory sleep study or formal polysomnography are more routinely employed. A systematic review of polysomnography findings in patients with OSA and laryngomalacia identified only four studies meeting the inclusion criteria.[11] Meta-analysis showed improvement after supraglottoplasty, but there was a high level of some residual disease (88 per cent of 33 children). Four studies showed an improved apnoea-hypopnea index, with a drop of a mean of 12.5 points. Oxygen saturations improved from the nadir level by a mean of nearly 10 per cent.[11]

Similar findings, inevitably perhaps, resulted from a simultaneous systematic review which had included 13 studies for analysis.[12] That study investigated 64 patients with sleep exclusive laryngomalacia and 74 patients with congenital laryngomalacia, to judge the efficacy of supraglottoplasty in correcting the apnoea-hypopnea index and lowest oxygen saturation scores. For the latter group, meta-analysis showed an apnoea-hypopnea index decrease from a mean of 20.4 to 4 events per hour after surgery, and improved lowest oxygen saturation from a mean of 74.5 to 88.4 per cent. Again, complete cure was a rarity (26.5 per cent).[12]

Remarkably, a third systematic review was published in the same year (2016), again to review changes in sleep parameters after supraglottoplasty, but also to determine prognostic factors for success.[13] Now 11 studies met the inclusion criteria and again showed a statistically significant reduction of apnoea-hypopnea index of 8.9 events per hour and an increase in

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minimum oxygen saturations of 3.7 per cent. Cure (defined as an apnoea-hypopnea index of less than 1 event per hour) was only seen in 28 per cent. Supraglottoplasty, whether as a primary treatment (in the younger children) or secondary to other surgery, showed similar outcomes. Equally, the presence or absence of co-morbidities did not affect the chance of cure (25 per cent *vs* 21 per cent).[13]

Central sleep apnoea associated with laryngomalacia has attracted less investigation. A retrospective study of central sleep apnoea (defined as central apnoea index of 5 or more), conducted on 54 patients (mean age, 3.4 months), showed a prevalence of 46.3 per cent.[34] It was suggested that the highest risk was in those with neurological disease, hypotonia or syndromes, prematurity, and age less than three months. However, none of the factors identified proved statistically significant, which might represent a type II error and small sample size.[34]

Other associated abnormalities

The prevalence of gastroesophageal reflux in association with laryngomalacia, its influence on outcomes and the value of medical management has attracted much debate, but less at a high level of evidence. Expert opinion, (level 5) as shown by the recent International Pediatric Otorhinolaryngology Group consensus document, concludes that 'there is great variation in practice amongst the current group members' in the management of associated reflux.[58]

A systematic review of eight articles did conclude that endoscopic findings suggestive of reflux (arytenoid and posterior glottic oedema, vocal fold oedema, and lingual tonsil hypertrophy) were more common in laryngomalacia and subglottic stenosis.[14] A systematic review investigating an association between laryngomalacia and reflux reviewed 27 studies, and performed a meta-analysis on 6.[15] The findings suggested a prevalence of 59 per cent based on dual probe pH monitoring, but this was not statistically significantly greater in laryngomalacia than in other respiratory diagnoses. The authors noted greater reflux, indeed a 10-fold increase, in the more severe cases of laryngomalacia. Response to anti-reflux therapy was based on weak and inconsistent evidence, and benefit was generally apparent only after six months of therapy, possibly just reflecting the natural history towards recovery. Any histological evidence was of only mild laryngeal inflammation. Although reporting a co-existence, the authors concluded that any causal association lacks an evidence base and called for a randomised controlled trial of anti-reflux therapy against placebo.[15]

A survey of USA, Canadian and UK practice examined the management of reflux associated with severe laryngomalacia requiring surgery.[59] Of 101 respondents, only 89 per cent would treat for reflux, 54 per cent with proton pump inhibitors only and 41 per cent just with H_2 blockers. An empirical approach is suggested by the International Pediatric Otorhinolaryngology Group consensus, recommending anti-reflux therapy if the child has feeding and/or respiratory difficulty, but to 'consider observation' if respiratory symptoms are mild and the child shows good weight gain.[58] Persistence of symptoms despite maximal reflux suppression requires the exclusion of an underlying neurological abnormality. The authors reported that H_2 antagonists are better tolerated than proton pump inhibitors by infants, and that the latter lacks Food and Drug Administration approval for this indication. Some would favour a 'step-down approach', employing both approaches and dropping one at the earliest opportunity; others, the reverse.[58]

