Research Article

Functional deficits in post-operative adolescent idiopathic scoliosis

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Received 13 June 2019

Accepted 8 June 2020

Abstract.

BACKGROUND: Little or no research currently exists investigating musculoskeletal strength, joint flexibility and cardiopulmonary capacity post-operative adolescent idiopathic scoliosis (AIS) patients.

PURPOSE: To explore if AIS patients following spinal fusion surgery have deficiencies in strength, endurance joint flexibility and pulmonary capacity (>12-month post-operative) compared to a matched sample of the general population.

METHODS: This retrospective case control study; AIS group ($n = 20$) and control group ($n = 20$) matched for gender, age and anthropometrics. Participants underwent standardised tests to establish pulmonary capacity via spirometry, upper and lower limb strength via manual muscle testing, upper and lower limb endurance via press-up and wall squat tests and joint flexibility via manual goniometry. Within session reliability and reproducibility of variables were assessed.

RESULTS: No significant differences between AIS and control cohorts were identified for mass (57.1 ± 9.0 vs. 62.8 ± 9.0 kg), height (164.7 ± 6.3 vs. 165.6 ± 6.0 cm) or BMI (21.2 ± 4.0 vs. 22.9 ± 2.7). Pulmonary and musculoskeletal deficiencies in the AIS cohort were identified, including significantly lower forced vital capacity (FVC; 2.6 ± 0.5 vs. 3.3 ± 0.5 L, $P < 0.001$) and forced expiratory volume in 1 second (FEV₁, 2.8 ± 0.6 vs. 3.3 ± 0.5 L, $P < 0.001$); restrictions in shoulder flexion ($P < 0.01$) and internal rotation ($P < 0.001$) weaker bilateral pinch grip ($P < 0.01$) and bilateral hip adductor strength ($P < 0.01$).

CONCLUSION: The results highlight that AIS patients still have major pulmonary and musculoskeletal impairments over a year after spinal fusion surgery. Clinicians should consider periodic assessment of pulmonary and musculoskeletal function with comparison to these age-matched reference values in order to improve the post-operative rehabilitation process.

Keywords: Adolescent idiopathic scoliosis, spinal fusion, functional impairments, physical activity, muscle dysfunction

1. Introduction

Scoliosis is defined as a 3-dimensional spinal deformity with lateral curvature $>10^\circ$ in the coronal plane and restricted rotation from fixed vertebrae [1].

The disorder can result in significant musculoskeletal deformity, pain, impaired pulmonary capacity, and long-term physiological problems [2]. Underlying causes can include congenital, neural, traumatic, infectious and rheumatic deformities of the spine [3]. Approximately 80% of diagnosed scoliotic deformities are idiopathic [4].

Adolescent idiopathic scoliosis (AIS) is the most common spinal deformity in growing adolescents with an estimated prevalence of 2-3% of the general

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population [1]. In some adolescents continued growth of abnormal curvature ceases and requires no clinical intervention. In others, deformity continually increases and eventually requires treatment. Current accepted protocol indicates no treatment for curves with Cobb angle $<10^\circ$, observation and annual re-testing for curves with Cobb angle up to 25° and bracing for deformities between $30\text{--}40^\circ$. For Cobb angles $>40\text{--}45^\circ$ surgical intervention fusing the spine is the preferred option [5]. The primary goal of spinal fusion surgery is to stop curve progression and correct abnormality in trunk posture [5].

Surgery is an invasive option requiring up to 12-months for a return to normal physical activity [6]. According to Westrick [7] current surgical techniques provide the best option for halting curve progression with little follow-up required. However, all forms of surgery, including spinal fusion surgery, have associated risks; Weiss [8] estimated the risk of complications in AIS surgery to be *circa* 20%, with the risk of a major complication at 8.6%. The most common complications from spinal fusion surgery include misplacement of pedicle screws (15.8%), psuedarthrosis or “false fusion” (5%), deep wound infections (3.1%) and neurological complications (1.5%) [8]. These complications have the potential to significantly impair post-surgical recovery and delay a return to normal physical activity. While a prospective study [6] documented that the majority (88.5%) of post-operative AIS patients had returned to unrestricted physical activity within a year, the authors did note that no formal consensus exists on return to physical activity after spinal surgery. A 20-year follow-up study [9] reported that lumbar range of motion and strength were significantly lower in post-operative AIS patients compared to age-matched controls. Considering the significantly greater prevalence of AIS in females [5] and the fact that the majority of physically active adolescent Irish females are involved in a competitive sport [10], it is important that post-surgical AIS patients are adequately assessed to determine if they are functionally capable of safe return to vigorous sport and exercise. The primary aim of our study was therefore to assess anthropometric, musculoskeletal and cardiopulmonary function in individuals with AIS who were greater than 12-months post-surgery and compare this data to a cohort of age and gender matched controls. A secondary aim was to establish the reliability and reproducibility of these assessments in order to determine if they can be reliably implemented by clinicians in an AIS cohort.

