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New insights in the prevalence of scoliosis and musculoskeletal asymmetries in adolescents with esophageal atresia

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ABSTRACT

Background: Increased risk of scoliosis and musculoskeletal abnormalities in adolescents with esophageal atresia (EA) is reported, but the impact of these abnormalities on physical fitness and motor skills are not known.

Methods: Scoliosis was assessed radiographically and shoulder and chest abnormalities by a standardized protocol. Physical fitness was evaluated with Grippit, Six-minute walk test, and International Physical Activity Questionnaire and motor skills by Motor Assessment Battery for Children.

Results: Sixty-seven EA adolescents median 16 (13–20) years participated. The prevalence of significant scoliosis ($\geq 20^\circ$) was 12% (8/67) whereas 22% (15/67) had mild scoliosis (10–19°). Vertebral anomalies occurred in 18/67 (27%), eight of them (44%) had scoliosis. The majority of adolescents (15/23) with scoliosis did not have vertebral anomalies. Musculoskeletal abnormalities were detected in 22–78%. Balance problems occurred three times more frequently than expected (44% vs. 15%, $p = 0.004$). Submaximal exercise capacity was significantly reduced compared to reference values ($p < 0.001$). Scoliosis $\geq 20^\circ$ was related to reduced physical activity ($p = 0.008$), and musculoskeletal abnormalities to reduced physical activity and impaired motor skills ($p = 0.042$ and $p < 0.038$, respectively).

Conclusions: Significant scoliosis was diagnosed in 12% of the EA adolescents and related to reduced physical activity. Musculoskeletal abnormalities identified in more than half of the patients, were related to reduced physical activity and impaired motor skills, and exercise capacity was significantly below reference group. EA patients with and without vertebral anomalies need health-promoting guidance to prevent impaired motor skills and consequences of reduced physical activity.

Level of evidence: Prognostic Study, Level II

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1. Introduction

Children with esophageal atresia (EA) are at risk of developing scoliosis, musculoskeletal abnormalities, impaired motor skills and reduced exercise capacity [1–6]. Motor skills and exercise capacity

are vital in keeping up with peers in daily activities during childhood and in adolescence. The prevalence of scoliosis and musculoskeletal abnormalities in children with EA and impact on physical fitness at different ages are poorly understood.

A recent systematic review reports scoliosis after open EA repair with a prevalence ranging from 3% to 67% [7]. EA patients have increased risk of developing both primary scoliosis related to vertebral anomalies and secondary scoliosis without vertebral anomalies. Scoliosis may cause pain, reduced physical fitness and may affect daily activities and quality of life. Scoliosis and musculoskeletal abnormalities are well-recognized complications after neonatal thoracotomy [5,6,8]. The prevalence of deformities seems

Abbreviations: EA, Esophageal atresia; IPAQ, International Physical Activity Questionnaire; MABC-2, Motor Assessment Battery for Children, Second Edition; METs/week, Metabolic Equivalent Task minutes per week; 6MWT, Six-minute walk test; VACTERL, Vertebral defect, Anorectal malformations, Cardiac defect, Trachea-Esophageal fistula, Renal abnormalities, and Limb abnormalities.

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to be reduced, but not eliminated, by muscle sparing thoracotomy [9,10].

We speculated that EA adolescents with scoliosis and musculoskeletal abnormalities have more difficulties with muscle strength, functional exercise capacity, daily life physical activities and motor skills.

The primary aim of our study was to assess the prevalence of scoliosis, vertebral anomalies, and musculoskeletal asymmetries in the shoulder and chest wall in adolescents with EA.

Our secondary aim was to present physical fitness (muscle strength, functional exercise capacity and daily physical activities) and motor skills in EA adolescents, and to explore if scoliosis and musculoskeletal abnormalities are risk factors for reduced physical fitness and impaired motor skills.

2. Material and methods

2.1. Participants

All survivors with EA born between January 1996 and December 2002 ($n = 125$) and operated in one of the three tertiary hospitals in Norway were eligible. We excluded ($n = 7$) patients with neuromuscular or cognitive impairments, e.g. cerebral palsy, muscular dystrophy and trisomy 21. All assessments were performed between 2015 and 2017.

