BMJ Paediatrics Open

Surgical management of neuromuscular scoliosis in paediatric patients: experiences from a tertiary centre multidisciplinary team

Faris Khan,[1] Anas Khan ,[2,3] Lucy Chinnery,[1] Jake Loveridge,[1] James Zhang,[1] Theofilos Polychronakis[4]

To cite: Khan F, Khan A, Chinnery L, *et al*. Surgical management of neuromuscular scoliosis in paediatric patients: experiences from a tertiary centre multidisciplinary team. *BMJ Paediatrics Open* 2025;**9**:e002456. doi:10.1136/bmjpo-2023-002456

► Additional supplemental material is published online only. To view, please visit the journal online (https://doi.org/10.1136/bmjpo-2023-002456).

FK and AK contributed equally.

FK and AK are joint first authors.

An earlier draft of this work was presented at the British Paediatric Respiratory Annual Meeting 2022 under the title of 'Role of comorbidities in the management of neuromuscular scoliosis (NMS): a single centre experience'. The abstract for this presentation is published in the British Medical Journal (BMJ) Archives of Disease in Childhood.

Received 15 December 2023
Accepted 2 February 2025

For numbered affiliations see end of article.

Correspondence to
Faris Khan; fk317@cam.ac.uk

ABSTRACT

Background Management of neuromuscular scoliosis (NMS) is challenging, with both surgical and conservative options involving risks. This study aimed to evaluate multimorbidity in patients with NMS and how this influences multidisciplinary team (MDT) decisions as well as postoperative outcomes.

Methods A retrospective cohort study of patients referred for assessment by the scoliosis MDT in the 8-year period between 2013 and 2021 from a single tertiary centre.

Results 84 patients with NMS were referred for assessment to the MDT. The most common underlying cause of NMS was cerebral palsy (51%). The MDT recommended surgery for 60 patients and 24 were conservatively managed. There were no significant differences in age, sex, body mass index or baseline Cobb angle between the two groups. Patients recommended surgery had fewer comorbidities (2.3 vs 3.5, p<0.05) and greater Cobb angle progression in the 18 months prior to MDT decision (22° vs 8°, p<0.05). No single comorbidity significantly influenced the MDT decision. Of the 48 patients that proceeded with surgery, immediate postoperative complications were documented in 54.1%, with no mortality. The most common complications were postoperative anaemia and respiratory infections. Multivariate logistic regression identified the use of non-invasive ventilation, forced vital capacity <70% of predicted and full-time wheelchair use as significant predictors of immediate postoperative complications. Improved posture was the most common long-term outcome (41.7%) and 81.3% of patients reported no complications at 12 months following their surgery.

Conclusions Multimorbidity in children with NMS influences scoliosis MDT decisions, alongside factors such as scoliosis curve progression. Immediate postoperative complications were common but longer term outcomes were favourable for most patients. Further research aiming to better inform shared decision-making, improve surgical selection and ultimately enhance the quality of life for patients with NMS is required.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Management of neuromuscular scoliosis (NMS) poses complex challenges for patients, their families and clinicians, with limited published recommendations available.

WHAT THIS STUDY ADDS

⇒ This study focuses on children and young people with NMS to understand factors that impact multidisciplinary team (MDT) decisions and what the short- and long-term outcomes are for those who undergo surgery.

⇒ Factors typically considered by the MDT included age, underlying disease, curve progression, symptoms, baseline respiratory function, expected outcomes (pain control, improved posture) and patient and family wishes.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Immediate, postoperative complications are more common in children who are overweight, have significant lung function impairment, use non-invasive ventilation at home, have a tracheostomy, use a wheelchair full time or have a history of hip surgery.

⇒ Long-term outcomes after scoliosis surgery are generally good, particularly in improving pain and posture. The effect of scoliosis surgery in respiratory function and survival is not clear.

⇒ Management of NMS in children requires a personalised approach and informed shared decision-making between professionals, children, families and carers, as recommended by the National Institute for Health and Care Excellence.

INTRODUCTION

Neuromuscular scoliosis (NMS) presents as a clinical complication in children with a variety of medical conditions experiencing impairments of muscle control. These conditions may range from neuromuscular weakness, such as Duchenne's muscular dystrophy, to diseases of the central nervous system, such as cerebral palsy and other neurodevelopmental and genetic disorders.[1] Compared with idiopathic scoliosis (the most common type of spinal deformity), NMS is associated

with significant morbidity and often an unfavourable prognosis.[1] If left untreated, scoliosis can contribute to progressive restrictive lung disease, chronic back pain, poor posture and diminished self-esteem.[2 3]

Management of patients with NMS is challenging due to the often high number of comorbidities and must strike a careful balance between reducing discomfort (eg, through improved sitting posture) and the risk of complications associated with spinal surgery.[4 5] Currently, the mainstay non-surgical strategy for managing NMS is bracing. While bracing can improve sitting position in some patients, its effect on curve progression is minimal, acting primarily as an external support for balance.[1] As such, surgical intervention is regarded as the definitive management. Published outcomes of scoliosis surgery report high patient satisfaction rates and improved quality of life, but its effect on lung function remains an area of ongoing research. Some studies indicate lung function improvement at long-term follow-up, while others report no significant change or even a decline in lung function after surgery. Moreover, these procedures come with risks and limitations, such as postoperative mobility constraints.[6–11]

The decision to proceed with scoliosis surgery is also challenging for the patients' parents and carers. Pain level, quality of life and return to physical activities postoperatively are a common concern.[12] The postoperative recovery period is demanding for the parents because of high level of anxiety and uncertainty about long-term outcome.[13] It is important to manage parents' stress as this can have a direct impact on their child's physical and mental well-being.[14] It is essential that parents and guardians are actively involved in the decision-making process.