2. Material and methods

2.1. Study design

A retrospective case-control trial involving individuals with AIS ($n=20$) who were greater than 12-month post-surgery and controls ($n=20$) matched for gender, age and anthropometrics was performed. Prior to study commencement an *α-priori* test was performed indicating that for an effect size of 0.9, an α level of 0.05 and a statistical power at 0.85 the required sample size was 19 individuals per group.

Participants in the AIS cohort were recruited via information leaflets issued by administrative gatekeepers in Crumlin Childrens’ Hospital and the Blackrock Clinic, to a large cohort of AIS patients who were >12 -month post-operation. Participants in the control cohort were recruited via information posters at local schools and universities in the greater Dublin area. Written details of all test procedures were provided in an information leaflet in advance of their scheduled appointments. Informed written consent was obtained from all participants. Written parental consent was required for participants under the age of 16.

Inclusion criteria for the AIS cohort required participants to have a diagnosis of AIS and have received spinal fusion surgery >12 -month prior to study commencement. Exclusion criteria for both AIS and control cohorts included age 14–35yr, musculoskeletal injury, balance problems or reported neurological condition restricting exercise, playing elite competitive sport at a senior level, pregnant or a breastfeeding mother, or advised on medical grounds not to exercise.

ACSM Health Status and Health History Questionnaires were completed by all participants as part of the pre-trial screening. Participants who had incomplete or dissatisfactory questionnaires were excluded.

Participants were instructed to wear shorts and light clothing for testing and refrain from physical activity or sport on the test day. Additionally, they were advised to remove all jewellery and have a light meal at least 2 hours prior to testing, with no caffeine consumption, or smoking, for a minimum of 30 minutes (min) before test commencement. All participants underwent the same validated tests to establish musculoskeletal flexibility, strength, endurance and cardiopulmonary function. All data were collected by a single operator who was a CORU certified physiotherapist, skilled in anthropometric, musculoskeletal and cardiopulmonary assessment. Ethical approval

was granted by Our Ladies Children's Hospital Crumlin (OLCHE) Dublin, Ireland and all testing procedures adhered to the Declaration of Helsinki.

2.2. Anthropometric measures

Height was assessed using a portable stadiometer (Seca, Hamburg, Germany) to the nearest centimeter (cm) with participant's heels, buttocks and upper back touching the stadiometer and head positioned in the Frankfurt plane, body mass to the nearest 0.1 kilogram (kg) was measured using a digital scale (Body Fat Scale, Gewerbestrasse, Austria) and body mass index (BMI) was subsequently calculated. A Harpenden skinfold caliper (Baty International, West Sussex, UK) assessed dominant side triceps skinfold in standing and medial calf skinfold in sitting, data were recorded to the nearest 0.1 millimetre (mm). Limb length data was recorded using a standard measuring tape to the nearest cm. Upper limb data were recorded from spinous process of C7 to tip of the longest digit on both limbs. Lower limb data were measured from anterior superior iliac spine to medial malleolus on both limbs.

2.3. Cardiopulmonary measures

Resting blood pressure and heart rate were assessed using an automated sphygmomanometer (Omron Healthcare, The Netherlands). Mean Systemic Arterial Pressure (MSAP) was subsequently calculated. Pulmonary function tests were performed using a hand-held spirometer (MicroMedical, Surrey, UK) following the guidelines of the American Thoracic Society [11]. Measurements, recorded in litre (L), included forced expiratory volume in 1 second (FEV₁) and forced vital capacity (FVC), and ratio of FEV₁ to FVC computed (FEV₁/FVC). Tests were repeated every minute until two satisfactory results were achieved showing data within 5% or 150 millilitre (mL) of each other.