2.2. Design

This cross-sectional study was conducted in the out-patient clinic during interdisciplinary follow-up at our tertiary level university hospital. In addition to clinical and motor assessments the EA adolescents filled out a questionnaire mapping physical activity.

2.3. Medical characteristics

Demographics and clinical data were retrieved from medical records;

- (1) Demographic data: sex, gestational age (GA), prematurity and birth weight.
- (2) Clinical data: EA classification according to Gross [11], cardiac anomalies requiring surgery, VACTERL (Vertebral defects, Anorectal malformations, Cardiac defect, Trachea-Esophageal fistula, Renal abnormalities and Limb abnormalities) association [12], tracheomalacia, duration of ventilation and length of initial hospital stay. Surgical procedures were categorized as: posterolateral right-sided thoracotomy, right-sided thoracotomy with muscle sparing technique, cervical surgical access, re-do surgery of esophagus or trachea-esophageal fistula, sternotomy, fundoplication and previous gastrostomy. Anastomotic strictures requiring > 3 dilations were registered.
- (3) At follow-up: height, (height for age (HFA)), and weight were registered, and body mass index (BMI) calculated according to Norwegian reference data [13].

2.4. Musculoskeletal assessment

2.4.1. Radiographic evaluation

X-ray examinations of the spine were evaluated by two experienced radiologists. Vertebral anomalies were recorded and Cobb angle was evaluated for scoliosis. Scoliosis was divided into Cobb angle $10-19^\circ$, $20-45^\circ$ and $> 45^\circ$ [14].

2.4.2. Clinical evaluation

All standardized assessments were performed following a written procedure by an experienced pediatric physical therapist (UIM). We examined the adolescents in the upright position.

Shoulder asymmetry was identified as a difference of ≥ 2 cm between the left and the right acromion height (yes/no) [15].

Winged scapula was defined as a prominent medial border of the scapula towards the chest wall. Assessment was done in a resting position and during movement with full flexion and abduction of the arms (yes/no) [16].

Atrophy of the pectoralis major muscle was registered by bilateral inspection and palpation of muscle volume (yes/no).

2.5. Assessment of physical fitness

2.5.1. Muscle strength

Grip strength was measured with the validated Grippit instrument for both healthy individuals and subjects with chronic conditions [17–19]. The patients were tested as described by Häger-Ross et al. [17]. The highest peak strength values were recorded. As normative values we used the age-appropriate peak grip strength for the right and left hand reported in Swedish children [17].

2.5.2. Functional exercise capacity

The validated six-minute walk test (6MWT) was used according to the manual to assess the submaximal level of functional exercise capacity reflecting activities of daily living [20]. The 6MWT can be used as a predictor of aerobic capacity in children with chronic medical conditions [21,22]. We used the 95% confidential interval for gender and age categories 12–15 years and ≥ 16 years obtained from a reference group of healthy Austrian children [23].

2.5.3. Physical activity

We evaluated self-reported physical activity with the validated short Norwegian version of the International Physical Activity Questionnaire (IPAQ), which is a questionnaire of physical activity related to daily life during the past seven consecutive days [24,25]. We used the Guidelines for Data Processing and Analysis of the International Physical Activity Questionnaire [26]. The results were calculated into Metabolic Equivalent Task minutes per week scores (METs/week), and then categorized into a level of physical activity: high, moderate, or low [26].

2.6. Assessment of motor skills

Motor skills were evaluated with the Motor Assessment Battery for Children, Second Edition (MABC-2) [27]. A total MABC-2 test-score consists of the sub-scores: manual dexterity (fine motor skills) and gross motor skills (ball and balance skills). We used the 11–16 years age band, with the reference data from the United Kingdom to classify motor performance as normal (percentile score > 15), at risk for motor delay (percentile score 6–15), or motor delay (percentile score < 6) [27].

