



Comparison of the postoperative changes in trunk and lower extremity muscle activities between patients with adult spinal deformity and age-matched controls by using surface electromyography

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1 Title: Comparison of the postoperative changes in trunk and lower extremity muscle activities between patients with adult spinal deformity and age-matched controls by using surface 2 3 electromyography 4 5 Abstract **Study Design**: 6 A prospective study 7 **Objective:** 8 9 To investigate the paravertebral and lower extremity muscle activities using surface electromyography (S-EMG) in patients with adult spinal deformity (ASD) comparing with those of age-matched controls. 10 **Summary of Background Data:** 11 Although the paravertebral muscle is greatly involved in ASD pathology, little is known about the 12 contribution of lower extremity muscle on maintaining standing posture. 13 14 **Methods:** Fourteen patients with ASD (1 man, 13 women; mean age, 67.1 years) who underwent corrective fusion 15 surgery with at least 2 years of follow-up and age-matched controls (1 men, 7 women; mean age, 69.3 years) 16 were enrolled. The muscle activities of the thoracic and lumbar erector spinae (TES and LES), external 17 oblique (EO), gluteus maximus (GM), rectus femoris (RF), and biceps femoris (BF) were recorded in the 18

19 upright and anterior flexion positions using S-EMG pre-operatively and 1 year post-operatively.

# 20 **Results:**

21	Compared with controls, patients showed a significantly higher muscle activity in the LES and BF at rest
22	in a standing position. After corrective fusion surgery, the muscle activity of LES decreased and that of RF
23	increased (p<0.05), and the changes reached the level of the controls. When the posture changed from
24	upright to anterior flexion, the controls showed increased muscle activity of the BF, whereas the patients
25	showed decreased muscle activity of the TES and RF and increased muscle activity of the BF. Post-
26	operatively, muscle activity of the TES, LES, GM, and BF increased and that of the RF decreased.
27	Conclusions:
28	ASD patients required a higher activity of the lower extremity and trunk muscles to maintain a standing
29	position compared to the age-matched controls. Significant increase of the GM, BF, and TES muscle
30	activities during anterior bending suggest the presence of mechanical stress concentration caused by fixed
31	lumbar spine.
32	Keywords: adult spinal deformity, lower extremity, electromyography, operation, paraspinal muscle
33	Level of Evidence: Level III
34	Key points:
35	• We assessed the paravertebral and lower extremity muscle activities using surface electromyography
36	in patients with adult spinal deformity (ASD) and compared the results with those of controls.

- The patients with ASD required a higher activity of the lower extremity and trunk muscles to
- 38 maintain a standing position, compared with age-matched controls.
- After corrective fusion surgery, the muscle activity of lumbar erector spinae decreased and that of
- 40 rectus femoris increased.
- 41 The muscle activity of gluteus maximus, biceps femoris, and thoracic erector spinae significantly
- 42 increased during anterior bending after surgery.

#### 45 Introduction

Although various factors, such as disc degeneration, osteoporosis-related vertebral fracture, and 46 impairments in strength and function of the trunk muscles, affect the development and deterioration of 47 48 spinal alignment, the etiology of adult spinal deformity (ASD) is still unclear [1,2]. Many authors reported that the paravertebral muscles are greatly involved in the development and progression of spinal deformity 49 [2-5]. Takemitsu et al.[6] revealed that patients with lumbar degenerative kyphosis had a significantly lower 50 lumbar extensor strength and marked atrophy of the paraspinal muscles with fatty infiltration than 51 individuals with no history of degenerative lumbar spine disease. According to the "cone of economy" 52 53 theory proposed by Dubousset et al.[7], anterior tilting of the trunk would increase the work of the paravertebral extensor muscles in maintaining an upright posture. We previously reported that trunk tilting 54 during standing and walking was significantly correlated with the cross-sectional area of the paravertebral 55 muscles [8]. Hanada et al. [9] evaluated the paravertebral muscle activation amplitudes during walking using 56 surface electromyography (S-EMG) in elderly patients with low back pain and demonstrated that the back 57 58 extensor muscles were significantly activated to higher amplitudes compared to the asymptomatic control group, indicating the important role of these muscles in stabilizing the spine. Hyun et al.[10] reported that 59 the patients with proximal junctional failure (PJF) after a long spinal fusion surgery had lower 60 thoracolumbar muscularity and higher fatty degeneration than patients without PJF, indicating that the 61 paravertebral muscles were also crucial for maintaining the postoperative sagittal alignment and preventing 62