2.4. Flexibility measures

Flexibility measurements were preceded by a gentle warm-up consisting of light jogging for 3 min. Upper and lower limb joint range of motion (ROM) were assessed using a standard universal goniometer (Baseline Evaluation Instruments, NY, USA) and validated protocols [12]. While the gold standard for measuring joint ROM is radiography, the use of goniometry shows a high level of reliability and

accuracy [13]. Upper limb measures included bi-lateral shoulder flexion, extension, internal and external rotation. Lower limb measures included bi-lateral hip flexion, extension, abduction and adduction, ankle plantarflexion and dorsiflexion. All measurements were assessed twice and an inter-test difference >5° required recording of a further measurement. A mean of the 2 or 3 measurements was subsequently calculated. Lumbar spine flexion and extension were measured using a validated tape measure test [14]. Lumbar spine, hamstring and hip flexors were also assessed using a standard sit and reach (SAR) box (Cranlea, Birmingham, UK) [15]. Following a warm-up, including hamstring stretches and 10 touch the toes in standing, participants had 3 attempts, data were recorded to the nearest 0.5 cm.

2.5. Musculoskeletal strength and endurance

Muscular strength and endurance measurements were preceded by an additional 3-min warm-up of light jogging. Upper limb strength was assessed using a hand-grip dynamometer (Takei, Tokyo, Japan) using a validated protocol [16]. Three maximal attempts were recorded bilaterally with a 30 second (s) rest between alternate hands; maximum force (kg) data were recorded. More localised pinch strength tests were also measured using a digital pinch-grip analyser (MIE Medical Research, Leeds, UK) using validated protocols [17]. Testing required a horizontal grip on the handle using all digits on one hand. Three bi-lateral maximal attempts were assessed with a 1-min rest between alternate hands, maximum force data in Newton (N) were analysed. Back muscle strength [18] was assessed using a Takei back-D dynamometer; maximum data (N) from three attempts was analysed. A manual muscle tester (Lafayette Instrumentation, NY, USA) assessed lower limb muscle strength using validated protocols [19], data were recorded in kg of pressure to the nearest 0.1 kg. Bi-lateral hip flexors and extensors, knee flexors and extensors, ankle plantar and dorsiflexors, and hip abductors and adductors were assessed. Three measurements were recorded for each strength test and muscle assessed, the lowest was eliminated, and a mean of the remaining two were used for analysis. Upper limb endurance was quantified using the modified push-up test [15]. Participants were encouraged to perform as many full-range modified push-ups as possible without pausing until failure and number fully completed recorded. Lower limb muscle endurance was measured using the one leg wall-squat

test [20]. A standard chronograph recorded wall-squat duration, a rest period of 3 min was included prior to testing the opposite leg.

2.6. Statistical analysis

Group results are presented as mean and standard deviation (SD). Intra-session data reproducibility in both cohorts were quantified using relative technical error of measurement (%TEM), inter-class correlations (ICC) and 95% limits of agreement (LoA) calculated on repeated strength tests. D'Agostino and Pearson's test assessed data normality. Data were normally distributed, therefore un-paired Student's *T*-tests compared inter-group differences. Bonferroni corrections were applied for multiple pairwise comparisons, with an adjusted critical- α set within the following test families; anthropometric ($\alpha=0.005$), cardiopulmonary ($\alpha=0.01$), flexibility ($\alpha=0.0038$), musculoskeletal strength data ($\alpha=0.0038$). Meaningfulness of detected differences were subsequently quantified for significant findings using Cohen's *d*. An effect size (*d*) of <0.20 was considered trivial, 0.20 to 0.49 small, 0.50 to 0.79 moderate and >0.80 large. All statistical analysis was conducted in Graphpad Prism version 6.0 (Graphpad Software, CA, USA).

