NEUROMUSCULAR SCOLIOSIS IN CHILDREN: SURGICAL TREATMENT AND LUNG FUNCTION (ANALYTICAL AND SYSTEMATIC REVIEW)

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Objective. To systematically review current publications on surgical correction of neuromuscular scoliosis in children and its relationship with lung function.
Material and Methods. A search of scientific sources was conducted in accordance with PRISMA standard. The protocol was developed a priori and was not included in international registries of systematic reviews. The search included PubMed/Medline, Scopus, the Cochrane Library, Google Scholar, eLibrary.ru, CyberLeninka, and Rucont. Of the 938 database entries, 69 studies were included in the review.
Results. The most important positive effect of surgical correction of spinal deformity associated with neuromuscular scoliosis on pulmonary function is considered to be stabilization or slowing of the progression rather than regression of respiratory impairment. The main controversy lies in the fact that the method that provides maximum correction and stability (posterior instrumentation and fusion) irreversibly halts the growth of the spine and thorax in growing children, potentially limiting lung development. At the same time, growth-friendly technologies are associated with an expectedly smaller immediate deformity correction and with a higher incidence of planned postoperative complications, which, however, are incomparably less severe than with final fusion. Data on the effectiveness of many growth-preserving systems (Shilla, Luque trolley) in neuromuscular scoliosis remain fragmentary.
Conclusion. The analysis of surgical correction techniques in neuromuscular scoliosis and their impact on patients' respiratory function demonstrates a lack and inconsistence of data; there are no uniform criteria for assessing respiratory function; patient cohorts differ in the nosology and prognosis of the underlying disease, severity of functional status, age, and magnitude of deformity.
Key Words: neuromuscular scoliosis; growth-friendly spinal fixation systems; posterior spinal fusion; minimally invasive surgery without fusion.
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Neuromuscular scoliosis (NMS) is a severe orthopedic complication of a number of neuromuscular diseases, predominantly of congenital genesis (spinal muscular atrophy, childhood cerebral palsy, Duchenne muscular dystrophy, myelomeningocele, spinal cord injuries associated with myelopathy, genetic syndromes and others), differentiating, first of all, by the predominant central or peripheral neuron or muscular link of impairment [1–5]. Taking into account the population prevalence of neuromuscular diseases (1 case per 3–3.5 ths. of the population) and the frequency of neuromuscular scoliosis in them (60–90%, including in the most frequent variant – childhood cerebral palsy with severe motor impairments [Gross Motor Function Classification System - GMFCS IV–V] NMS – 85%), the problem acquires tremendous clinical, social and economic significance [4, 5].

Concomitant respiratory disorders are typical for NMS, usually caused by a combination of weakness of the respiratory musculature with secondary restrictive changes against the background of deformities of the chest and impairments of diaphragmatic movements, which becomes the main cause of respiratory failure, leading to a decrease in the quality of life, disability and death of patients [6–10].

It is known that conservative methods of treating NMS (corsets, special seats, physiotherapy) are not only unable to stop the progression of the disease, but can also worsen breathing, due to which they must be applied early, but to a limited extent [11–16].

The probability of the development of neuromuscular deformity in childhood cerebral palsy is inversely proportional to the degree of motor impairments: the less the patient moves independently, the higher the risk of progression of the curvature. According to a prospective registry of childhood cerebral palsy in Sweden, including 962 children, in children with GMFCS III, IV and V at the age of up to 10 years, scoliosis of magnitude ⩾40° degrees is detected in 2%, 5% and 20% of patients respectively, while by the age of 20 the corresponding indicators already amount to 8%, 35% and 75%; while in not a single case did scoliosis exceed 40 degrees with GMFCS I–II [17].

Drug therapy affects the timing, severity and progression of NMS and is associated with modern possibilities of targeted therapy: thus, oral corticosteroids slow down the progressing weakness in Duchenne muscular dystrophy, delaying the development of scoliosis to adolescent or young age [18], and in spinal muscular atrophy, gene therapy and *SMN2* gene modifiers can preserve muscle strength, delaying the development of scoliosis

[19, 20]. At the same time, the high incidence, the modern level of knowledge about genetics and the understanding of the features of NMS of various genesis in children are accompanied by an insufficient awareness of pediatricians, pediatric surgeons and orthopedists about the variants of their course, complications and possibilities of surgical treatment. All this prompted us to analyze modern literature devoted not so much to well-known, as to debatable aspects of this problem.