A multidisciplinary team (MDT) typically makes the decision to recommend surgery or opt for a conservative approach.[15] The composition of these teams varies across centres and may include specialists such as spinal surgeons, musculoskeletal physiotherapists, scoliosis nurse specialists, paediatric anaesthetists, paediatric respiratory physicians, dietitians, paediatric neurologists, gastroenterologists and community-based clinicians. Publishing evidence on how MDTs make decisions could offer valuable insights for patients and their families regarding the risks, benefits, indications and potential complications of surgery. This knowledge could ultimately lead to improved quality of care for patients and their families.[16]

This study aims to analyse multimorbidity in patients with NMS, and how this influences MDT decision regarding their suitability for surgical management, and postoperative outcomes, using data from a single specialist centre.

METHODS

Study design

We conducted a retrospective cohort study of all patients with NMS assessed by the scoliosis MDT at Addenbrooke's Hospital, Cambridge, UK, a specialist regional centre for the management of childhood scoliosis.

The MDT comprises spinal surgeons, responsible for assessing disease severity, surgical risks and leading postoperative care, and paediatric anaesthetists responsible for assessing suitability for general anaesthesia. Consultant paediatricians assess patients' medical risks and comorbidities. Radiologists and neuroradiologists provide insights on imaging, including spinal radiographs and MRIs. Finally, specialist scoliosis nurses, physiotherapists and community-based professionals, who have prior interactions with the patient and family, represent the family's preferences and contribute to long-term care and follow-up.

Electronic patient records within the 7-year period from 1 January 2013 to 31 December 2020 were analysed, adhering to the Strengthening the Reporting of Observational Studies in Epidemiology checklist during methodology design and result analysis.[17] The study encompassed all patients with a confirmed diagnosis of NMS who were subsequently assessed by the MDT regarding the decision to proceed with either spinal fusion surgery or magnetic rod placement. Patients were excluded from the study if they had a diagnosis inconsistent with NMS, lacked a recorded MDT decision or did not fall within the 8-year period between 2013 and 2021. The electronic medical records system at the tertiary centre began in 2013, and the data were collected to include MDT decisions up to July 2021.

Data collection and sources

Medical records and radiographic data for all patients were reviewed. Demographic patient information included neuromuscular condition, gender, age, weight, height, and body mass index (BMI), previous brace use, lung function tests, mobility status and sleep study data. A BMI<20 kg/m^2 was considered underweight, 20–25 normal, 25–30 overweight and >30 obese. Comorbidities were identified by review of medical records and were divided into general and respiratory comorbidities. General comorbidities included percutaneous endoscopic gastrostomy feeding; nil by mouth; epilepsy; developmental delay; and previous hip surgery. Respiratory comorbidities included recurrent respiratory tract infections (RRTIs); premature birth (gestation less than 37 weeks); requirement for non-invasive ventilation (NIV) at home; tracheostomy; sleep disordered breathing; and forced vital capacity (FVC) less than 70% of predicted for height (FVC<70%) using lung function equations which were at the time recommended.

The radiographic parameters included in the analysis were derived from an independent review of the patients' records and included primary curve magnitude and location at the time of MDT decision, as well as curve magnitude 6, 12 and 18 months before MDT decision. All Cobb angle measurements were provided by a radiologist. A progressive curve was defined as an increase of more than 10° within a 12-month period.

Surgical details, including the type of surgery, the spinal levels involved and estimated blood loss, were also collected. Intraoperative blood loss was recorded both in absolute terms and as a percentage of body weight.

Immediate postsurgery outcome data were gathered and comprised the length of stay (LOS) in the paediatric intensive care unit (PICU), patient-controlled analgesia use duration, time until mobilisation, duration until urinary catheter removal and the total hospital LOS. Immediate postoperative complications were categorised into bleeding, urinary tract infection (UTI), respiratory infection, shock, acute kidney injury and surgical site infection (SSI). We defined immediate postoperative complications as those that occurred prior to a patient's discharge from the hospital following surgery up to a maximum of 30 postoperative days. Bleeding included any post-op bleeding that required transfusion. Long-term outcomes included qualitative benefits and complications reported by patient or family at follow-up at 6–12 months following operation.

Data analysis

Patients were classified based on the decisions made by the MDT, specifically, whether surgery was offered, or conservative approach was recommended. T-test, χ^2 test and correlation coefficients were used to analyse the various clinical variables where appropriate. Among the patients who underwent surgery, logistic and linear regression was performed, and results presented as ORs and effects on mean. To maintain consistency, a single individual collected all data, which were then reviewed by a second person for verification. All statistical analyses were conducted in R (V.4.3.1).[18] P values ≤0.05 were considered significant.

Patient and public involvement

No patient was involved.

RESULTS

Baseline characteristics

A total of 84 patients with NMS were reviewed by the MDT within the 7-year period matching the inclusion criteria (table 1). The underlying cause of NMS included 43 (51%) patients with cerebral palsy, 14 (17%) patients with neuromuscular disease and the remaining 27 (32%) patients had another underlying cause (online supplemental information 1).

For patients with NMS, the mean age at MDT decision was 13.1 years and 48 (57.8%) patients were female. Scoliosis curve locations were either thoracic (24%), thoracolumbar (39%), lumbar (24%) or a double s-shaped curve (13%). The mean number of comorbidities was 2.6. The single most common comorbidity in this group was RRTIs, present in 36 (43%) patients.