3. Results

3.1. Participant characteristics

Forty post-operative scoliosis participants who had received spinal correction surgery in Our Ladies Children's Hospital Crumlin (OLCHE) were contacted and asked to participate in the current study. Thirty-two responded expressing an interest. Of these, twenty ($n=20$) participants met all inclusion criteria and were available to take part. A matched cohort of healthy controls ($n=20$) was subsequently recruited from local schools and universities.

In total, 38 females and 2 males participated in the study. The mean age ($\pm$ SD) for the control and AIS groups were 18 ± 1 and 18 ± 2 year, respectively. The time range between surgery and assessment was 14 to 40 months for AIS participants. All AIS participants had spinal curvatures more than 80° and received the same type of surgery; posterior correction with spinal fusion. Eleven of the participants had full thoracic fusions, seven had thoracic-lumbar fusions and two individuals had lumbar only fusions. Participant

Table 1
Group mean (SD) anthropometric and cardiopulmonary data

	Control	AIS	<i>d</i>
Anthropometrics			
Age (yr)	18 (1)	18 (2)	–
Mass (kg)	62.8 (9.0)	57.1 (9.0)	–
Height (cm)	165.6 (6.0)	164.7 (6.3)	–
BMI ($\text{kg}\cdot\text{m}^{-2}$)	22.9 (2.7)	21.2 (4.0)	–
Right triceps skinfold (mm)	10.8 (4.5)	14.5 (6.1)	–
Right medial calf skinfold (mm)	12.4 (5.8)	14.3 (5.0)	–
Right upper limb length (cm)	85.0 (4.0)	84.2 (3.9)	–
Left upper limb length (cm)	84.6 (3.5)	84.5 (3.4)	–
Right lower limb length (cm)	87.2 (3.7)	88.4 (5.0)	–
Left lower limb length (cm)	86.9 (3.7)	88.4 (4.9)	–
Cardiopulmonary			
Resting HR (beats min^{-1})	74 (10)	83 (17)	–
MSAP (mmHg)	85 (9)	86 (10)	–
FEV ₁ (L)	3.3 (0.5)	2.6 (0.5)***	1.47
FVC (L)	3.6 (0.5)	2.8 (0.6)***	1.47
FEV ₁ / FVC (%)	91.5 (7.4)	92.3 (5.5)	–

Asterisk symbol (*) infers significant inter-group differences, * $P<0.05$ and *** $P<0.001$.

characteristics for both cohorts are presented in Table 1. There were no statistically significant inter-group differences detected for any of the anthropometric measures ($P>0.005$ for all comparisons).

3.2. Cardiopulmonary measures

There were no significant inter-group differences in mean resting heart rate or blood pressure (see Table 1). However, significant differences were observed in pulmonary data. FEV₁ was significantly lower in the AIS group compared to age matched controls (2.6 ± 0.5 vs. $3.3 \pm 0.5\text{L}$, $P<0.001$, $d=1.47$). FVC was also significantly lower in the AIS group (2.8 ± 0.6 vs. $3.6 \pm 0.5\text{L}$, $P<0.001$, $d=1.47$). No significant inter-group difference was detected for FEV₁/FVC ratio data.

3.3. Flexibility measures

Upper and lower limb joint flexibility data are presented in Table 2. The control group were in general more flexible than AIS for all joint measurements with the exception of ankle plantarflexion. Significant inter-group differences were detected in bi-lateral shoulder flexion and internal rotation (see Table 2). Specifically, bilateral shoulder flexion (156 ± 19 vs. $171 \pm 13^\circ$ on right, $P<0.01$, $d=0.92$; 158 ± 18 vs. $173 \pm 12^\circ$ on left, $P<0.01$, $d=0.88$) and bilateral internal rotation (54 ± 15 vs. $76 \pm 21^\circ$ on right, $P<0.001$, $d=1.39$; 54 ± 15 vs. $77 \pm 24^\circ$ on left, $P<0.001$, $d=1.20$) were significantly lower