2.7. Statistics

Data are summarized as numbers (%), mean (SD or range), and median (range) as appropriate. MABC-2 results are presented as categorical data. For comparisons, we have used Mann Whitney tests as appropriate. Correlation analyses were calculated with Spearman's rho. For comparing outcome data in 6MWT with reference data, the results in 6MWT and reference data were converted to z-scores [23]. Normative data values for specific percentiles (1, 2.5, 5, 10, 25, 50, 75, 90, 95, 97.5, 99) were Box-Cox transformed to remove skewness and meet the requirements for a Gaussian distribution. From these a normality plot ($x =$ transformed value,

y = the z-value in the standard normal distribution associated with the percentile) was constructed and estimates for the expectation value μ and standard deviations were calculated. Patient data values (X) were treated likewise. From the value Y = Box-Cox transformed X , the z-score = $(Y - \mu)/s$ was calculated and incorporated in normality plot. To be biologically relevant, the mean z-score difference between the study group and the reference group must supersede the Cohen's $d = 0.2$ criterium. Statistically significant values were accepted at the level $p = 0.05$. Data are analyzed with the use of SPSS Statistics version 25 (IBM, Armonk, NY).

2.8. Ethics

Informed written consent was obtained from all parents and patients. The study has obtained approval from The Norwegian Regional Ethics Committee for Medical Research (2014/1224/REK).

3. Results

3.1. Patients

Among the 125 EA adolescents identified 16 patients (13%) died because of associated major anomalies or serious complications. Of the 109 eligible, seven patients were excluded (Fig. 1). Thirty-four patients (33%) declined participation and 68 adolescents attended follow-up. As one adolescent refused radiographic examination, we were able to include 67 (66%) patients median 16 (13–20) years of age.

3.2. Clinical evaluation

Medical characteristics are listed in Table 1. There were no statistical differences in basic data between the 67 participants and 35 non-participants.

3.3. Radiographic evaluation

3.3.1. Scoliosis

At follow-up 44/67 (66%) had no scoliosis ($< 10^\circ$). Scoliosis between 10° and 19° was observed in 15 (22%) patients, $20\text{--}45^\circ$ in seven (10%) and $> 45^\circ$ in one (1.5%) patient (Fig. 2). One patient with Cobb angle 37° at follow-up had several serious comorbidities with vertebral/costal anomalies and severe early onset scoliosis $> 120^\circ$. This patient had been operated on several times with rib based distraction and vertebral column resection. None of the other patients with scoliosis needed correctional surgery and these patients (12 girls and 10 boys) had a mean Cobb angle of 19° (SD 11) at mean 16.5 years of age (SD 2.2). There was a significant correlation between scoliosis ($\geq 10^\circ$) and age ($r = 0.452$, $p = 0.03$, Fig. 2). All patients with $> 20^\circ$ curvature were 16 years or older and were considered mature.

3.3.2. Vertebral anomalies

In total, 18/67 (27%) adolescents were diagnosed with vertebral anomalies, located at the cervical-thoracic level in eight patients, at the lumbar-sacral level in six, and in four adolescents the vertebral anomalies were located in both the upper and lower spine. Among the patients with vertebral anomalies 8/18 (44%) had scoliosis. Fifteen of the 23 (65%) with scoliosis did not have vertebral anomalies. In the patients without vertebral anomalies the curvature was in the upper thorax and convex to the left in 12 out of 15 patients. The median Cobb angle of the eight patients with scoliosis and vertebral anomalies was 27° ($10\text{--}37^\circ$) compared to median 12° ($10\text{--}48^\circ$) in the patients with scoliosis but no vertebral anomalies

($p = 0.185$). Fifteen of 49 patients (31%) without vertebral anomalies developed scoliosis ($\geq 10^\circ$). In the patients with minimal curvature ($10\text{--}19^\circ$), 3/15 (20%) had vertebral anomalies compared to 5/8 (63%) in the patients with large curvatures ($\geq 20^\circ$).

3.4. Assessment of physical fitness

3.4.1. Muscle strength

When using the Gripit instrument, a significant difference in grip strength between males and females for right and left hand was detected, $p = 0.004$ and $p < 0.001$ respectively, with all mean peak grip strength results lower and outside the reference range values [17]. But peak grip strength between right and left hand did not differ significantly in either males or females ($p = 0.574$ and $p = 0.762$, respectively).