MDT decision

The MDT decision-making process, documented in a standardised MDT outcome proforma (online supplemental information 2), considered factors such as underlying diagnosis, surgical and medical risks and age. Key investigations included MRI, spinal radiographs and pulmonary function tests. Patients underwent a comprehensive medical review, typically by a respiratory paediatric consultant, to evaluate risks, including the likelihood of postoperative ventilation. MRI, routinely reviewed by a neuroradiologist, assessed for syrinx, Chiari malformations or other abnormalities. Other factors such as degree of disability, nutritional status, functional reserve and skin condition were also evaluated. Although patients or families were not present at the MDT, their preferences were considered and documented. Before the MDT decision, patients and families had the opportunity to discuss the risks and benefits with a member of the MDT, and while some families chose to decline surgery,

Table 1 Baseline characteristics and outcomes of patients included in the study

	All patients n=84	Offered surgery n=60	Conservative management n=24	P value
Age, years	13.1±0.8	13.1±1.0	13.6±1.3	0.55
Female, %	57.8	57.6	58.3	0.95
Weight, kg	38.7±2.9	38.6±3.3	38.8±6.0	0.85
BMI centile	51.4±8.7	49.9±9.9	55.8±18.3	0.59
Cobb angle, °	75.4±4.4	76.9±4.4	71.7±10.8	0.39
Total comorbidities, n	2.6±0.3	2.3±0.4	3.5±0.5	<0.05
General comorbidities, n	1.7±0.2	1.6±0.3	2.2±0.4	<0.05
Respiratory comorbidities, n	0.9±0.2	0.7±0.2	1.3±0.3	<0.05
Change in curve*, °	15 (6–36)	22 (10.5–38.5)	8 (1.5–14)	<0.05

Values reported as mean±SD, unless otherwise stated.
P value represents two-tailed t-test result between groups offered surgery and not offered surgery.
*Change in curve refers to the absolute change in Cobb angle (as reported based off radiographic data) in the 12–18 months before multidisciplinary team (MDT) decision and is reported as median (IQR).
BMI, body mass index.

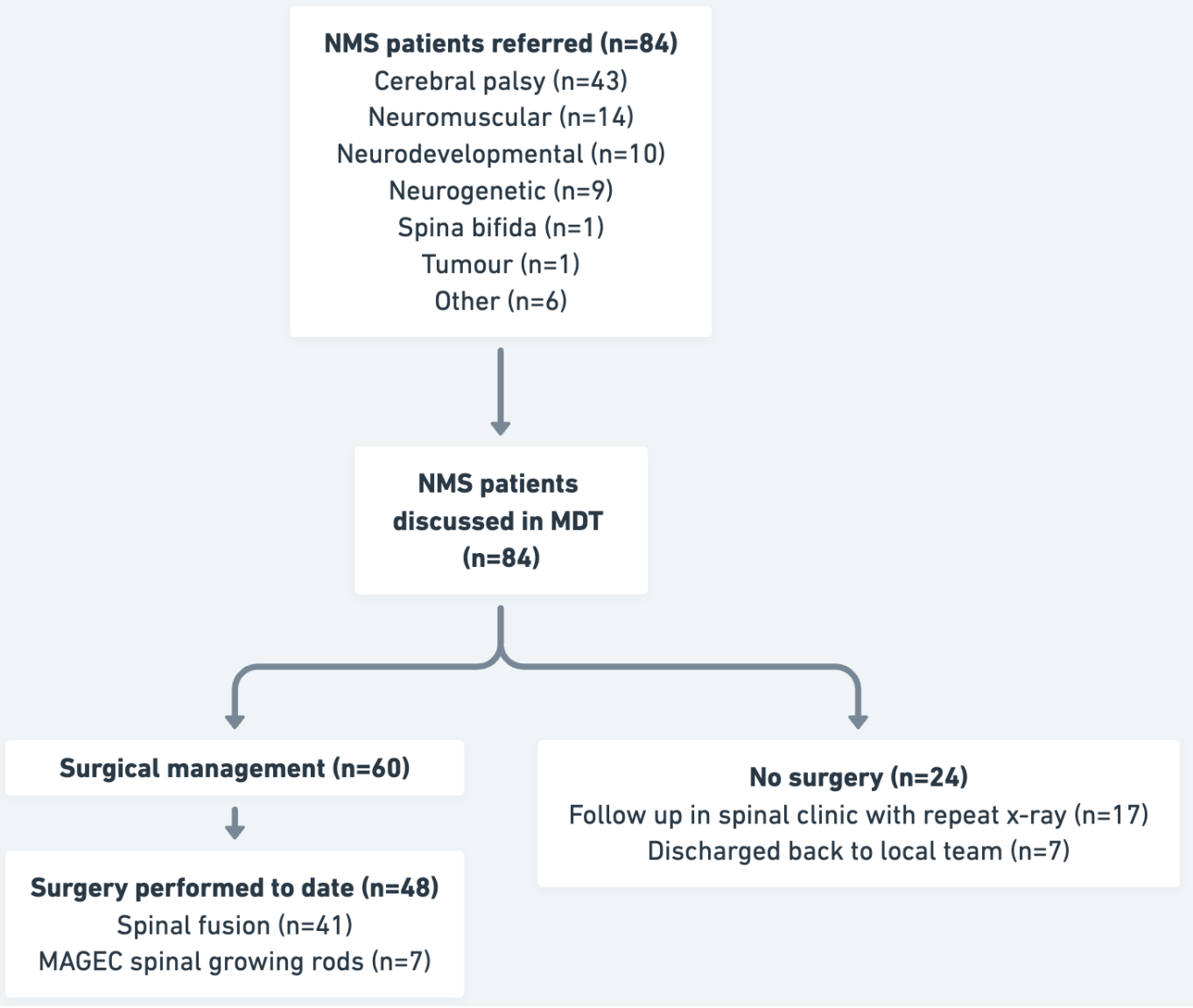

Figure 1 Diagram depicting flow of patients through study. MAGEC, MAGnetic Expansion Control; MDT, multidisciplinary team; NMS, neuromuscular scoliosis.

these decisions were made collaboratively after understanding the surgical implications. Common reasons for families declining surgery included significant surgical/medical risks, minimal expected benefits, well-controlled symptoms such as pain or acceptable sitting position.

24 patients (28.6%) were considered unsuitable for surgery (figure 1). Reasons for recommending conservative management were multifactorial and included high anaesthetic risk (eg, spinal cord abnormalities) and significant medical comorbidities such as RRTIs or congenital cardiac abnormalities. Additionally, four patients were deemed suitable candidates from a medical and surgical perspective, but conservative treatment was recommended due to stable spinal radiographs. A list of reasons is provided in online supplemental information 3.