Objective of the study was an analysis of modern publications devoted to the surgical correction of neuromuscular scoliosis in children and its connection with lung function.

The methodology of selecting publications corresponds to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) recommendations. The protocol was developed a priori, but was not registered in international registers of systematic reviews (International Prospective Register of Systematic Reviews – PROSPERO, etc.), which corresponds to an analytical and systematic study.

Eligibility criteria

Inclusion criteria

1. Pathology: neuromuscular scoliosis of any etiology (childhood cerebral palsy, spinal muscular atrophy, Duchenne muscular dystrophy, myelomeningocele and other neuromuscular diseases).

2. Type of publications: meta-analyses, systematic reviews, prospective and retrospective clinical studies, case series and unique observations, as well as clinical guidelines on NMS.

3. Age of patients in publications: aged 18 and younger at the time of operation.

4. Corrective operations on the spine: posterior final instrumental correction/fixation, growth-sparing technologies and guided growth systems with the presence of data on primary (degree/magnitude of deformity correction (Cobb angle), frequency and structure of perioperative and long-term complications, quality of life indicators of patients and/or their families) and secondary outcomes (change in lung function, including vital capacity (VC), forced vital capacity (FVC), forced expiratory volume in 1 second, lung structures according to CT data, presented in absolute values or in percentages of those required).

Exclusion criteria

1. Publications devoted exclusively to neurological features, heredity, genetics, medical treatment of neuromuscular diseases and conservative treatment of neuromuscular scoliosis.

2. Studies of the adult population.

3. Descriptions of surgical techniques without evaluating outcomes.

4. Experimental (on animals) and biomechanical studies.

5. Editorial articles, expert opinions, reports on single (<5) cases, except for unique techniques.

6. Publications in languages other than Russian and English.

Information sources and search strategy

The search was conducted in English- and Russian-language sources in the electronic databases PubMed/Medline, Scopus, Cochrane Library, Google Scholar, eLibrary, CyberLeninka, RUKONT. Timeframes of the search: period from January 2015 to December 2025.

The search strategy included a combination of keywords and Medical Subject Headings terms using logical operators AND/OR, including English-language ones: ("neuromuscular scoliosis" OR "myelomeningocele scoliosis" OR "cerebral palsy scoliosis") AND ("spinal fusion" OR "surgical treatment" OR "growing rods" OR "growth-friendly" OR "Vertical Expandable Prosthetic Titanium Rib") AND ("pulmonary function" OR "lung function" OR "respiratory function" OR "vital capacity") AND (child* OR adolescent* OR pediatric*).

Equivalent terms were used when searching Russian-language publications. The search strategy was adapted for each database. Additionally, a manual search by reference lists of included articles and relevant systematic reviews was performed.

Selection process

All identified records were exported to a bibliographic reference manager with subsequent removal of duplicates. The selection of publications was carried out in two sequential stages by one researcher: 1) screening of titles and abstracts for compliance with inclusion and exclusion criteria; 2) full-text assessment of potentially relevant publications.

Quantitative restrictions (sample size, type of intervention, age range within the pediatric population) were not applied at the selection stage and were analyzed descriptively in the results section.

Data extraction and bias risk assessment

From the included studies, the following information was extracted:

- authors, year of publication, study design;
- number and age of patients, nosological structure;
- type of surgical intervention;
- indicators of lung function, degree of deformity correction, complications.

Due to the predominance of non-randomized designs, a formal quantitative assessment of systematic bias risk was not the goal of the review.

Data synthesis

Taking into account the pronounced clinical and methodological heterogeneity of the included studies (various etiologies of neuromuscular scoliosis, age of patients, surgical techniques, methods of assessing respiratory function), conducting a meta-analysis was deemed inappropriate. A qualitative data synthesis was performed with thematic grouping by two parameters:

1) type of surgical intervention (final fixation versus growth-sparing systems);

2) main outcomes (lung function, deformity correction, complications).