Table 2
Group mean (SD) joint flexibility data

Joint	Variable	Right			Left		
		Control	AIS	<i>d</i>	Control	AIS	<i>d</i>
Shoulder	Flexion	171 (13)	156 (19)**	0.92	173(12)	158 (18)**	0.88
	Extension	55 (17)	55 (14)	–	57 (15)	50 (15)	–
	Int. Rotation	76 (21)	50 (15)***	1.39	77 (24)	54 (15)***	1.20
	Ext. Rotation	82 (17)	82 (11)	–	88 (12)	81 (14)	–
Hip	Flexion	119 (10)	115 (10)	–	120 (10)	116 (15)	–
	Extension	22 (6)	18 (8)	–	25 (9)	20 (10)	–
	Abduction	52 (15)	43 (15)	–	48 (11)	42 (15)	–
	Adduction	30 (11)	25 (10)	–	30 (10)	27 (11)	–
Ankle	Plantarflexion	65 (17)	69 (10)	–	64 (17)	69 (12)	–
	Dorsiflexion	13 (6)	16 (5)	–	15 (5)	16 (5)	–

The unit of measure throughout is °. Asterisk symbol (*) infers significant inter-group differences, * $P < 0.05$, ** $P < 0.01$ and *** $P < 0.001$.

Table 3
Group mean (SD) lumbar spine flexibility and strength data

Joint	Variable	Control	AIS	<i>d</i>
Lumbar Spine	Flexion (°)	4.9 (1.3)	3.4 (1.8)**	0.97
	Extension(°)	3.3 (1.3)	1.9 (1.0)***	1.21
	Strength (kg)	82.7 (16.4)	70.4 (16.2)	–
	SAR (cm)	29.1 (15.8)	13.8 (11.5)**	1.11

Asterisk symbol (*) infers significant inter-group differences, * $P < 0.05$, ** $P < 0.01$ and *** $P < 0.001$.

SAR infers sit and reach test.

Table 4
Group mean (SD) strength data

Joint	Variable	Right			Left		
		Control	AIS	<i>d</i>	Control	AIS	<i>d</i>
Upper limb	Squeeze test	30.3 (5.7)	26.7 (3.9)	–	29.5 (5.8)	25.9 (3.8)	–
	Pinch-grip test	255 (61)	203 (33)**	1.05	239 (59)	187 (42)**	1.02
Hip	Flexion	18.1 (3.9)	15.9 (4.3)	–	17.8 (4.7)	15.9 (5.6)	–
	Extension	18.6 (4.0)	14.5 (4.4)*	0.99	18.8 (5.2)	14.9 (6.1)	–
	Abduction	11.7 (4.0)	8.9 (1.7)	–	11.7 (4.8)	9.1 (1.8)	–
	Adduction	10.1 (4.0)	6.9 (1.3)**	1.06	9.3 (3.0)	6.5 (1.0)**	1.26
Knee	Flexion	12.4 (3.6)	11.9 (3.1)	–	12.1 (3.6)	11.8 (3.1)	–
	Extension	17.1 (4.0)	16.6 (4.4)	–	17.5 (4.4)	16.8 (4.8)	–
Ankle	Plantarflexion	17.6 (5.0)	15.6 (3.1)	–	18.6 (5.7)	15.6 (3.3)	–
	Dorsiflexion	14.4 (6.3)	10.4 (3.4)	–	15.3 (7.6)	10.8 (3.4)	–

The unit of measure is kg except for Pinch-grip test (N). Asterisk symbol (*) infers significant inter-group differences, * $P < 0.05$, ** $P < 0.01$ and *** $P < 0.001$.

in the AIS group. No significant inter-group differences were observed for flexibility at the hip or knee joints. Lumbar spine flexion (4.9 ± 1.3 vs. $3.4 \pm 1.8^\circ$, $P < 0.01$, $d = 0.97$) and extension (3.3 ± 1.3 vs. $1.9 \pm 1.0^\circ$, $P < 0.001$, $d = 1.21$) were significantly greater in control, reflecting the group's greater lumbar mobility. Reduced lumbar flexibility in AIS was reiterated by the SAR test where mean reach distance for AIS was significantly lower (13.8 ± 11.5 vs. $29.1 \pm 15.8^\circ$, $P < 0.001$, $d = 1.11$, see Table 3).

3.4. Musculoskeletal strength and endurance

Strength test data are presented in Table 4. Results indicate that the control group had greater upper limb strength, with significant inter-group differences observed in bi-lateral pinch-grip strength (see Table 4). Significant differences in lower limb strength were identified in bi-lateral hip adduction strength, and right hip extension strength (see Table 4). No inter-group difference in lumbar extension strength was observed (see Table 3).