Swallowing dysfunction was studied in a large retrospective cohort analysis of 324 patients with laryngomalacia.[35] Gastroesophageal reflux was again noted in a high proportion, 69.8 per cent, but also dysphagia in 50.3 per cent and failure to thrive in 9.6 per cent. Nonetheless, there was no significant relationship between laryngomalacia severity and swallowing abnormalities, whether on symptoms, clinical swallowing evaluations by speech and language pathologists, modified barium swallow studies, or fibre-optic endoscopic evaluation of swallowing. Indeed, their experience of the rate of abnormal findings on such studies, irrespective of obvious clinical symptoms, led to a recommendation that all infants with laryngomalacia undergo dysphagia assessment.[35]

The literature tends to concentrate on the influence of such recognised associations as reflux, neurological disease, syndromes and other airway abnormalities on prognosis and surgical success, rather than on their prevalence.

A study of 201 infants with varying laryngomalacia severity sought evidence of secondary airway lesions, and found 104, a higher number than expected.[36] Subglottic stenosis was found in just over one-third of cases, with a similar rate for tracheomalacia. Secondary airway problems were more prevalent in severe laryngomalacia (79 per cent) than in mild laryngomalacia (28.8 per cent), and, in the mild to moderate cases, they significantly increased the need for surgery. Infants with secondary airway problems were far more likely to have reflux than those without (84.6 per cent *vs* 45.4 per cent; $p < 0.0001$).[36]

In the reverse process, a study of 139 children with congenital tracheoesophageal fistula and/or oesophageal atresia investigated the rate of associated airway disorders.[37] Laryngomalacia was the least prevalent disorder (4.3 per cent), compared with subglottic stenosis (12.9 per cent), vocal fold paralysis (21.6 per cent) or laryngeal cleft (25.9 per cent). The commonest associated airway abnormality proved to be tracheomalacia (37.4 per cent).[37]

Edmondson *et al*. suggested that the vast majority of children reported in such cases series are Caucasian, and the results may not apply to a more ethnically diverse population, such as seen in the Bronx,

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New York.[38] Their small series of 78 children with laryngomalacia was dominated by Afro-American and Hispanic subjects, with only 4 Caucasians. Certainly, their experience contrasts with the literature, with 18 premature births and 21 low birth weights. Twenty-eight per cent of patients had a neurological abnormality and 30 per cent underwent surgery. Whether these findings truly relate to genetic rather than socio-economic factors must be questioned.[38]

Staging of severity and indications for surgery

In a condition that generally presents mild systemic upset, and where the natural tendency is towards spontaneous remission, indications for surgery are fundamental to evaluating outcomes. A low threshold for intervention will surely select many whose natural history was to recover, artificially boosting apparent success rates.

A particularly interesting consensus document surprisingly largely overlooks this decision.[58] The authors repeatedly note 'variation in practice' amongst the membership throughout the text. Of 21 questions tabled for consensus, no fewer than 12 are qualified by the word 'consider'.[58]

Indications for surgery are subjective and rarely documented, centring on the worsening of an ill-defined variety of airway symptoms (especially cyanosis and apnoeic episodes), feeding difficulties and failure to thrive.[59]

Natural history of condition

There is little doubt that the vast majority of laryngomalacia cases settle spontaneously by 12–18 months of age, and are probably cared for by paediatricians and so never referred to surgeons, as is reflected in the ENT literature.

Typical of such reports is a retrospective study of 120 consecutive patients with laryngomalacia, over a 4-year period.[39] In that study, 115 cases resolved without surgery, at a mean age of 7.6 months, and only 5 patients required supraglottoplasty.

A recent systematic review addressing the natural history in otherwise healthy infants could only identify 3 papers (411 patients), all retrospective, which met the study inclusion criteria.[16] Eighty-nine per cent of cases 'resolved' (i.e. were free of stridor) over a period ranging from 4 to 42 months. The authors suggested that, with such a low level of evidence, 'Prospective longitudinal trials are required to better understand the natural history'.