3.4.2. Functional exercise capacity

One patient interrupted the test because of pain in both legs. The median walking distance assessed with 6MWT was 643.5 (473–780) meters. The mean z-score of the study group was -0.87 (SD 1.20), being significantly different from that of the reference group with a mean z-score = 0 ($p < 0.001$) (Fig. 3). Twelve adolescents (18%) had lower functional exercise capacity than the lowest reference limit [23].

3.4.3. Physical activity

Forty adolescents (60%) did not meet the national and international recommendation of 60 min of daily physical activity during one week for adolescents (calculated to at least consisting of 1764 METs/week) [26,28,29]. IPAQ total score did not differ between males and females ($p = 0.922$), with self-reported daily physical activity levels classified as low in 38%, moderate in 35% and high in 27%.

3.5. Assessment of motor skills

Forty-one adolescents (61%) met the appropriate age-criteria for evaluation with MABC-2 scores. Twelve patients (29%) were classified with definite motor function delay (Fig. 4). Balance skills were most frequently affected with only 56% scoring within normal range (Fig. 4).

3.6. Correlation analyzes

Self-reported physical activity was significantly positively correlated to functional exercise capacity ($r = 0.300$, $p = 0.014$).

Low self-reported physical activity was correlated to scoliosis $\geq 20^\circ$ and to identified winged scapula ($r = -0.537$, $p = 0.008$ and $r = -0.251$, $p = 0.042$, respectively). Total motor skills, with balance skills most frequently affected, were negatively correlated to atrophy of the right pectoralis muscle ($r = -0.529$, $p < 0.001$), and fine motor skills correlated to shoulder asymmetry and atrophy of right pectoralis major muscle ($r = -0.361$, $p = 0.022$ and $r = -0.330$, $p = 0.038$, respectively).

4. Discussion

In this study we confirmed our suspicion that scoliosis and musculoskeletal abnormalities are related to physical fitness and motor skills in adolescents born with EA.

One third of the EA adolescents had scoliosis which was correlated to reduced daily physical activity. Interestingly, the majority of patients with scoliosis, 15/23 (65%), did not have vertebral anomalies. This suggests that EA patients without vertebral anomalies also need regular follow-up visits into adolescence or adulthood to evaluate scoliosis. Exercise capacity in EA adolescents was,