The results are presented below in text and tabular formats.

Results

The scheme for selecting information sources for the review is presented in Fig.

According to national and international recommendations, surgical treatment is the main method of correcting pronounced and progressing NMS and simultaneously the main object of professional discussions. Its common goals are

considered to be preventing the progression of deformity, creating a stably balanced spine to improve vertical position, including while sitting; improving or stabilizing respiratory function and improving socialization, including facilitating patient care by reducing pain, discomfort and improving the quality of life. The magnitude of deformity at which surgical treatment is recommended depends on the neuromuscular disease, in connection with which the main indications for it in the Clinical Guidelines of the Ministry of Health of Russia are summarized as follows [21]:

- scoliosis greater than 40° (for spinal muscular atrophy – greater than 50°; for patients with Duchenne muscular dystrophy receiving glucocorticosteroids, – greater than 30°);
- annual progression of deformity of more than 5 degrees (for spinal muscular atrophy >10°);
- hyperkyphosis or hyperlordosis of more than 50 degrees; and
- global trunk imbalance in the frontal and (or) sagittal plane.

In cases where pelvic obliquity exceeds 15°, it is recommended to perform posterior instrumental fixation of the thoracic and lumbar spine with pelvic capture in children. In this case, for patients who have the ability to walk, pelvic fixation is not recommended, as well as for non-walking patients in the absence of an obliquity [8].

In general, methods of correcting neuromuscular scoliosis can be divided into two large groups [2, 22].

Growth-sparing (growth-friendly, GF, dynamic) systems are used in children of a younger age (as a rule, aged up to 8–10) or those with not yet completed significant skeletal growth. The strategy of such an operation corresponds to the criteria for the treatment of early-onset scoliosis (EOS), and its goal is partial correction of scoliosis with the preservation of the possibility of growth of the spine and chest, including for the growth of lung tissue. Growth-sparing constructs include various expandable constructs – vertically expandable prosthetic titanium ribs (VEPTR), magnetically controlled growing rods (MAGEC), traditional telescopic and parallel growing rods (TGR), «sliding» technologies Shilla and Luque trolley, and rarely used dynamic anterior systems Vertebral Body Tethering/Anterior Scoliosis Correction (VBT/ASC).

Conventional blocking systems provide instrumental correction with permanent, final fixation (spinal fusion). They are usually applied in patients older than 12 years, when the main growth of the skeleton is completed or close to completion, or at an earlier age in cases of life-threatening curvatures. Final posterior fixation stops the progression of scoliosis and significantly improves trunk balance, however, it negatively affects the development of the lungs.

A typically sequential combination of both approaches – initiation of treatment with the use of a "growing" system with a subsequent transition to permanent blocking of the spine.

Advantages and disadvantages of various methods of correcting NMS

An analysis of 10 retrospective cohort studies including data on 992 patients with neuromuscular spinal deformities revealed significant differences in surgical approaches and outcomes of NMS treatment in children (Table 1):

- at final fixation, modern rigid instrumentation with pedicle screws compared to hybrid or wire constructs provides better correction of the deformity (75% vs. 59%), reduces operation time (6.04 vs. 7.45 hours), blood loss (1785 mL vs. 3760 mL) and the frequency of pseudarthrosis development (5% vs. 22%, $p = 0.026$);
- growth-friendly surgery requires a significantly greater number of surgical procedures compared to single-stage posterior spinal fusion (8.7 vs. 1.6), is naturally accompanied by an increase in the number of postoperative complications associated with the expectation of family members of subsequent operations and provides lesser correction of the main curvature curve at the most effective first stage (38% vs. 62%, $p = 0.001$);
- minimally invasive surgery without spinal fusion (MIFS – Minimally invasive fusionless surgery) reduces the number of perioperative complications (OR – 4.6), the need for blood transfusion (OR = 14.0%; 95% CI: 6.3–33.0), the length of hospital stay (17.3 vs. 24.1 days, $p = 0.2$) and the duration of invasive ventilation (5.28 vs. 7.02 days, $p = 0.05$);
- more active use of vasopressors during single-stage final posterior fixation compared to "growing" rods and MIFS ($p = 0.06$) indicates greater hemodynamic instability of patients during final traditional spinal fusion;
- two-stage spinal fusion is safer compared to single-stage, during which a significantly higher complication rate and 2 cases of perioperative death were noted; at the same time, the overall complication rate in NMS is almost tripled (17.9% vs. 6.3%), and perioperative mortality – almost 10 times higher (0.30% vs. 0.02%) [33], exceeding that in idiopathic scoliosis;
- walking patients with NMS achieve results comparable to adolescent idiopathic scoliosis ($p = 1.0$ for complications), while non-walking patients stay in the intensive care unit significantly longer, require more blood transfusions, and have a higher complication rate ($p < 0.001$).