Clearly, few studies compare the natural history or best medical management with surgical outcomes. Largely using growth and thriving as outcome measures, rather than the airway, a case–control comparison of 51 infants with moderate to severe congenital laryngomalacia compared supraglottoplasty, in 17 cases, with medical management (acid suppression therapy, speech and swallowing therapy, and/or high-calorie formula), in 34 matched controls.[19] The absence of randomisation of course does suggest the risk of selection bias; however, no difference in growth was actually observed between the two groups. The conclusion could only be that 'Medical management and close observation … may be a viable alternative to supraglottoplasty in appropriately selected infants'.[19]

A similar retrospective study, of 89 patients, compared outcomes of supraglottoplasty with those of a wait-and-see policy, and considered the influence of co-morbidities.[20] Unsurprisingly, surgery was associated with a statistically significant faster resolution of symptoms than conservative management (5 weeks *vs* 29 weeks; $p = 0.026$), and synchronous airway lesions further prolonged symptoms. The authors found supraglottoplasty to be safe and effective in severe laryngomalacia, but did concede that 'the indication for surgery is not firmly established yet'.[20]

The effect of laryngomalacia on quality of life has been studied prospectively in a study using a questionnaire survey of 26 families of infants aged less than 1 year.[60] It compared responses for the 11 infants managed medically and the 15 infants who underwent supraglottoplasty, both before and after treatment. Both groups showed a statistically significant improvement over the presenting findings after a three-month interval. Unsurprisingly, those destined to undergo surgery showed higher scores at presentation, but ultimately there was no difference in quality of life scores between the surgically and conservatively managed infants.[60] A similar, but larger study (72 patients) showed that parents' perception of their child's health was particularly influenced by the degree of aspiration and penetration.[61]

Surgical techniques

There is a notable lack of detailed description of the surgical measures involved in what is termed 'supraglottoplasty' in most publications. Operative abnormalities to be addressed in such surgery include shortened aryepiglottic folds, a retro-positioned epiglottis, and excess and prolapsing arytenoid mucosa. The solution is generally some combination of division of the aryepiglottic folds, ablation of excess mucosa and anterior suspension of the epiglottis.[40]

A recent review of a 14-year experience of 79 patients undergoing laser supraglottoplasty showed limited success for those with postero-caudal displacement of the epiglottis, and for those with synchronous airway lesions, associated co-morbidities and prematurity.[41] A study comparing such rigid endoscopic methods in 27 patients, with a flexible potassium titanyl phosphate laser delivery system in a subsequent 30, suggested similar benefits, but obvious advantages for convenience and cost-effectiveness.[21]

Concerns about potential hazards of supraglottoplasty, especially stenosis, have led some to consider staged surgery, operating on one side and then the second if needed. An early UK study retrospectively

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compared the results of bilateral and unilateral supraglottoplasty in 106 paediatric patients with severe laryngomalacia.[22] Although selection bias seems inevitable in the absence of randomisation, it is notable that they reported a success rate of 95.7 per cent and a reduced risk of stenosis in the 47 patients who underwent unilateral surgery. Only seven patients in this group (14.9 per cent) required a second contralateral procedure, and the authors concluded that this 'seems to be a reasonable option'.[22]

More recently, a much smaller study ($n = 15$ infants) compared outcomes for unilateral (73 per cent resolution) or staged surgery (100 per cent response), with historical controls taken from the literature.[23] This study found that a second procedure was needed in 40 per cent of patients, but concluded that 'Staged supraglottoplasty appears to be an effective, low-risk method to treat severe laryngomalacia'.

Most descriptions of operative modifications, or procedures with new surgical tools, lack any comparative trials, involve retrospective studies and present small series. Typical is a study of microdebrider-assisted supraglottoplasty, the largest series to describe this, but comprising only 28 patients.[42] Coblation® is recorded as used by a small minority,[59] but without any reports of outcome.

Post-operative care

A retrospective chart review of 65 patients with severe laryngomalacia undergoing supraglottoplasty suggested a very favourable course immediately post-operatively.[43] Only three patients required more than a single overnight stay, and all returned from the operating theatre extubated. In over three-quarters of patients, normal oral intake was possible within 4 hours of surgery.[43]

An international survey of practice showed marked variation; however, there was almost universal consensus on steroid use intra-operatively, but only 23 per cent administered antibiotics.[59] The level of post-operative care was significantly ($p = 0.009$) associated with familiarity with procedure. Those performing the highest numbers of procedures annually were least likely to continue intubation and admit to intensive care.[59] A retrospective study of 223 patients undergoing supraglottoplasty showed that 25 (11.2 per cent) required intensive care, with intubation, ventilation, racemic adrenaline or high levels of oxygen therapy.[44] Predictors for this need, generally identified within 4 hours of surgery, were surgical duration longer than 30 minutes, non-Caucasian race and pre-operative gastroesophageal reflux, all proving highly statistically significant.[44]