Table 5
Reliability data for strength and tests

Variable	Control				AIS			
	Upper 95%LoA	Lower 95%LoA	% TEM	ICC	Upper 95%LoA	Lower 95%LoA	%TEM	ICC
Hip flexion (R)	2.9	-2.6	5.4	0.94	1.9	-0.9	3.1	0.98
Hip extension (R)	1.5	-1.7	3.1	0.98	1.8	-1.3	3.8	0.98
Hip flexion (L)	2.8	-2.2	2.1	0.99	2.1	-1.2	4.2	0.99
Hip extension (L)	1.5	-0.8	2.1	0.99	1.7	-1.2	3.6	0.99
Knee extension (R)	2.3	-2.3	4.7	0.96	2.2	-2.3	4.6	0.97
Knee extension (L)	1.9	-1.7	3.6	0.98	1.7	-2.0	4.1	0.98
Knee flexion (R)	1.9	-1.3	4.9	0.97	1.8	-0.8	4.0	0.97
Knee flexion (L)	1.8	-1.5	4.9	0.97	1.4	-0.9	3.4	0.98
Ankle plantarflexion (R)	2.1	-2.0	4.1	0.98	1.9	-1.4	3.9	0.97
Ankle plantarflexion (L)	3.0	-1.4	5.0	0.97	1.6	-1.3	3.5	0.75
Ankle dorsiflex (R)	2.3	-1.6	5.0	0.99	1.5	-1.1	4.5	0.98
Ankle dorsiflex (L)	2.0	-2.2	4.9	0.99	1.2	-0.7	3.5	0.99
Hip abduction (R)	1.5	-1.5	4.5	0.98	1.2	-1.0	4.5	0.96
Hip abduction (L)	1.1	-1.1	3.4	0.99	0.9	-0.7	3.0	0.97
Hip adduction (R)	1.3	-1.4	4.8	0.98	1.0	-0.8	4.6	0.95
Hip adduction (L)	1.0	-1.0	3.6	0.99	0.8	-0.7	3.9	0.94
Hand Grip (R)	4.7	-3.4	5.2	0.92	3.8	-3.8	4.9	0.95
Hand Grip (L)	4.8	-2.3	5.6	0.92	5.0	-3.1	6.4	0.91
Pinch Grip (R)	13.5	-16.1	9.5	0.91	16.7	-15.2	16.3	0.88
Pinch Grip (L)	15.8	-12.2	9.6	0.91	19.7	-11.3	15.3	0.84
SAR	1.7	-4.7	5.3	0.99	1.5	-3.6	8.4	0.99

95% LOA data are presented in kg for all variables except SAR (cm).

Greater levels of upper limb muscular endurance were observed in the control group via the modified push-up test (24 ± 11 vs. 16 ± 8 repetitions), however this result did not attain statistical significance ($P=0.012$). No significant differences were identified in lower limb endurance assessed using bi-lateral wall squats. Although the control group had greater time to failure for both right (34 ± 36 vs. 22 ± 19 -s) and left wall squat test (29 ± 34 vs. 22 ± 15 s), neither test attained statistical significance.

3.5. Intra-session data reproducibility

Calculated ICC data are presented in Table 5. With the exception of AIS data for ankle plantarflexion in left limb, reliability for all measurements were deemed excellent. Computed %TEM data (≤ 5.0 %) for all assessed variables with the exception of right hip flexion in control and SAR data in both groups were deemed acceptable. Bland Altman analysis identified that difference data were homoscedastically distributed and had narrow 95% LoA about mean bias data close to zero in both groups.

4. Discussion

The current study identified a range of physiological and musculoskeletal deficiencies in 12-month

post-operative AIS patients when compared with healthy age-matched controls. Firstly, the AIS cohort had significantly lower lung function than controls. Secondly, the AIS cohort had significant restrictions in joint ROM, involving shoulder flexion, shoulder internal rotation and lumbar spine extension and flexion. Thirdly, the AIS cohort had significantly weaker upper limb strength in addition to lower limb weakness particularly in the muscle groups controlling and protecting the hip, such as the gluteal and hip adductor complex. The overall results highlight that individuals with AIS returning to unrestricted physical activity, 12-month after spinal-fusion surgery [6], do so with major functional impairments. These impairments include musculoskeletal weakness and restricted joint ROM, both of which are deemed intrinsic risk factors for sports injury [21]. Clinicians should be aware of these functional impairments in their patients prior to recommending a return to vigorous sport and exercise. This study demonstrated that standardised assessments of musculoskeletal function show high levels of reliability in both AIS and age-matched controls. We therefore support the use of these assessments as a means identifying individual functional deficits and developing more tailored post-operative rehabilitation programmes.