Thus, the approach to surgical treatment of patients with NMS is determined by age, mobility, and residual growth potential. In turn, optimal age ranges for transitioning between strategies remain insufficiently defined, and the risks of perioperative complications are high.

Posterior instrumental spinal fixation with final spinal fusion

With correct surgery, neuromuscular curvature can be corrected by 50–70% of the initial [9]. According to Tsirikos et al. [24], the use of a Unit Rod construct (a double rod connected cranially, pre-bent sagittally and frontally for caudal insertion into the pelvic bone at a 45° angle and fixed with sublaminar wire according to Luque) in 287 patients provided correction of scoliosis by an average of 68%. Modern screw systems also allow eliminating/reducing hyperkyphosis/hyperlordosis and correcting pelvic tilt when using iliac screws, which significantly improves sitting balance in non-walking children: they sit unsupported longer, improve head control, and also free their hands for functional activity.

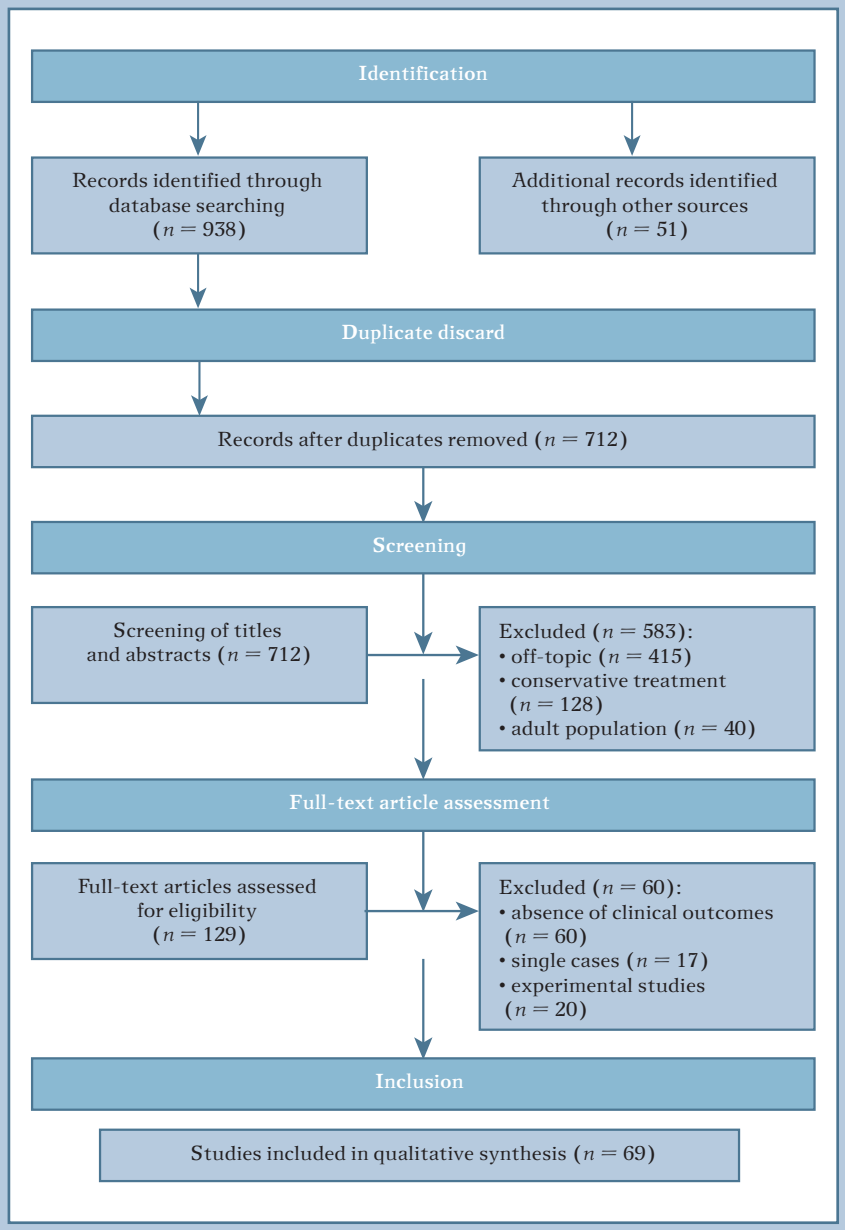

Fig.
Scheme of publication selection for analysis

Deformity reduction lowers the risk of bedsores, including those due to rib-pelvic impingement – contact of the lower ribs with the iliac crest [33].

The main positive *impact of surgery on breathing* is stabilization or slowing of lung function decline. Final fixation eliminates the progression of deformity and prevents further development of respiratory disorders. In other words, without restoring lost lung volume, surgery can prolong the period of relative function stability.

Lenhart et al. [33] report an increase in forced vital capacity (FVC) by 0.4 liters after spinal fusion in patients with spinal muscular atrophy, but the relative indicator (% of normal) continues to decline with long-term observation, albeit slower than before surgery.