Surgical outcomes and efficacy

The generally favourable results of supraglottoplasty dominate the literature on laryngomalacia. An often-cited systematic review of surgery outcomes in practice concentrated more on causes of failure, but was compromised by the paucity of high-level evidence.[17] Only 8 studies met even the generous inclusion criteria and all were level 4 case–control series. There were no prospective controlled trials to evaluate. Surgical failure, specified by the review as the need for tracheostomy, gastrostomy or revision surgery, was increased by the presence of co-morbidities (particularly ill-defined in the articles studied). Compared with isolated laryngomalacia, those with co-morbidities showed a risk ratio of 7.14 for surgical failure and of 4.33 for post-operative aspiration (the latter calculation based on data from only three studies). There were insufficient data to correlate outcomes with: age at surgery, technique employed or even laryngomalacia severity. Understandably, the review concluded that 'Randomized, prospective studies with well-defined protocols appear to be necessary to further stratify the risk of failure by the specific medical comorbidity and/or surgical technique used'.[17]

Subsequent retrospective studies continued to review personal experience and prove contradictory. One of the larger studies (comprising 148 patients undergoing supraglottoplasty, but only 115 with available case notes to analyse) showed a significant association between a delayed post-operative diagnosis of neurological disorder and surgical failure ($p < 0.001$).[45]

An earlier study obtained data from 74 of 95 children undergoing supraglottoplasty.[46] Reporting a 16 per cent failure rate, the authors found that, after analysing neurological disorder, age at surgery, cardiac disease, other airway problems, syndromes and so on, only prematurity (less than 34 weeks gestation) proved an independent risk factor (odds ratio = 4.85).[46] Concentrating just on infants and children (over 1 year of age) with either a syndromal or neurological co-morbidity, a study of 54 patients (23 syndromal and 31 neurological) reported an overall success rate of 67 per cent for supraglottoplasty.[47] For infants, the two groups showed similar outcomes (67 per cent and 69 per cent) for supraglottoplasty, which was largely driven by acute airway obstruction. For those aged over one year, where such surgery was instead driven by OSA, the neurological group did better (50 per cent *vs* 78 per cent).[47] The same authors, analysing 325 patients under 1 year of age and free of co-morbidities, could then evaluate the influence of prematurity on surgical results.[48] In that study, 136 term and 40 pre-term infants showed no difference in success rates (92.7 per cent and 90 per cent). Prematurity was associated with a higher rate of secondary airway lesions, and dysphagia was significantly worse both pre- and post-operation in those of gestational age of less than 32 weeks.[48]

A relatively small but unique study of patients with Down syndrome ($n = 18$) and laryngomalacia investigated the results of supraglottoplasty performed at a mean age of 7.7 months.[49] Nearly half of the patients did require subsequent further surgery such as adenotonsillectomy. Of this small group, two

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patients subsequently required tracheostomy, two required nasogastric feeding and two required revision supraglottoplasty, illustrating the greater challenge involved.[49]

Few studies consider objective measures of benefit, instead concentrating on predictors of compromised surgical results. A case–control study compared a series of growth curve measurements of body weight for: 15 patients with laryngomalacia who were merely observed, 71 patients with laryngomalacia who received medical treatment and 29 who underwent surgery.[24] Clearly the groups were highly selected, and the surgical group showed significantly lower scores at presentation, but with significant improvement by three months post-surgery. After 12 months, all groups showed values close to the mean.[24] An analysis of patient records studied catch-up growth in just those undergoing supraglottoplasty.[50] Seventy-six patients had height, weight and body mass index measurements pre- and up to nine months post-surgery. Most gain was seen in the first six months and, unsurprisingly, was greatest in those who were youngest and smallest at the start.[50]

It is likely that the commonest surgical approach to laryngomalacia, in the UK, is still the cold steel division of the aryepiglottic folds. As we have seen, there are no studies providing high-level evidence to suggest that any other technique is superior in isolated laryngomalacia, without co-morbidities.