63	junctional failure. On the other hand, the pelvis and lower extremity cooperatively compensated for spinal
64	kyphosis to prevent anterior translation of the axis of gravity, with the extent of compensation depending
65	on spine stiffness and musculature status [11]. Therefore, the lower extremity muscles also play an
66	important role in maintaining the standing posture. Understanding the function of these muscles is
67	fundamental to prevent or slow down the progression of deformity in these patients. To the best of our
68	knowledge, the specific contribution of the paravertebral and lower extremity muscles in maintaining the
69	standing posture for patients with sagittal malalignment has not been evaluated.
70	Measuring the cross-sectional area is a simple and effective way of assessing muscle; many authors have
71	therefore used this method to investigate the relationship between spinal deformity and the paravertebral
72	muscles [10,12]. However, a multi-faceted analysis of the important parameters, such as the quality of the
73	muscle tissue (measured using histological analysis), muscle strength (measured using isokinetic muscle
74	power), and muscle activity (measured using electromyography), should be considered when evaluating the
75	muscular pathologies. Among them, measurement of muscle activity using S-EMG is a less invasive
76	method that enables real-time assessment of multiple muscles in conjunction with motion.
77	Patients with spinal deformity require more muscle activity in their trunk and lower extremities to maintain
78	the standing position compared to healthy individuals. This increased activity leads to muscle fatigue and
79	pain, making it difficult to maintain a standing position for a long time. Restoring the correct posture with
80	surgery reduces the muscle activity. After surgery, we instruct patients to refrain from bending forward to

81	prevent PJF, but the scientific basis is unclear. Therefore, this study aimed to evaluate the muscle activity
82	of the paravertebral and lower extremity muscles using S-EMG in patients with ASD and to compare the
83	data with those of individuals without spinal deformity. The changes in muscle activity after corrective
84	fusion surgery and forward bending were evaluated as well.

## 86 Materials and methods

## 87 Enrollment of participants

This study was approved by the institutional review board of our institution, and informed written consent 88 89 was obtained from all patients. Patients with ASD who underwent corrective fusion surgery using long constructs from the lower thoracic spine to the pelvis between April 2016 and April 2018 in our department 90 91 with at least 2 years of follow-up were eligible for our study. We excluded patients with a history of spinal surgery, infection, and/or neuromuscular diseases, such as Parkinson's disease, who could not undergo 92 assessment with S-EMG, and those who experienced postoperative complications requiring revision 93 94 surgery during the follow-up period. We also excluded patients with hip or knee arthroplasty. The control population consisted of elderly patients with osteoarthritis who did not have spinal disease based on their 95 history and radiographic findings. Furthermore, degenerative changes found in these subjects were 96 attributed to their age. However, they did not have scoliosis or vertebral fractures. 97

# 98 Assessment using S-EMG

99	Prior to the application of S-EMG electrodes, all sites were cleaned with alcohol to ensure low impedance
100	(typically <5 kOhm). The pairs of 38-mm surface electrodes (Blue sensor SP-00-S, METS, Chiba, Japan)
101	were attached in the following muscles in only the right side of the participants: thoracic and lumbar erector
102	spinae (TES and LES), external oblique (EO), gluteus maximus (GM), rectus femoris (RF), and biceps
103	femoris (BF) (Fig. 1a). These active electrodes were placed 2 cm apart and parallel to the following muscle
104	fibers: TES (7 <sup>th</sup> thoracic and 2 cm lateral to the spinous process), LES (4 <sup>th</sup> lumbar level and 4 cm lateral to
105	the spinous process), EO (2 cm anterior from the line connecting between the tip of the iliac crest and rib),
106	GM (midpoint between the lateral aspect of the sacrum and greater trochanter), RF (midpoint between the
107	anterior superior iliac spine and tip of patella), and BF (midpoint between the ischial tuberosity and head
108	of fibula).
108 109	of fibula). Then, the EMG signals were recorded with a telemetric EMG system (TeleMyo™ DTS, Noraxon USA Inc,
108 109 110	of fibula). Then, the EMG signals were recorded with a telemetric EMG system (TeleMyo™ DTS, Noraxon USA Inc, Scottsdale, AZ) with a bandpass filter between 5 and 500 Hz and sampled at 1500 Hz. The S-EMG signals
108 109 110 111	of fibula). Then, the EMG signals were recorded with a telemetric EMG system (TeleMyo <sup>™</sup> DTS, Noraxon USA Inc, Scottsdale, AZ) with a bandpass filter between 5 and 500 Hz and sampled at 1500 Hz. The S-EMG signals were received from 6 channels and transmitted to the personal computer wirelessly.
108 109 110 111 111	of fibula). Then, the EMG signals were recorded with a telemetric EMG system (TeleMyo <sup>™</sup> DTS, Noraxon USA Inc, Scottsdale, AZ) with a bandpass filter between 5 and 500 Hz and sampled at 1500 Hz. The S-EMG signals were received from 6 channels and transmitted to the personal computer wirelessly. Participants were asked to maintain the posture during the 3-second recording of S-EMG data. The muscle
<ol> <li>108</li> <li>109</li> <li>110</li> <li>111</li> <li>112</li> <li>113</li> </ol>	of fibula). Then, the EMG signals were recorded with a telemetric EMG system (TeleMyo™ DTS, Noraxon USA Inc, Scottsdale, AZ) with a bandpass filter between 5 and 500 Hz and sampled at 1500 Hz. The S-EMG signals were received from 6 channels and transmitted to the personal computer wirelessly. Participants were asked to maintain the posture during the 3-second recording of S-EMG data. The muscle electrical activity was determined by calculating the mean value of the amplitude over a stable period. These
<ol> <li>108</li> <li>109</li> <li>110</li> <li>111</li> <li>112</li> <li>113</li> <li>114</li> </ol>	of fibula). Then, the EMG signals were recorded with a telemetric EMG system (TeleMyo <sup>™</sup> DTS, Noraxon USA Inc, Scottsdale, AZ) with a bandpass filter between 5 and 500 Hz and sampled at 1500 Hz. The S-EMG signals were received from 6 channels and transmitted to the personal computer wirelessly. Participants were asked to maintain the posture during the 3-second recording of S-EMG data. The muscle electrical activity was determined by calculating the mean value of the amplitude over a stable period. These data were obtained at rest in a standing position and maximum anterior flexion position with 10 seconds
<ol> <li>108</li> <li>109</li> <li>110</li> <li>111</li> <li>112</li> <li>113</li> <li>114</li> <li>115</li> </ol>	of fibula). Then, the EMG signals were recorded with a telemetric EMG system (TeleMyo™ DTS, Noraxon USA Inc, Scottsdale, AZ) with a bandpass filter between 5 and 500 Hz and sampled at 1500 Hz. The S-EMG signals were received from 6 channels and transmitted to the personal computer wirelessly. Participants were asked to maintain the posture during the 3-second recording of S-EMG data. The muscle electrical activity was determined by calculating the mean value of the amplitude over a stable period. These data were obtained at rest in a standing position and maximum anterior flexion position with 10 seconds rest in between. The results were normalized to the maximum activity observed during the maximum