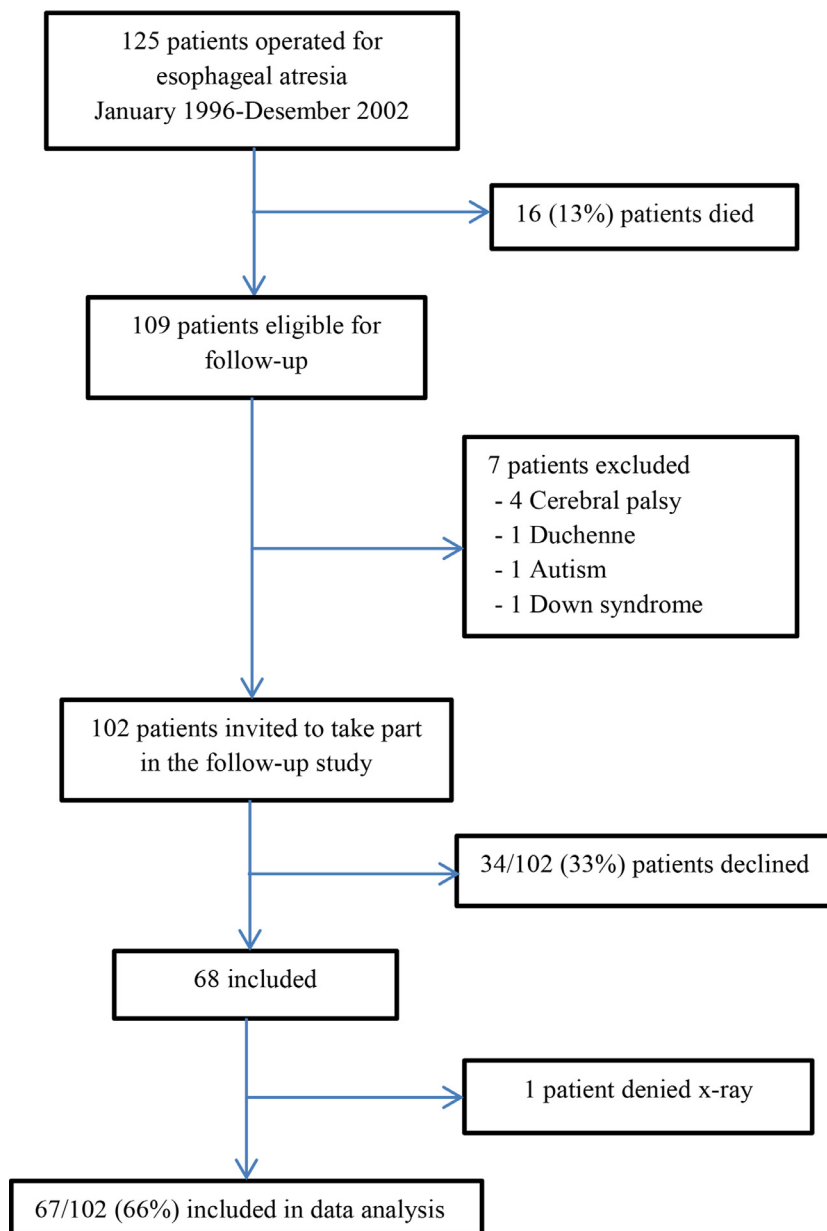


Fig. 1. Flowchart of the included and not included patients. A total sample of 67 adolescents with esophageal atresia (EA) included in the data analysis.

compared to reference values, significantly reduced and shoulder asymmetry and atrophy of the right pectoralis major muscle, were related to impaired motor skills, of which balance skills were the most affected.

Development of scoliosis after EA surgery and other thoracic procedures in children is well known [5-10,30]. In the general population the prevalence of mild scoliosis ($> 10^\circ$) ranges from 0.5% to 3% [14,15]. The EA patients in our study developed scoliosis 10 times more frequently than the normal population. This corresponds with other studies reporting a scoliosis incidence of 18-67% in EA patients [6,8,30,31].

Associated congenital vertebral anomalies are frequently seen in patients with EA and the incidence varies between reports (4-45%). This is in accordance with the 27% found in our study [30-33]. Patients with EA may develop primary scoliosis because of vertebral anomalies, but in our study patients with vertebral anomalies and scoliosis did not have significantly greater spinal curvatures than patients with scoliosis without vertebral anomalies.

The age of the child is of great importance when diagnosing and treating scoliosis. Sistonen et al. reported scoliosis in 56% of 100 adult EA patients after muscle cutting posterolateral thoracotomy, of which 44% had mild scoliosis ($10-20^\circ$) and 12% with more severe curvature ($> 20^\circ$) [31]. They reported a greater number of patients with mild scoliosis, and we therefore cannot ignore the possibility of mild scoliosis becoming overt during adolescence and into adulthood. This would also be suggested by the significant correlation between scoliosis $\geq 10^\circ$ and age in EA adolescents in our study.

As we did a cross-sectional study of our cohort, the data do not allow determination of age of onset of scoliosis. However, it could be assumed that this happens during puberty when skeletal growth is most rapid [15]. This implies that EA children, irrespective of vertebral anomalies, need prolonged follow-up to identify those with Cobb angle $> 20^\circ$ for referral to an orthopedic surgeon.

A systematic review by Mishra et al. reported a 13% prevalence of scoliosis in EA children without vertebral anomalies ($n = 937$)

Table 1
Demographics and clinical evaluations of participants and non-participants.