For conservatively managed patients, the MDT often made referrals to optimise care, including orthotics for sitting support (n=2), sleep studies to assess the need for long-term ventilation (n=1) and dietitians to review and optimise nutrition (n=3). One patient with sitting discomfort was referred to paediatric orthopaedic surgeons for hip dysplasia. Non-surgical patients were either discharged to local teams (n=7) or followed-up by spinal surgeons with 6–12 month reviews (n=17). Follow-up included interval supine spinal radiographs to monitor curve progression, with the option for reassessment by the MDT if necessary.

Surgical management was recommended in the remaining 60 (71.4%). With regard to general characteristics such as age, gender and BMI, there was no difference between the two groups; however, the group surgery was recommended had fewer pre-existing comorbidities and increased change in spinal Cobb angle in the months preceding surgery. There was no association between scoliosis spinal location (thoracic, thoracolumbar, lumbar

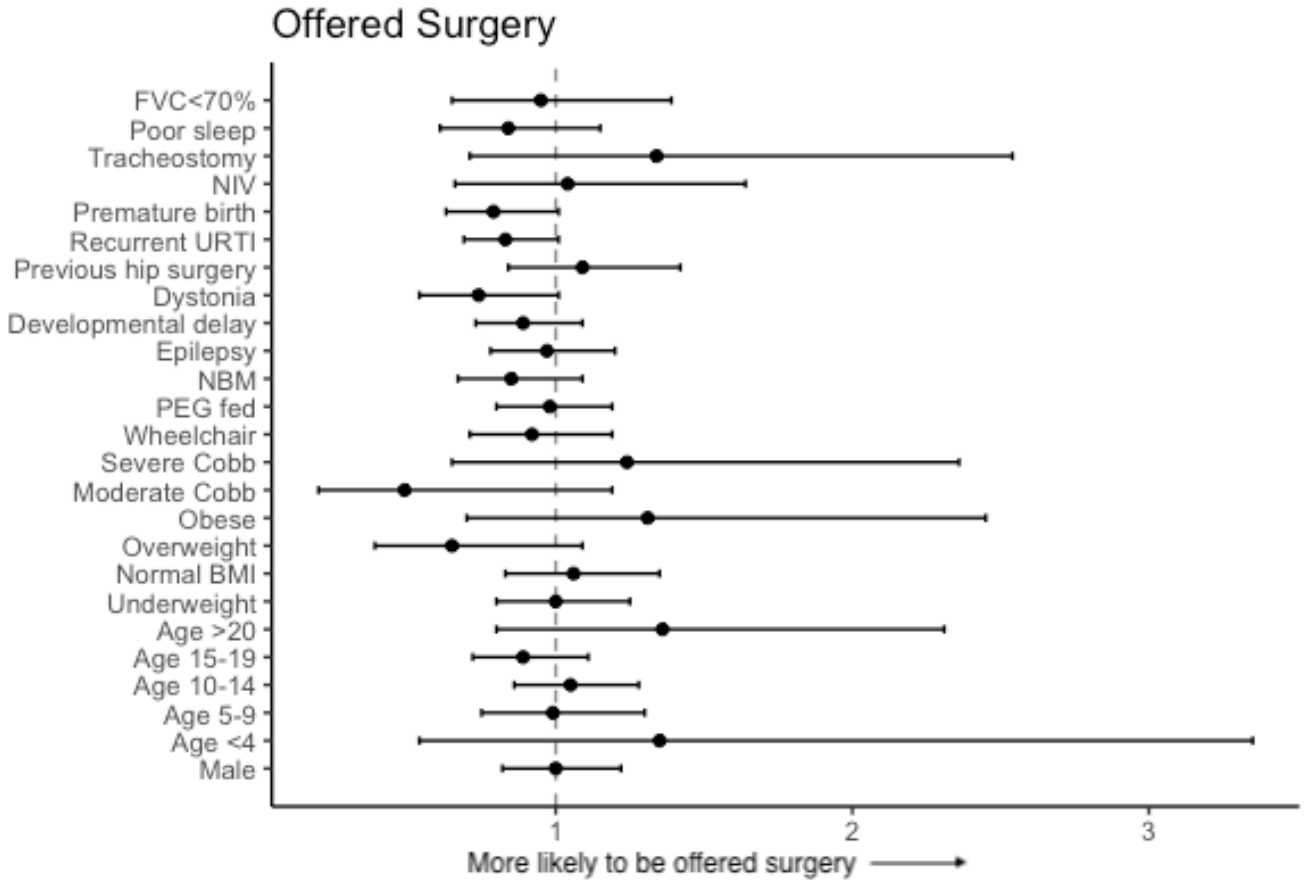

Figure 2 Forest plot showing OR (and 95% CIs) of being offered surgery for each comorbidity. No individual comorbidity significantly impacted surgery decision. BMI, body mass index; FVC, forced vital capacity; NBM, nil by mouth; NIV, non-invasive ventilation; PEG, percutaneous endoscopic gastrostomy; URTI, upper respiratory tract infection.

or s-shaped) and the decision to recommend surgery (X^2 (3, n=84)=2.6, p=0.45); similarly, there was no significant association between underlying cause of NMS and decision to offer surgery (online supplemental information 1).

When comparing the conservative management group with the surgery group, the former had a significantly higher total number of comorbidities (3.5 vs 2.3, p<0.05), a significantly higher number of general comorbidities (2.2 vs 1.6, p<0.05), a significantly higher number of respiratory comorbidities (1.3 vs 0.7, p<0.05) and a relatively non-progressive curve (median increase of 8° vs 22° in the 12–18 months before MDT decision, p<0.05). However, after univariate logistic regression no individual comorbidity was found to significantly influence the MDT decision (figure 2).

Surgery

Of the 60 patients that surgery was offered, 48 have undergone surgery to date with the remaining 12 on the waiting list. Patients under the age of 10 underwent surgery using MAGnetic Expansion Control (MAGEC) spinal growing rods (n=7) and patients older than 10 underwent more traditional spinal rod insertion (n=41).[19] The effectiveness of traditional spinal fusion techniques compared with MAGEC spinal rods has not been analysed in this study. Visual estimation of blood loss (EBL) ranged from 5 mL/kg to 86 mL/kg. Median EBL was 20 mL/kg (IQR 15–30 mL/kg). 40 (83%) patients received blood intraoperatively. 21 (44%) patients were transfused at least 1 unit postoperatively.