117	to perform a maximum isometric movement against resistance. For trunk muscles (TES, LES, and EO),
118	MVC was measured using a fixed trunk dynamometer (Takei Scientific Instruments Co., JPN) (Fig. 1b, c),
119	and for lower extremity muscles (GM, RF, and BF), MVC was measured by the manual resistance applied
120	by the investigator (Fig. 1d, e, f). The mean amplitude for the 3 trials was calculated to obtain the MVC
121	value.
122	The EMG data were analyzed by using myoRESEARCH® 3 (Noraxon, Scottsdale, USA). After
123	rectification and smoothing, the EMG signals were amplitude normalized to the average MVC value
124	(%MVC). The average MVC value was the average of 0.5 seconds before and after the maximum muscle
125	activity. In patients with ASD, the muscle activity was assessed pre-operatively and at 1 year post-

126 operatively.

127 Radiographic measurements

A standardized lateral view of the entire spine in the standing position was obtained for all participants at 128 each measurement time point; they were asked to relax their heads while looking straight ahead, without 129 pulling in the chin, with their hands placed on their clavicles, and with a 1.5-m distance between the 130 radiographic tube and the patient. The following alignment parameters were measured from the 131 radiographs: sagittal vertical axis (SVA), pelvic tilt (PT), pelvic incidence (PI), lumbar lordosis (LL), and 132 thoracic kyphosis (TK). 133

# 135 Data analysis

136	Among controls, we compared the muscle activity measured pre-operatively with that measured at post-
137	operatively. Moreover, the muscle activity changes depending on the posture (at rest in a standing position
138	versus maximum anterior flexion) were assessed. The spinopelvic parameters (SVA, PT, PI, LL, and TK)
139	were compared between the patients and controls.
140	To compare the muscle activity and radiographic parameters, paired t-test and Wilcoxon test were used for
141	intragroup changes and Mann-Whitney U test for intergroup changes. The Spearman correlation coefficient
142	was calculated to evaluate the correlations between muscle activity and radiographic parameters. To verify
143	the accuracy of a fixed trunk dynamometer, trunk muscle strength (flexion and extension) was measured
144	three times in 11 healthy volunteers, and the infraclass correlation coefficient (ICC) was determined.
145	All statistical analyses were performed using SPSS version 23.0 (SPSS Inc., Chicago, IL). A P-value <0.05
146	was considered significant.
147	
148	Results
149	We examined 14 patients with ASD (1 man, 13 women) and 8 elderly volunteers (1 men, 7 women). The
150	mean age and range of the patients and elderly volunteers were 67.1 (standard deviation [SD]: 7.9) and 69.3

- 151 (SD: 9.3) years, respectively. The mean body mass index was 21.4 (SD: 2.6) and 22.0 (SD: 1.7) kg/m<sup>2</sup>,
- 152 respectively. There were no differences in demographic data between the patients and controls. The mean

153 follow-up period of the patients with ASD was 43.9 months (range, 28-45) months.