Variables	Participants n = 67	Non-participants n = 35	P-value
Demographic data			
Gender, male; n (%)	39 (58)	21 (60)	0.862
Gestational age, weeks; median (range)	38 (31–42)	39 (27–42)	0.216
Prematurity, (< 37 weeks GA); n (%)	24 (36)	8 (23)	0.101
Birth weight, grams; median (range)	2820 (1380–4570)	2800 (495–4020)	0.871
Clinical data			
Gross A; n (%)	3 (5)	1 (3)	0.690
Gross C; n (%)	58 (87)	29 (83)	0.617
Gross D; n (%)	4 (6)	1 (3)	0.491
Gross E; n (%)	2 (3)	3 (9)	0.217
Cardiac anomaly requiring surgery; n (%)	3 (5)	4 (12)	0.225
VACTERL association;* n (%)	14 (21)	4 (11)	0.273
Tracheomalacia; n (%)	32 (48)		
Number of days on ventilator; median (range)	2 (1–43)		
Initial hospital stay, days; median (range)	22 (8–264)	20 (11–140)	0.667
Surgery			
Posterolateral right-sided thoracotomy; n (%)	62 (91)	31 (89)	0.203
Right-sided thoracotomy, muscle sparing; n (%)	3 (4)		
Cervical surgical access;** n (%)	2 (3)		
Re-do surgery (esophagus);*** n (%)	7 (10)		
Sternotomy;**** n (%)	3 (4)		
Fundoplication; n (%)	9 (13)		
Previous gastrostomy; n (%)	12 (18)		
> 3 esophageal dilations; n (%)	26 (39)		
Data at follow-up			
Age, years; median (range)	16 (13–20)		
Weight, kg; median (range)	58 (33–111)		
SDS-BMI; median (range)	−0.03 (−3.91–3.10)		
Height, cm; median (range)	167 (138–185)		
SDS-HFA; median (range)	−0.65 (−4.56–1.77)		
Shoulder asymmetry; ***** n (%)	42 (63)		
Winged scapula; n (%)	15 (22)		
Atrophy of right pectoralis muscle; n (%)	52 (78)		

* VACTERL, Vertebral defect, Anorectal malformations, Cardiac defect, Trachea-Esophageal fistula, Renal abnormalities and Limb abnormalities.

** Two patients with H-fistula.

*** Re-do surgery; One re-thoracotomy (n = 5), two re-thoracotomies (n = 1), and three re-thoracotomies (n = 1).

**** Patients with congenital heart disease (CHD) needing surgery with sternotomy.

***** In 37/42 (88%) the right shoulder was elevated compared to the left.

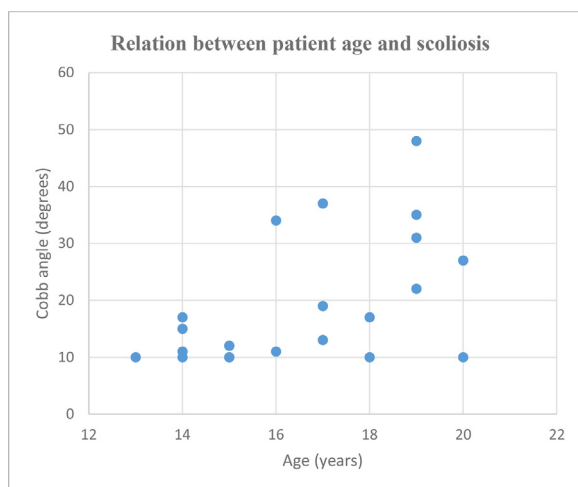


Fig. 2. Scatterplot of adolescents with esophageal atresia (EA) with Cobb angle $\geq 10^\circ$ and age (years). Significant correlation between scoliosis $\geq 10^\circ$ and age (years) ($r = 0.452$, $p = 0.03$).

[7]. Most patients in Mishra's review were younger than the patients in our study, as scoliosis increases with age this may be one reason for the apparent higher prevalence of scoliosis in our study.

In our patients as in most EA patients with thoracic scoliosis without vertebral anomalies, the spinal curvature is convex to the left, i.e. opposite the right posterolateral thoracotomy [8,31]. In

contrast, Soliman et al. reports the curvature convex to the right in a corresponding group of patients [30]. Thus, there may be multiple factors at play in the development of spinal curvatures in EA patients.

With regards to thoracotomy techniques, acquired rib fusion related to tight intercostal closure has been discussed as the cause of the development of scoliosis [7,30,31,34,35]. Sistonen et al. found rib fusions in 30% of adults after thoracotomy, and 60% of these patients developed scoliosis, concluding that rib fusion was a possible risk factor for scoliosis [31]. In contradiction to this, Soliman et al. reported 17% rib fusion in 106 EA children and found no significant relationship between rib fusion and the development of scoliosis [30]. Unfortunately, we were unable to examine postoperative chest X-rays, so we cannot conclude on the frequency of tight intercostal closure and rib fusions in our cohort.