Immediate postoperative outcomes

26 (54.1%) patients experienced immediate postoperative complications that were documented (table 2). Five patients developed more than one complication, but no patient experienced more than two categories of postoperative complications. The most common complications were postoperative bleeding (n=21) and respiratory infection (n=17). Respiratory infection was a clinical diagnosis (based on symptoms, raised inflammatory markers and imaging such as chest X-ray when required). Only one patient experienced SSI and one experienced UTI symptoms; in both cases the offending organism was not identified. There was no immediate mortality. Multivariate logistic regression revealed that FVC<70%, NIV use at home and full-time wheelchair use were significant comorbidities, increasing the risk of immediate postoperative complications (figure 3). Table 3 summarises the

Table 2 Table showing short- and long-term surgical outcomes for patients in the study

Outcome	Results
Surgeries performed, n	48
Immediate postsurgery outcomes, days (median and IQR)	
PICU LOS	2 (1–3)
Total hospital LOS	7 (5–10)
PCA duration	3 (3–4)
Duration for mobilisation	4 (3–7)
Catheter removal	4 (3–6)
Immediate postoperative complications, n (%)	
Anaemia (requiring transfusion)	21 (44)
Respiratory infection	17 (35)
Acute kidney injury	4 (8)
Wound site bleeding	3 (6)
Shock	3 (6)
Surgical site infection	1 (2)
Urinary tract infection	1 (2)
Mortality	0 (0)
Total	47
Long-term outcomes, n (%)	
Benefits	
Posture, balance, mobility	20 (42)
Respiratory (breathing, infections)	8 (17)
Improved pain	7 (15)
Confidence	3 (3)
Sleep	2 (4)
Complications	
None reported	39 (81)
Musculoskeletal pain	4 (8)
Pelvic tilt	2 (4)
Long-term NIV	2 (4)
Reduced mobility	1 (2)
Mortality	0 (0)

LOS, length of stay; NIV, non-invasive ventilation; PCA, patient-controlled analgesia; PICU, paediatric intensive care unit.

main comorbidities that were associated with significantly poorer immediate postoperative outcomes.

Long-term follow-up outcomes

On discharge, patients received a patient information leaflet with a timeline for resuming activities and starting physiotherapy (online supplemental information 4). Surgery was well tolerated at 6–12 months of follow-up, with most patients (n=39) reporting no complications. Most common benefit included improved posture (n=20), while complications were rare, including musculoskeletal pain (n=4), worsened sitting position and pelvic tilt (n=2) and need for long-term NIV (n=2) (table 2).

Evidence of long-term outcomes for conservatively managed patients was limited, as they were primarily managed locally for underlying conditions and comorbidities. Among the 24 in this cohort, two (8.3%) died within 12 months of their MDT discussion due to progression of their pre-existing medical conditions.

DISCUSSION

This study offers valuable insights into the clinical decision-making process around treatment options for patients with NMS, a complex and multifaceted clinical area still fraught with challenges. To our knowledge, it is the first study dedicated to analysing decision-making in this patient group. As acknowledged in previous published studies, NMS management poses considerable difficulty for practitioners, with surgical intervention often being the only long-term treatment option.[20 21] The decision to offer surgery is a complex one, involving the evaluation of numerous comorbidities. Each case was discussed in depth by the MDT, taking into consideration the severity and combination of comorbidities, the patient's overall health status, the potential benefits and risks of surgery and the opinion of the patient and their family. There were no strict criteria or scoring system employed; rather, decisions were made on a case-by-case basis after thorough discussion. It is within this realm that MDTs have proven their worth, encompassing a range of professionals whose collective expertise enhances the decision-making process.

Our data show how diverse this group of patients is, in terms of underlying diagnosis, comorbidities and scoliosis progression. To a certain extent, this explains the lack of standardised risk stratification and guidelines. In this disease, MDTs have limited evidence from which they must make difficult decisions. Looking at this centre's experience, patients who received conservative treatment had significantly higher total comorbidities and a higher incidence of respiratory issues. Our findings support previous studies in that a significant correlation was observed between comorbidities and postoperative complication risk, specifically respiratory ones.[4 20] Furthermore, the low postoperative mortality outcomes (n=0) observed are consistent with existing studies that show a 30-day mortality rate of 0%.[22] These results may be due to the MDT's ability to select the most appropriate candidates for surgery as well as high-quality perioperative care, optimised for this high-risk group, in mitigating complication risk related to comorbidities.[23–25]

Another notable finding was the discrepancy between our data and other studies regarding postoperative complications. While SSIs are commonly reported, this was an uncommon complication in our group of patients.[20] We noted a high prevalence of postoperative respiratory infection which did not significantly affect LOS in PICU (17 days vs 8 days, p=0.21) and total LOS in hospital (9 days vs 3 days, p=0.11) when compared with patients without postoperative respiratory infection.