According to other studies [34, 35], in patients with spinal muscular atrophy and other NMS prior to surgery, FVC decreased by ~5–8% per year, whereas after correction the decline rate slowed to ~2–3% per year. With an observation of 5 years or more in progressive neuromuscular diseases, a further decrease in vital capacity (%), associated with the natural course of the underlying disease and respiratory muscle weakness, is noted.

In the early postoperative period, a decrease in vital capacity may be observed compared to preoperative data due to pain syndrome, chest stiffness, soft tissue edema [36]. However, after 6–12 months, indicators usually return to baseline [37]. According to the authors, subjectively noted relief in breathing is associated with more effective diaphragm work and improved sputum drainage due to the elevation of ribs and release of basal lung regions after straightening the spine. Overall, the long-term effect of posterior fixation on respiratory function is characterized as stabilizing the existing level.

Disadvantages and complications. Final fixation (spinal fusion) in NMS is a surgery with prolonged anesthesia, significant blood loss, and risk of complications. In childhood cerebral palsy, there is an inverse relationship between blood loss volume (in % of CBV) during deformity correction surgery and patient size: patients of smaller stature lose a larger relative volume of blood. Several studies have shown a decrease in mortality in the long-term period and an improvement in health-related quality of life of patients with neuromuscular diseases who underwent spinal fusion and recovered after surgery without serious complications [38–42]. At the same time, surgical treatment of neuromuscular scoliosis has the highest risk of complications among all forms of scoliosis, reaching 75% depending on the underlying etiology and treatment center [9, 43, 44]. In a large (2154 patients) sample by Rumalla et al. [45] with 17.9% of postoperative complications in NMS, the main ones were blood loss requiring transfusion, deep wound infection, including those