Complications of surgery

Complications of supraglottoplasty are few, but include reports of new onset or worsening of aspiration and stenosis. Any review of safety must include the lowest levels of evidence, even isolated case reports. However, a systematic review of surgical outcomes, based on three studies satisfying the inclusion criteria, confirmed an increased risk of post-operative aspiration for those patients with associated co-morbidities (risk ratio = 4.33) when compared to those without.[17] A lack of data prevented evaluation of the significance of age at surgery or technique used.

In a retrospective review of 468 patients, most aged 28 days to 2 years, 10 per cent experienced aspiration after supraglottoplasty, an association not found to be statistically significant.[51] The risk of aspiration was positively correlated with: an age of less than 18 months, revision surgery, any underlying neuromuscular abnormality and the need for post-operative gastrostomy (presumably only to be expected, as required by aspiration rather than promoting it).[51] Analysis excluding the patients with neurological co-morbidities reduced the aspiration risk to 5.8 per cent.

Most such reports will represent a surgical failure to correct swallowing difficulties, rather than causing or worsening them, as few studies objectively exclude swallowing disorders prior to surgery. The same authors, in a much larger study (2360 children's records), wisely then excluded from analysis those experiencing obvious aspiration before surgery, and found that post-operative risk increased with degree of prematurity (5.9 per cent, odds ratio = 2.3).[52]

A retrospective review reported on a 5-year experience of 50 infants (mean age of 4.5 months) with severe laryngomalacia who required cold steel supraglottoplasty and maximal reflux suppression.[53] None of the infants developed aspiration *de novo*, as shown on fibre-optic endoscopic evaluation of swallowing and laryngopharyngeal stimulation testing. Pre-operatively, laryngeal penetration was seen in 88 per cent, and aspiration beyond the vocal folds was observed in 72 per cent. Post-operatively, these conditions resolved in 81.8 per cent and 86.1 per cent respectively. Failure was universally associated with co-morbidities such as congenital heart disease, syndromes or neurological abnormality.[53]

An unexpectedly higher rate of aspiration, but a tendency to resolve by a mean of 6 months, was noted in a study reviewing bilateral CO_2 laser supraglottoplasty in 52 infants.[54] All infants underwent a post-operative swallowing evaluation and videofluoroscopy. Initial aspiration rates of 20 out of 52 (37 per cent) post-operatively contrasted with 9 out of 52 prior to surgery. Of the latter group, eight patients continued to aspirate after surgery and seven required gastrostomy (all with neurological co-morbidities).[54] The same research group retrospectively compared 39 patients undergoing either CO_2 laser ($n = 21$) or cold steel supraglottoplasty ($n = 18$).[55] The rates of new onset aspiration were 56.3 per cent and 30.8 per cent respectively, but this difference did not achieve statistical significance, and the problem was temporary and easily controlled.

A similar retrospective study did exclude all those with pre-operative swallowing difficulties, to investigate 24 children undergoing supraglottoplasty using a variety of techniques.[56] Unfortunately, only 17 children underwent post-operative swallowing evaluation, but 6 out of 17 did now show swallowing dysfunction. All responded to dietary modification, positioning and anti-reflux management, and showed significant recovery by four weeks.[56] The very limited numbers did not allow any analysis of the relative risks of the various techniques.

A similar favourable long-term outcome was reported in a review of 75 infants following bilateral supraglottoplasty, of whom 48 had no co-morbidities.[57] Of the latter, 46 out of 48 infants had unchanged or improved oral intake. The two infants experiencing a worsening showed a return to normal oral intake by two months. Of the less fortunate infants, with co-morbidities, 22 per cent required dietary modification, nasogastric tube feeding or gastrostomy.[57]

Conclusion

The evidence for the efficacy and safety of supraglottoplasty in the management of severe laryngomalacia is sound, if based on limited quality data. High-quality research data prevent many treatment issues from

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being addressed. The role of reflux and the place of maximal suppression therapy need high-level evidence from well-designed prospective clinical trials. An accepted classification or grading of severity system for laryngomalacia is essential to determine the need for and choice of surgery, and to compare results. Indications for surgery should be clearly stated in cohort studies and case series. Future studies must specify precisely what surgery was performed when describing 'supraglottoplasty'. Outcomes should provide objective data and be compared with the natural tendency for resolution. The influence of co-morbidities, and of more racially, ethnically and/or socioeconomically diverse study populations, should be clarified.

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Address for correspondence:
Mr Liam M Flood,
ENT Department,
James Cook University Hospital,
Marton Rd, Middlesbrough TS4 3BW, UK

E-mail: Liam.flood@nhs.net

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