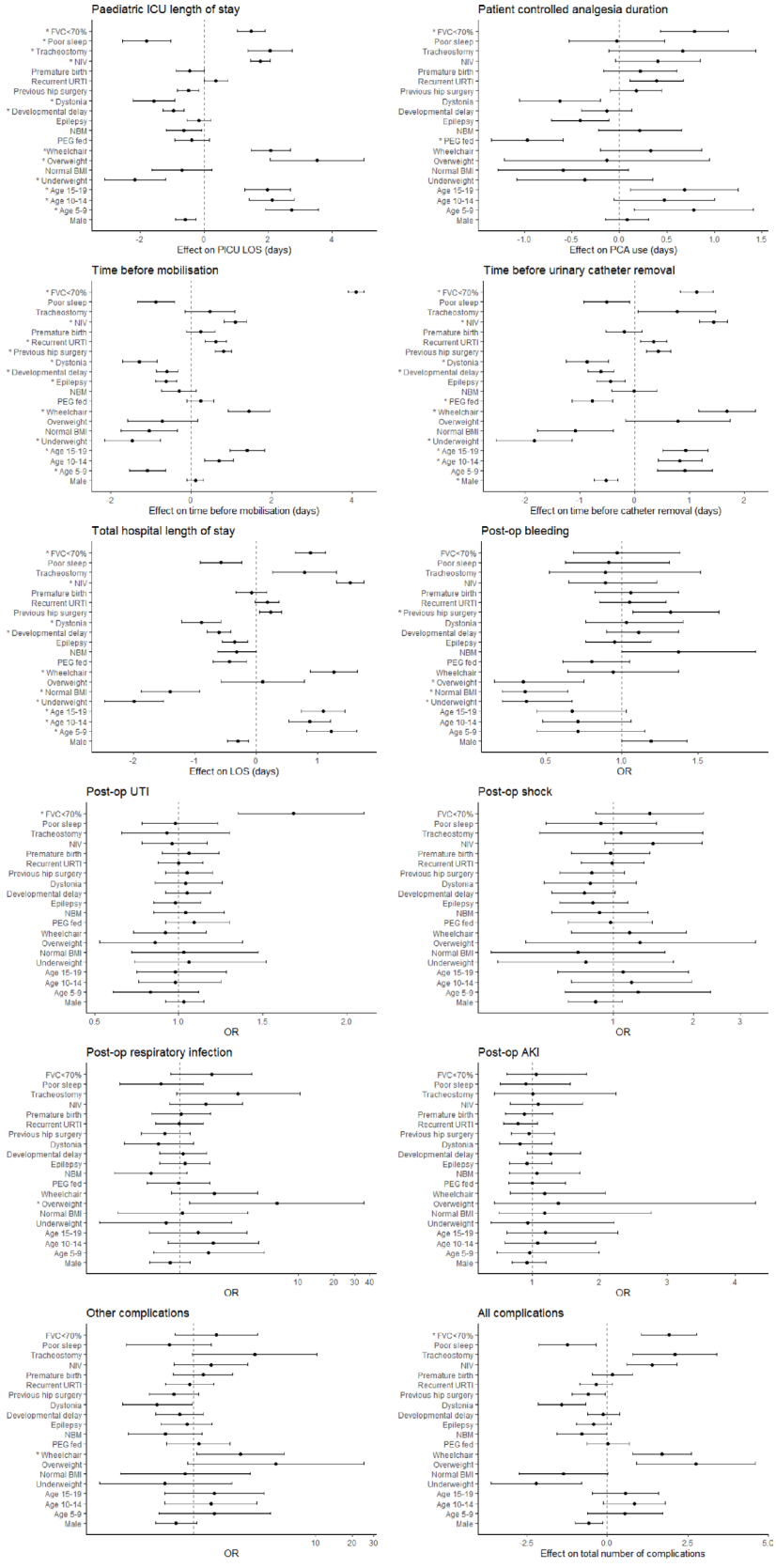

Figure 3 Forest plot showing the effects of comorbidities on short-term postoperative complications. Continuous outcomes presented as effect on mean±SD. Binary outcomes presented as ORs with 95% CIs. *Indicates significant results. BMI, body mass index; FVC, forced vital capacity; ICU, intensive care unit; LOS, length of stay; NBM, nil by mouth; NIV, non-invasive ventilation; PCA, patient-controlled analgesia; PEG, percutaneous endoscopic gastrostomy; PICU, paediatric intensive care unit; URTI, upper respiratory tract infection; UTI, urinary tract infection.

Table 3 Table summarising all comorbidities that were associated with significantly worse immediate postoperative outcomes in patients undergoing surgery for neuromuscular scoliosis

Risk factor	PICU LOS (days)	PCA use (days)	Mobilisation (days)	Catheter removal (days)	Total LOS (days)	Post-op bleed	Post-op UTI	Post-op respiratory infection	Other	Total
Overweight	3.5 (±1.5)	–	–	–	–	–	–	6.6 (1.2 to 35.9)	–	–
Wheelchair	2.1 (±0.6)	–	1.4 (±0.5)	1.7 (±0.5)	1.3 (±0.4)	–	–	–	2.4 (1.1 to 5.5)	–
Previous hip surgery	–	–	0.8 (±0.2)	–	–	1.3 (1.1 to 1.6)	–	–	–	–
Recurrent URTI	–	–	0.6 (±0.3)	–	–	–	–	–	–	–
NIV	1.8 (±0.3)	–	1.1 (±0.3)	1.4 (±0.3)	1.5 (±0.2)	–	–	–	–	–
Tracheostomy	2.1 (±0.7)	–	–	–	–	–	–	–	–	–
FVC<70%	1.5 (±0.4)	0.8 (±0.4)	4.1 (±0.2)	1.1 (±0.3)	0.9 (±0.2)	–	1.7 (1.4 to 2.1)	–	–	1.9 (±0.9)

Continuous outcomes presented as effect on mean (±SD).
Binary outcomes presented as ORs (95% CIs).
FVC, forced vital capacity; LOS, length of stay; NIV, non-invasive ventilation (at home); PCA, patient-controlled analgesia; PICU, paediatric intensive care unit; URTI, upper respiratory tract infection; UTI, urinary tract infection.