Table 1
Analysis of publications selected for the study

Publication	Study design	Comparison groups	Sample size	Observation period	Data set
Mattila et al. [23]	Pairwise matched cohort	Hybrid fixation/only pedicle screws	33/3	Minimum 2 years	Prospective
Tsirikos et al. [24]	Retrospective cohort	1 stage/2-stage operation (anterior-posterior spinal fusion)	45	N/A	N/A
Li et al. [25]	Retrospective multicenter cohort	Posterior spinal fusion/staged operations (growth-friendly) + final spinal fusion	16/43	Minimum 2 years after final spinal fusion	Multicenter database
Njiki et al. [26]	Retrospective cohort	Posterior spinal fusion/growing rods	75/65	N/A	N/A
Sarwahi et al. [27]	Retrospective cohort	Walking patients with neuromuscular deformity/ non-walking patients with neuromuscular deformity/ idiopathic scoliosis	54/120/158	N/A	2005–2018
Akesen et al. [28]	Retrospective cohort	Posterior fixation to S1 vertebra/ posterior fixation with pelvic capture	23/13	Median – 20 months (12–66)	2011–2015
Gaumé et al [29]	Retrospective cohort	Posterior spinal fusion/minimally invasive fixation (MIFS)	75/65	Early postoperative period	2012–2017
Reames et al. [30]	Retrospective analysis of a multicenter database	Idiopathic/congenital/ neuromuscular scoliosis	13360	N/A	2004–2007
Funk et al. [31]	Retrospective analysis	Non-rigid (more than 50% – sublaminar wire + Galveston rods or iliac screws)/rigid (more than 50% – pedicle screws and iliac screws) constructs	23/7	On average 3.3 years (1–12)	1998–2012
Phillips et al. [32]	Retrospective review	2 iliac screws/4 iliac screws	50	N/A	N/A

N/A – not available

requiring repeated surgery and hardware removal, and prolonged wound healing amid protein-energy malnutrition [46]. The literature also notes pleural (atelectasis, hydro-/pneumothorax) and implant-dependent complications – hardware fractures, screw transposition, pseudarthrosis in the bone graft zone, etc. The administration of bisphosphonates used to improve bone tissue quality and, correspondingly, reduce the risk of implant-associated complications does not exclude side effects in the form of acute phase reactions and hypocalcemia, especially after the first infusion [47]. If several infusions are necessary (which can take years), they can be performed not only before, but also after surgery [48].

In patients with childhood cerebral palsy of functional level V according to the GMFCS, who underwent spinal fusion of the spine, according to univariate logistic regression analysis, a higher rate of severe complications associated with epileptic seizures, non-verbal status, use of tracheostomy and/or gastrostomy tubes was identified [40]. Patients who have undergone spinal fusion are also subject to a higher risk of polymicrobial and Gram-negative infections than occurs after other elective orthopedic procedures [49–51]. Among the consequences of final fixation in neuromuscular scoliosis, proximal junctional kyphosis (PJK) requiring correction and thoracic insufficiency syndrome against the background of spine and chest growth restriction are also mentioned [52].

As already mentioned, in non-walking patients, performing fixation using iliac or S2AI screws to correct pelvic tilt improves sitting balance, but practically deprives the patient of even hypothetical walking [46]. The largest long-term observation of non-walking patients with childhood cerebral palsy who underwent spinal fusion showed that 10 years after the primary surgery, 22% of patients required repeat surgery due to implant instability, pseudarthrosis, surgical site infection, prominent/symptomatic implants, including with the development of proximal junctional kyphosis [52].

Optimization of muscle tone and spasticity (medication, either through intrathecal administration of baclofen via an implanted pump, or selective dorsal rhizotomy) can help reduce the risk of instrumentation complications, but also promote scoliosis progression. Despite the fact that only 3% of patients experience neurological complications, uncertainty remains regarding whether prophylactic procedures should be performed to minimize these risks [41]. One of the most serious complications for such patients are cardiological ones, constituting 1.8% [45]. Understanding the underlying etiology and potential risks associated with each disease (for example, conduction disturbances in patients with Rett syndrome or cardiomyopathy in muscular dystrophy), can save lives.

Not all growth-sparing systems, originally proposed within the concept of early-onset scoliosis treatment in actively growing patients aged under 10, have found application in neuromuscular deformity surgery.

VEPTR (Vertically Expandable Prosthetic Titanium Ribs), developed specifically for the treatment of thoracic insufficiency syndrome [53], did not find practical application in neuromuscular scoliosis due to their indirect effect on the deformed spine through impact on the chest.