Atrophy of right pectoralis major muscle was registered in more than two thirds of our EA adolescents. This corroborated by a previous report by Cherup et al. after posterolateral thoracotomies in children [36]. We also found impaired grip strength in both hands and no difference between the right and the left hand. Previous studies have demonstrated that in case of right-handed dominance, the strength in the right hand is better than the left hand [17,37]. Lack of strength in a dominant right hand, in combination with atrophy of the right pectoralis major muscle, may pose extra challenges for children and adolescents with EA.

Safa et al. identified in a cohort of 104 children, including 51 EA patients after thoracic procedures including thoracoscopy, musculoskeletal deformities in 39% and scoliosis in 16%. Division of

Table 2
Algorithm for relevant examinations by a pediatric physical therapist in a multidisciplinary follow-up program for children born with esophageal atresia, from infancy throughout childhood into adolescence.

Domains	Assessments	Relevance / intervention
Infancy (0–1 years)		
Motor development	Age-appropriate locally available formal tests	Early referral pediatric physical therapist and provide guidance in follow-up procedure Early referral pediatric physical therapist and orthopedic surgeon if indicated
Musculoskeletal development	Structured physical examination X-ray spine if indicated	
Preschool age (2–5 years)		
Motor development	Age-appropriate locally available formal tests	Referral pediatric physical therapist Motor activity through play Referral pediatric physical therapist and orthopedic surgeon if indicated
Musculoskeletal development	Structured physical examination X-ray spine if indicated	
School age (10–12 years, before puberty)		
Motor development	Age-appropriate locally available formal tests	Referral pediatric physical therapist Referral pediatric physical therapist and orthopedic surgeon if indicated
Musculoskeletal development	Structured physical examination X-ray spine	
Physical fitness	Age-appropriate locally available tests	Encourage to regular physical activity Sports participation / exercise training
- Exercise capacity - Muscle strength		
Adolescence (≥ 13 years into adulthood)		
Motor development	Age-appropriate locally available formal tests	Referral pediatric physical therapist Referral pediatric physical therapist and orthopedic surgeon if indicated
Musculoskeletal development	Structured physical examination X-ray spine if indicated	
Physical fitness	Age-appropriate locally available tests	Regular physical activity Sports participation / exercise training
- Exercise capacity - Muscle strength		

Z-score plot of walking distance

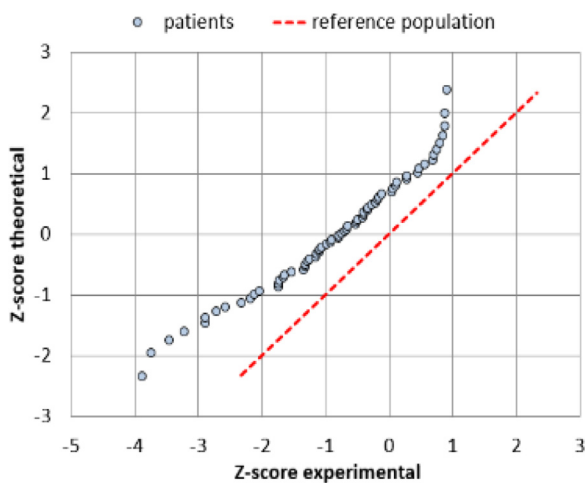


Fig. 3. Z-score plot of six-minute walk test in adolescents with esophageal atresia (EA) ($n = 66$, one missing data). The blue dotted line shows the EA adolescents and the red dotted line shows the reference group [23]. In addition to be statistically significant, the mean z-score difference = -0.865 also superseded the Cohen's $d = 0.2$ criterion, thus being of biological importance.

the serratus anterior muscle was in Safaś study the only significant predictor of developing musculoskeletal deformities, most notably scoliosis. They concluded that the risk of musculoskeletal deformities might be reduced by thoracotomy with muscle sparing technique [9]. Interestingly, in a prospective follow-up study,