Variables such as seasonal changes and postoperative ward occupancy might contribute to these disparities and should be considered.[26 27] There may also be discrepancy between respiratory infections that are culture proven, and the clinically diagnosed postoperative lower respiratory tract infections (LRTIs) in our study. Furthermore, patients with NMS may be more prone to respiratory infections due to poor cough and poor swallow reflexes common in this patient group.[28 29]

There are limitations in this study which warrant acknowledgement. The retrospective nature may introduce biases related to data accuracy and recall, and it does not allow for direct comparison between patients with and without MDT decisions.[30] Attempting to manage these patients without MDT involvement in a prospective comparative study would likely be unethical, given the multifaceted needs of patients with NMS. The small sample size due to the rarity of NMS and the limited range of considered variables could affect the generalisability of the results. Furthermore, patient-reported outcome measures and longer term outcomes in the conservatively managed group were not recorded. The single-centre design, while allowing for an in-depth analysis of MDT decisions, may not be transferrable to other centres with different teams and resources. The single-centre design may also mean that the study's results are influenced by the specific practices and decision-making paradigms of our centre's MDT.[31 32] Similarly, variations in surgical practices, such as the type of spinal surgery performed, could impact the generalisability of our findings.[25] There may also be a bias in our MDT's decision-making due to the focus on high-risk patients. As a result, the study might not fully capture the diversity of cases seen in the wider clinical practice or other centres.[33 34] Future multicentre prospective observational studies should be conducted to validate our findings and further explore the factors influencing MDT decisions.

Despite these limitations, this research has shed light on several key areas. We identified the main seven comorbidities that negatively impacted short-term outcomes (table 3). These are commonly not modifiable factors, but anticipatory care and more aggressive perioperative management could reduce immediate postoperative complications. However, conservative route may need to be considered in patients with high number of comorbidities particularly those with higher BMI, significant lung function impairment, established respiratory failure requiring NIV and reduced mobility requiring full-time wheelchair use (table 3). Further studies should focus on how these comorbidities affect longer term quality of life and mortality and efficacy of preoperative, intraoperative and postoperative care.[24]

The long-term benefits of surgery, especially in terms of improved quality of life, are evident from previously published research.[35–37] Our study aligns with these findings, demonstrating improvements in posture, breathing and pain, with most patients experiencing no long-term complications from surgery. Factors such as the patient's

functional status and quality of life, the potential for curve progression, as well as the ability to optimise these risk factors require ongoing careful review by the MDT. Once assessed by the NMS MDT, patients were evaluated and followed up the spinal surgeons or at their local hubs, with the possibility of being referred again to the MDT. It is good practice for MDTs to re-evaluate patients who are initially not offered surgery to determine whether the risk-benefit profile has changed over time.

The National Institute for Health and Care Excellence formally recognised shared decision-making in 2015 as a cornerstone of patient-centred care.[38] Although MDTs are resource intensive, our findings show that they play a crucial role in making informed, comprehensive and patient-centred decisions for complex patients with NMS. While immediate postoperative complications are common, effective postoperative care allowed all patients to eventually be discharged from hospital with LOS comparable to what has been previously reported.[39 40] Our MDT appears successful at identifying high- and low-risk patients. For the patients with NMS who cannot be so clearly stratified into high- and low-risk groups, the correlation between comorbidities and surgical risk is more nuanced, and future research should focus on these patients.

In conclusion, our findings highlight the complexity of decision-making in the management of paediatric patients with NMS. The involvement of MDTs is essential, as these patients present with a range of complex medical, surgical and social challenges that cannot be distilled into a standardised algorithm. The expertise of the MDT allows for individualised, case-by-case assessments but further research is needed to identify factors that predict better surgical outcomes or indicate when conservative management is more appropriate. Larger, multicentre studies and understanding of variations in MDT composition are necessary to optimise preoperative and postoperative care for patients with NMS to ensure the maximum number of patients able to benefit from the quality-of-life improvements provided by spinal correction surgery.

Author affiliations
[1]University of Cambridge School of Clinical Medicine, Cambridge, UK
[2]Imperial College Healthcare NHS Trust, London, UK
[3]University Hospitals Sussex NHS Foundation Trust, Worthing, UK
[4]Addenbrooke's Hospital, Cambridge, UK

Acknowledgements We thank Sarah Charlton (Specialist Scoliosis Nurse, Addenbrooke's Hospital, Cambridge) for assisting in providing the list of patients with scoliosis.

Contributors All authors (FK, AK, LC, JL, JZ, TP) contributed to the study conception, design of the study and the interpretation of the findings. Data collected were performed by FK. Analysis was performed by FK and AK. The first draft of the manuscript was written by FK and AK, and all authors commented on previous versions of the manuscript. TP provided supervision and guidance throughout. All authors read and approved the final manuscript and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. FK is responsible for the overall content (as guarantor).

Funding The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not applicable.

Ethics approval Not applicable.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available upon reasonable request.

ORCID iD
Anas Khan http://orcid.org/0000-0003-3435-6251

REFERENCES

1 Murphy RF, Mooney JF. Current concepts in neuromuscular scoliosis. *Curr Rev Musculoskelet Med* 2019;12:220–7.
2 Tsiligiannis T, Grivas T. Pulmonary function in children with idiopathic scoliosis. *Scoliosis* 2012;7:7.
3 Zhang J, He D, Gao J, *et al*. Changes in Life Satisfaction and Self-esteem in Patients with Adolescent Idiopathic Scoliosis With and Without Surgical Intervention. *Spine (Phila Pa 1986)* 2011;36:741–5.
4 Weissmann KA, Lafage V, Pitaque CB, *et al*. Neuromuscular Scoliosis: Comorbidities and Complications. *Asian Spine J* 2021;15:778–90.
5 Loughenbury PR, Tsirikos AI. Current concepts in the treatment of neuromuscular scoliosis: clinical assessment, treatment options, and surgical outcomes. *Bone Jt Open* 2022;3:85–92.
6 Ahmed MM, Abdelhalim HA, Elamir RMM. Pulmonary function before and after surgical correction of scoliosis. *Egypt J Bronchol* 2021;15:25.
7 Angeli M, Alpantaki K, Pandis N, *et al*. The effect of scoliosis surgery on pulmonary function in spinal muscular atrophy patients: review of the literature and a meta-analysis. *Eur Spine J* 2022;31:2279–86.
8 Kinnear WJM, Kinnear GC, Watson L, *et al*. Pulmonary function after spinal surgery for idiopathic scoliosis. *Spine (Phila Pa 1986)* 1992;17:708–13.
9 Pehrsson K, Danielsson A, Nachemson A. Pulmonary function in adolescent idiopathic scoliosis: a 25 year follow up after surgery or start of brace treatment. *Thorax* 2001;56:388–93.
10 Yuan N, Fraire JA, Margetis MM, *et al*. The effect of scoliosis surgery on lung function in the immediate postoperative period. *Spine (Phila Pa 1986)* 2005;30:2182–5.
11 Obid P, Bevot A, Goll A, *et al*. Quality of life after surgery for neuromuscular scoliosis. *Orthop Rev (Pavia)* 2013;5:e1.
12 Chan P, Skaggs DL, Sanders AE, *et al*. Pain is the greatest preoperative concern for patients and parents before posterior spinal fusion for adolescent idiopathic scoliosis. *Spine (Phila Pa 1986)* 2017;42:E1245–50.
13 Lamontagne LL, Hepworth JT, Salisbury MH, *et al*. Optimism, anxiety, and coping in parents of children hospitalized for spinal surgery. *Appl Nurs Res* 2003;16:228–35.
14 Salisbury MH, LaMontagne LL, Hepworth JT, *et al*. Parents' self-identified stressors and coping strategies during adolescents' spinal surgery experiences. *Clin Nurs Res* 2007;16:212–30.
15 Negm EE, Saraph V, Said MS. Surgical management of neuromuscular scoliosis: approaches, pitfalls and outcomes. *Pediatr Traum Orthop Reconstr Surg* 2020;8:137–50.