MAGEC (Magnetically Controlled Growing Rods), the main advantage of which is the absence of the need for surgical manipulation during a staged corrective maneuver, provide spinal support and indirectly support chest growth, preventing restriction and slowing the annual decline in VC [54–57]. The disadvantages of such constructs (high cost, mechanical breakages, system fatigue, internal mechanism wear, and loss of effect by four years after intervention in 80% of patients) are well known and are not related to the etiology of the deformity.

Traditional growing rods (TGR) are routinely used in children aged under 10 [55–59], however, data on the risks of their application in neuromuscular scoliosis in the literature are extremely scarce. From their main advantages, one can note predictable significant (40–50%) deformity correction, preservation of spinal growth, and low dependence on bone density [59, 60]. The use of sliding construct technologies (Shilla Growth Guidance System and Luque trolley) in neuromuscular scoliosis and their effect on respiratory function require further study due to extremely limited experience [60, 61].

In the single report on dynamic Anterior Spinal Correction (ASC) for progressive post-traumatic myelopathy from the level of D10 (plegia of ASIA grade A) in an 11-year-old girl, fixation of the T1–L5 without spinal fusion provided a decrease in the scoliotic curve from 60° to 7° by the time of skeletal maturity over three years [62].

The problem of the impact of instrumental spinal fixation in neuromuscular scoliosis on respiratory function is one of the key ones (Table 2).

It has been noted that in type II spinal muscular atrophy, final spinal fusion demonstrates a slowdown in the drop of VC up to 2–3% per year [4, 63].

A study of a small number of patients with NMS 3–4 months after the installation of MAGEC showed stabilization of FVC instead of the expected drop [55]. This is especially relevant for patients with childhood cerebral palsy, where respiratory disorders progress regardless of orthopedic correction [64–66].

The possibility of using "growing" spinal systems in children older than 10 years

Patients with severe NMS usually have serious concomitant problems (respiratory failure, osteopenia, general muscle weakness, or high spasticity, etc.), making extensive surgery risky. The use of "growing" systems in high-risk patients may be justified, as it allows distributing correction over time and avoiding prolonged single-stage surgery [59, 67].

Miladi et al. [68] had a study with 100 patients with NMS aged 5 to 21 years (the majority – with childhood cerebral palsy, average age – 11 years 6 months), an original bipolar construct was used, fixed proximally using a double hook claw and distally using iliosacral screws via a minimally invasive approach. A decrease in scoliotic deformity by an average of 61% (from 89° to 35°), pelvic tilt angle – by 83% (from 29° to 5°), and average kyphosis magnitude – from 68° to 33° with an increase in trunk height by 7 centimeters, in the absence of spinal fusion, was accompanied by 26% complications (12 mechanical and 16 infectious).

Special attention to Cahill et al [69], who noted in 89% of children treated with "growing" rods the development of spontaneous ankylosis, sufficient to maintain correction, which allowed the authors to suggest the possibility of refusing the final surgery if a satisfactory correction profile and trunk height are achieved by the time growth is complete. In non-walking patients older than 10 years with severe neurological pathology, such an approach may be especially relevant due to three components:

– reduction in surgical risks with a comparable stabilization effect;

– the possibility of lengthening the interoperative period with TGR from the classic 6–8 month interval to 12 months;

– the possibility to gain time for chest and lung growth, avoiding final surgical correction, gradually correcting the deformity with a lower risk of respiratory decompensation.

Table 2
Data of major publications evaluating the impact of neuromuscular scoliosis correction on lung function