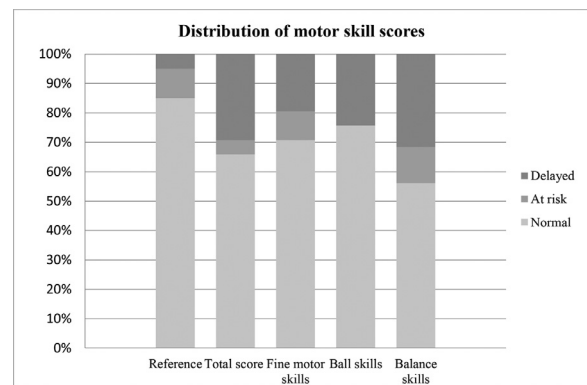


Fig. 4. Motor skill score results (normal, at risk, and delayed) evaluated with Motor Assessment Battery for Children, Second Edition (MABC-2) in esophageal atresia (EA) adolescents ($n = 41$). Reference data (percentile rank), total motor score, fine-, and gross (ball and balance) motor skill scores. The EA adolescents scored significantly worse in balance skills compared to reference data ($p = 0.004$).

wherein 94 out of 106 EA patients had a muscle sparing technique, Soliman reported a 49% prevalence of scoliosis [30]. This may also confirm that EA children, despite minimal traumatic thoracic approach, should be followed-up throughout childhood with the awareness of musculoskeletal abnormalities and scoliosis.

Daily physical activities below national recommendation were reported by more than half of our patients, and reduced daily physical activity and impaired motor skills were related to scoliosis and musculoskeletal abnormalities. We speculate that musculoskeletal asymmetries after thoracotomy may affect trunk stability, leading to impaired gross motor performance, and particu-

larly impaired balance skills. The reasons why the EA adolescents seem to exercise less than reference population are probably multifactorial. We suggest that lack of muscle strength and reduced submaximal exercise capacity are important factors and may discourage physical activity and hence lead to impaired motor performance and reduced physical activity. For a young EA patient physical activity and exercise capacity are important when it comes to socializing with peers, promoting somatic health along with improving cognitive, emotional, and psychosocial development [38]. Earlier studies on quality of life have reported low scores in physical functioning in EA adolescents, which may also be explained by reduced physical performance as registered in our study [39,40]. Therefore, we advocate a multidisciplinary follow-up protocol including standardized examinations by a dedicated pediatric physical therapist for all children with EA throughout childhood into adolescence, to be aware of the risk of developing scoliosis and to provide tailor-made lifestyle counselling (Table 2).

Our study has some limitations: A limited number of patients were assessed for motor development, because the widely used MABC-2 is only validated up to 16 years of age. Validated tests for clinical assessments of muscular asymmetries are missing. The evaluations were, however, performed by standardized assessments following a written procedure, and therefore, we think the observations may contribute to the knowledge on long-term musculoskeletal abnormalities in adolescents with EA.

Closure of the intercostal space may impact on development of scoliosis [9,31,34], and our study is limited in that we were not able to evaluate the closure of the intercostal space in our patients. On the other hand, a systematic review which showed a prevalence of scoliosis in EA adolescents of 13%, found no effect from rib fusion [7]. The impact of intercostal space closure on scoliosis is therefore still unknown.

Strengths of the current study are the relatively large sample of EA adolescents included, particularly concerning the scoliosis evaluations, and that all participants were evaluated by an experienced pediatric physical therapist in one single tertiary level clinic. The instruments used for the evaluations of physical fitness and motor skills are all well validated tests. All assessments (both clinical examinations and questionnaires) were performed during the same day.

5. Conclusion

Scoliosis and musculoskeletal asymmetries were diagnosed in more than one third of the EA adolescents and the prevalence of scoliosis of $\geq 20^\circ$ is high (12%). The recognition of the frequent occurrence of scoliosis in patients without vertebral anomalies, that may not become apparent until the child is older, also provides a warning and possible need for closer follow-up to identify patients needing timely referral for orthopedic evaluation.

Exercise capacity in EA adolescents was significantly lower compared to the reference population and the prevalence of scoliosis and musculoskeletal abnormalities were significantly related to reduced physical activity and impaired motor skills. These sequelae may affect daily life activities with peers and thus affect social life in young EA patients.

Declaration of interest

None

Acknowledgment

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:[10.1016/j.jpedsurg.2022.10.002](https://doi.org/10.1016/j.jpedsurg.2022.10.002).

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