16 Woolf SH, Grol R, Hutchinson A, *et al*. Clinical guidelines: potential benefits, limitations, and harms of clinical guidelines. *BMJ* 1999;318:527–30.
17 von Elm E, Altman DG, Egger M, *et al*. The strengthening the reporting of observational studies in epidemiology (STROBE) statement: guidelines for reporting observational studies. *The Lancet* 2007;370:1453–7.
18 R: the R project for statistical computing. Available: https://www.r-project.org/ [Accessed 15 Aug 2023].
19 MAGEC system. NuVasive. Available: https://www.nuvasive.com/procedures/spine/magec/ [Accessed 15 Aug 2023].
20 Toll BJ, Samdani AF, Janjua MB, *et al*. Perioperative complications and risk factors in neuromuscular scoliosis surgery. *J Neurosurg Pediatr* 2018;22:207–13.
21 Cloake T, Gardner A. The management of scoliosis in children with cerebral palsy: a review. *J Spine Surg* 2016;2:299–309.
22 Matsumoto H, Fano AN, Herman ET, *et al*. Mortality in neuromuscular early onset scoliosis following spinal deformity surgery. *J Pediatr Orthop* 2022;42:e234–41.
23 Nasr VG, Staffa SJ, Zurakowski D, *et al*. Pediatric risk stratification is improved by integrating both patient comorbidities and intrinsic surgical risk. *Anesthesiology* 2019;130:971–80.
24 Pawar D. Common post-operative complications in children. *Indian J Anaesth* 2012;56:496–501.
25 Mikhail C, Pennington Z, Arnold PM, *et al*. Minimizing blood loss in spine surgery. *Global Spine J* 2020;10:71S–83S.
26 Anthony CA, Peterson RA, Polgreen LA, *et al*. The seasonal variability in surgical site infections and the association with warmer weather: a population-based investigation. *Infect Control Hosp Epidemiol* 2017;38:809–16.
27 Xiang B, Jiao S, Si Y, *et al*. Risk factors for postoperative pneumonia: a case-control study. *Front Public Health* 2022;10:913897.
28 Voulgaris A, Antoniadou M, Agrafiotis M, *et al*. Respiratory involvement in patients with neuromuscular diseases: a narrative review. *Pulm Med* 2019;2019:2734054.
29 Sedra F, Shafafy R, Sadek A-R, *et al*. Perioperative optimization of patients with neuromuscular disorders undergoing scoliosis corrective surgery: a multidisciplinary team approach. *Global Spine J* 2021;11:240–8.
30 Talari K, Goyal M. Retrospective studies - utility and caveats. *J R Coll Physicians Edinb* 2020;50:398–402.
31 Bellomo R, Warrillow SJ, Reade MC. Why we should be wary of single-center trials. *Crit Care Med* 2009;37:3114–9.
32 Unverzagt S, Prondzinsky R, Peinemann F. Single-center trials tend to provide larger treatment effects than multicenter trials: a systematic review. *J Clin Epidemiol* 2013;66:1271–80.
33 Whiteman AR, Dhesi JK, Walker D. The high-risk surgical patient: a role for a multi-disciplinary team approach? *Br J Anaesth* 2016;116:311–4.
34 Hong NJL, Wright FC, Gagliardi AR, *et al*. Examining the potential relationship between multidisciplinary cancer care and patient survival: an international literature review. *J Surg Oncol* 2010;102:125–34.
35 Sitoula P, Holmes L Jr, Sees J, *et al*. The long-term outcome of early spine fusion for scoliosis in children with cerebral palsy. *Clin Spine Surg* 2016;29:E406–12.
36 Mercado E, Alman B, Wright JG. Does spinal fusion influence quality of life in neuromuscular scoliosis? *Spine (Phila Pa 1986)* 2007;32:S120–5.
37 Lin JL, Tawfik DS, Gupta R, *et al*. Health and economic outcomes of posterior spinal fusion for children with neuromuscular scoliosis. *Hosp Pediatr* 2020;10:257–65.
38 National Institute for Health and Care Excellence (NICE). Shared decision making. NICE guideline [NG197]. 2021. Available: https://www.nice.org.uk/guidance/ng197 [Accessed 26 Nov 2024].
39 Fletcher ND, Bellaire LL, Dilbone ES, *et al*. Variability in length of stay following neuromuscular spinal fusion. *Spine Deform* 2020;8:725–32.
40 Simpson BE, Kara S, Wilson A, *et al*. Reducing patient length of stay after surgical correction for neuromuscular scoliosis. *Hosp Pediatr* 2022.