Publication	Study design/ number of observations	Nosology/ patient group	Type of surgical intervention	Methods for assessing respiratory function	Evaluation timing (observation period)	Key lung function indicators (dynamics)	Main conclusions regarding respiratory function
Lenhart et al. [33]	Retrospective cohort/ 16 patients	SMA	Growth-sparing systems	Spirometry, X-ray	Long-term observation (exact time not specified)	FVC (absolute increase by 0.4 liters, but decrease in % of normal)	Increase in absolute volume of FVC, but the relative indicator (% of normal) continues to decline
Alhammoud et al. [35]	Systematic review/ 14 studies, total number of patients – 240	SMA and other NMS	Various (mostly PIF)	Spirometry	Long-term observation (data before and after surgery)	Annual decline in VC/FVC (% of normal)	Before surgery: decline by 5–8% per year. After PDF, the decline slows to ~2–3% per year
Holt et al. [37]	Retrospective cohort/16 patients	SMA	PIF	Spirometry	Early postoperative period (not specified) and 6–12 months	VC/FVC	In the early period, a decrease is possible due to pain, edema. By 6–12 months, return to baseline level
Shaw et al. [55]	Retrospective cohort/48 patients	NMS (various)	MAGEC (magnet rods)	Spirometry	3–4 months after installation	FVC	Stabilization of FVC instead of expected drop
Veldhoen et al. [58]	Retrospective cohort/43 patients	NMS or syndromic scoliosis	Various (mostly growth-sparing)	Spirometry	Short-term postoperative period and assessment of decline rate	Decline rate of pulmonary function	Assessment of short-term effect and impact on the rate of long-term function decline. The monthly rate of change in FVC did not change significantly
Miladi et al. [68]	Retrospective cohort/100 patients	NMS (mostly CP)	Growth-sparing systems	Clinical assessment	Perioperative period	Duration of IMV	Decrease in the duration of invasive mechanical ventilation compared to PSF
Sarwahi et al. [27]	Retrospective multicenter cohort/120 patients	NMS (walking and non-walking)	PIF	Clinical outcomes	Perioperative period	Duration of IMV, length of stay in ICU	Non-walking patients stay longer on IMV and in the ICU

SMA – spinal muscular atrophy; FVC – forced vital capacity; PIF – posterior instrumental fixation; NMS – neuromuscular scoliosis; CP – cerebral palcy; IMV – invasive mechanical ventilation; ICU – intensive care unit.

Conclusion

The conducted analysis of surgical techniques and their impact on respiratory function in NMS demonstrates a deficit and inconsistency of available data.

First of all, the problem is associated with the lack of unified criteria and timing for assessing respiratory function, nosological diversity of neuromuscular diseases, differences in patients by severity of functional status (mobility), age, body mass index, skeletal growth potential, and deformity magnitude.

The most important positive effect of surgical correction of spinal deformity on respiratory function turned out to be not regression, but slowing the progression of the corresponding disorders (!). Prognostically least certain in this regard are patients with childhood cerebral palsy, having a multifactorial nature of such disorders.

The method providing maximum correction and stability – posterior instrumental bone fusion, irreversibly arrests the growth of the spine and chest, potentially limiting lung development, which is especially important in growing children. At the same time, growth-sparing technologies are associated with an expected lower single-stage correction at a higher rate of planned complications. But at the same time, their severity is incomparably lower than in final spinal fusion.

Data on the effectiveness of many growth-sparing systems (Shilla Growth Guidance System, Luque trolley) in NMS remain fragmentary.

Finishing the review, we would like to define a series of questions, which, in our opinion, can become the subject of subsequent study, discussion and debate.

1. It has been proven that conservative treatment of NMS (corsets, special seats, physiotherapy) is unable to stop the progression of severe deformities. Moreover, a rigid corset mechanically worsens respiratory function in such patients. Why then, given the recommendations to operate on such children at deformities exceeding 40–50°, in reality do they usually fall into the field of vision of a spine surgeon when deformities are close to and exceeding 90°?

2. Developing in 60–90% of patients with neuromuscular diseases and progressing as they grow, neuromuscular scoliosis leads to severe chest deformity, restrictive respiratory disorders and respiratory failure. The connection between spinal deformity correction and lung condition is far from an unambiguous understanding: if in progressively developing neuromuscular diseases operations slow down or stabilize the rate of respiratory function deterioration, then how does lung function change in patients with relatively stable neurological status, for example, in childhood cerebral palsy?

3. Despite a multitude of factors potentially influencing outcomes, general indications for staged and final correction of neuromuscular scoliosis are mainly determined by growth potential. What are the limits of individualizing their treatment strategy, including regarding the possibility of less traumatic interventions in patients older than 10 years?

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