4.1. Cardiopulmonary measures

The AIS cohort had significantly lower lung capacity than age-matched controls, supporting previous research [22, 23]. The Society on Scoliosis Orthopaedic and Rehabilitation Treatment (SOSORT) guidelines [4] list abnormal restrictive ventilation patterns, impaired muscle function and asymmetric chest wall movement as significant pulmonary impairments in AIS. Several potential causes have been postulated for these impairments including; lateral flexion dysfunction, vertebral rotation, thoracic cage limitations and stiffness. An early paper by Shneerson and Edgar [22] examined pre-and post-operative pulmonary data from AIS patients and concluded that spinal fusion led to anatomical improvements with little or no change in pulmonary function. These findings have been supported by other studies [23]. It is possible that the deficits in pulmonary function associated with AIS can be ameliorated through conservative interventions such as inspiratory muscle training (IMT). Alves & Avanzi [24] reported significant improvements in inspiratory and expiratory pressure following a 4 month intervention of IMT in a cohort of severe AIS patients who had not undergone surgery. However, it remains to be seen if such an approach might improve lung function in AIS patients following spinal-fusion surgery. Nonetheless, impaired pulmonary function can have severe implications for exercise capacity [25] and such impairments should be identified and if possible improved upon before AIS patients return to vigorous exercise.

4.2. Joint flexibility

The current study demonstrated that significant deficits in shoulder and spinal mobility exist in AIS patients who are more than 12 months post-surgery. While all measures of flexibility in the lower limb joints were reduced in the AIS cohort, no significant inter-group differences were observed at the hip, knee or ankle (see Table 2). To our knowledge, no published studies exist which have assessed shoulder flexibility in AIS patients. Several studies have examined shoulder balance and scapulohumeral rhythm [26–28] supporting the premise that development of AIS impairs functional movement of the shoulder joint [28]. The current study demonstrates that significant bi-lateral restrictions in shoulder mobility are evident in post-operative AIS participants, specifically in shoulder flexion and internal rotation.

Lin et al. [26] reported shoulder dysfunction on the convex side of the spinal curvature but no evidence of dysfunction on the concave side; however, they did not assess post-operative participants. Post-operative assessment of shoulder mobility along with targeted stretching exercises may facilitate a faster return to normal shoulder mobility, however the efficacy of such an intervention has yet to be demonstrated. Further research aimed at improving shoulder mobility and function following spinal fusion surgery is therefore warranted, since impaired range of motion is a risk factor for shoulder injury in many sports [21, 29]

Significant differences were also identified in lumbar mobility both in flexion and extension along with SAR assessment (see Table 4). Considering the nature of spinal fusion surgery, this finding is unsurprising and in agreement with previous research which demonstrated impaired spinal mobility both in cohorts undergoing bracing and those who underwent spinal fusion [9, 28]. Danielsson et al. [9] reported a significant correlation between spinal mobility and impaired daily function measured during a 20-yr follow-up from spinal fusion surgery. They also reported a stronger correlation between lumbar strength and daily function. While spinal fusion surgery may physically limit the capacity to improve lumbar ROM, the findings from Danielsson et al. [9] suggest that it is worthwhile developing lumbar strength (specifically lumbar extensor strength) in post-operative AIS patients in order to improve long-term performance of activities of daily living.

4.3. Strength

The current results highlight that significant upper and lower limb strength deficits exist in >12 month post-operative AIS patients. Previous research investigating skeletal muscle strength in pre-operative AIS patients has reported significant weakness in both upper and lower limb muscle groups, measured via hand-grip dynamometry and isometric knee extension, respectively [30]. While the current study did not measure pre-operative muscle strength, a comparison of knee extensor strength data with the results presented by Martinez-Lorens et al. [30] suggests that spinal fusion surgery may positively influence knee muscular strength. The significant bi-lateral weakness of the hip observed in the current study is in agreement with previous research which has reported hip muscle strength asymmetries [32, 33]. Hopf et al. [34] assessed pre- and post-operative AIS and control groups and observed asymmetrical hip abductor

and adductor EMG activity in both the pre- and post-operative AIS cohorts. These combined findings [32–34] suggest that post-operative AIS patients with hip muscle strength deficits may require a combination of strength and neuromotor exercises to relearn appropriate patterns of muscle activation.

No significant inter-group difference in lumbar extensor strength was observed in the current AIS cohort. This finding contradicts the work of Danielsson et al. who observed weaker lumbar flexion and extension in both spinal-fusion and bracing cohorts, during a 20-y follow-up [9]. Previous research [28] has reported asymmetry in spinal musculature in terms of mass, structure and function, concluding that pre-operative AIS patients were weaker when rotating toward their curve's concave side. While the current AIS cohort did display weaker lumbar extension strength than their age matched controls (70.4 ± 16.2 vs. 82.7 ± 16.4 kg, $P=0.022$), this finding did not attain statistical significance during multiple pairwise comparison. The high degree of variance in lumbar strength measures, along with the large number of strength assessments performed in this study, may explain this disagreement from the existing literature.

4.4. Test reliability

Despite significant functional deficits compared to their age-matched controls, the AIS cohort demonstrated similarly reliable performance of all strength tasks as indicated by the large ICC, low TEM and narrow 95% LOA ranges (see Table 5). Measurements are generally deemed clinically relevant if the ICC's are greater than 0.90 [33]. With the exception of ankle plantarflexion and pinch grip strength, all measures in this study exceeded that threshold. Since the significant differences observed exceeded the 95% LOA for each measure, these differences can be considered clinically relevant. In addition the results highlight that this test battery can reliably be used to assess musculoskeletal function in post-operative AIS patients. Future studies could therefore use this test battery to reliably track changes in musculoskeletal strength and flexibility in AIS populations and compare to healthy control data.

4.5. Limitations

Before drawing conclusions from the current study, it is important to highlight several limitations. Firstly, no pre-operative data were collected from the AIS cohort, so it is impossible to determine if outcome measures improved or worsened following surgical

intervention. Secondly, the AIS cohort in the current study came from a single site and the majority were under the care of a single clinician. Outcome measures may vary depending on the pre- and post-operative clinical care provided. The post-operative care pathway for scoliosis patients in Ireland consists of a 3-month post-operative patient review by a surgeon. Referral for post-operative physiotherapy is not universal and is usually made on an '*ad-hoc*' basis, dependent on caregiver's opinion. It was beyond the scope of the current study to determine the level of post-operative rehabilitation which the AIS cohort underwent. Thirdly, manual field-based assessments of muscular strength and endurance were used in the current study. The gold standard for muscular strength testing is isometric or isokinetic dynamometry, while radiography is considered the gold standard for measuring joint ROM. However, access to laboratory based equipment and a radiographer did not allow for these measurement to be performed in the current study. Finally, it was not possible to determine if cardiopulmonary or musculoskeletal deficits identified are systemic in origin or due to underlying physical activity levels. This point has previously been highlighted by Martinez-Lorenz et al. [30] as it is important that the underlying cause of functional and physiological impairments in AIS be established. Further research is warranted to establish if a supervised post-operative strength and conditioning programme could potentially offset some of these deficits.

5. Conclusions

The current study identified significant musculoskeletal and cardiopulmonary deficits among post-operative AIS patients. In addition, the study established that standardised assessments of musculoskeletal and cardiopulmonary function show high levels of reliability in both AIS and age-matched controls. Clinicians should therefore consider periodically assessing these variables in post-operative AIS patients and developing a tailored rehabilitation programme to correct identified deficits prior to recommending a return to unrestricted physical activity. While spinal fusion surgery remains an important intervention in the treatment of severe progressive scoliosis, the overall findings highlight the need for a more focused management of post-operative patients through the use of periodic musculoskeletal assessment and targeted exercises to reduce any functional deficits.

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