Regarding ASD pathologies, out of 14 patients with ASD, 13 had de novo scoliosis and one had progressed 154 idiopathic scoliosis. There were no cases of post-traumatic fractures or iatrogenic deformity. The mean 155 156 number of levels fused was 8.4 segments, with an upper instrumented vertebra (UIV) of T7 in 1 patient, T9 in 3, and T10 in 10 patients. All patients underwent sacroiliac fusion using bilateral S1 and iliac screws. 157 158 Sagittal alignment, as represented by the spinopelvic parameters, in the patients with ASD that was significantly worse at baseline compared with controls, improved significantly at 2 year post-operatively 159 (Table 1, Fig. 2). 160 161 The fixed trunk dynamometer showed high reliability, with ICC values for trunk flexion and extension muscle strength of 0.944 and 0.864, respectively. Regarding the S-EMG of the trunk and lower extremity, 162 at rest in a standing position, the patients with ASD showed a significantly higher muscle activity in LES 163 and BF than the controls (p<0.05) (Table 2 and Fig. 3). After corrective fusion surgery, a decrease in LES 164 muscle activity and an increase in RF muscle activity were observed (p<0.05), and the changes reached the 165 level of the controls (Table 2). On the other hand, on anterior flexion, there was no significant difference 166 between the ASD patients and controls. However, a significant increase in TES muscle activity was 167 observed after corrective fusion surgery (p < 0.05) (Table 3). 168

169 When the posture changed from standing to anterior flexion, the control subjects showed minimal changes

in muscle activity, with only the BF showing a significant increase (Fig. 4). However, the patients with

171	ASD showed a significant decrease in TES and RF and a significant increase in BF (Fig. 5). After corrective
172	fusion surgery, TES showed a significant increase in muscle activity at the anterior flexion position
173	compared to that pre-operatively. Moreover, a significant increase in LES, GM, and BF, and a significant
174	decrease in RF were observed (Fig. 6).
175	
176	Discussion
177	Several reports have investigated the paravertebral muscle activity using S-EMG for patients with spinal
178	disease [13,14]. However, few reports have investigated the paravertebral muscle activity in patients with
179	spinal kyphosis. Enomoto et al.[15] demonstrated that the patients with lumbar degenerative kyphosis had
180	a higher muscle activity of the paravertebral muscles at rest in a standing position than age-matched patients
181	with lumbar spinal canal stenosis and healthy volunteers. Our results are consistent with the findings of the
182	previous report. We also showed that when maintaining the upright posture, the lower extremity muscles,
183	such as GM, RF, and BF, and trunk muscles, including TES, LES, and EO, required a higher muscle activity
184	in patients with ASD than in health young participants (Table 2). Prior et al.[16] revealed that a significant
185	increase in the BF muscle activity was observed when the pelvis moved from a normal position to
186	retroversion. Patients with ASD maintained the standing posture through pelvis retroversion (high pelvic
187	tilt) [11]. Therefore, not only trunk anterior tilting but also pelvic retroversion could contribute to an
188	increase in BF muscle activity in patients with ASD. Spinal kyphosis could also be compensated by the

189	lower extremity through hip extension and knee bending to maintain global alignment [11,17]. Therefore,
190	the lower extremity muscles need higher muscle activity during standing in patients with ASD than in
191	healthy young individuals who require minimal muscle activity to maintain the standing posture.
192	On the other hand, after corrective fusion surgery, the muscle activity of LES decreased and that of RF
193	increased significantly (Table 2). The fixed lumbar spine using an instrument and muscle denervation could
194	be affect the decrease of LES muscle activity after operation. Although the BF showed higher activity than
195	the RF pre-operatively, after the operation, the RF showed higher activity (Table 2). These results suggested
196	that during a forward trunk tilt, the BF requires more effort compared to RF to maintain the standing
197	posture; however, sagittal spinal realignment through corrective surgery would facilitate the use of RF with
198	knee extension to reduce the load on the BF. Despite involving healthy individuals as the study subjects,
199	Wang et al.[18] revealed that with anterior trunk tilting, an increase in BF and erector spinae activation was
200	observed, accompanied by a decrease in RF activity, with the opposite pattern being observed in posterior
201	trunk tilting. In fact, an increase in BF activity and a decrease in RF activity in the flexion position than at
202	rest in a standing position were observed in both controls and patients (Figs. 4 and 5). Although sagittal
203	alignment was corrected through surgery, every muscle still required a higher activity to maintain the
204	standing posture in the patients than in controls, because the fixed spine is different from the flexible spine,
205	with the former possibly increasing the load on the non-fixed area such as the thoracic spine, pelvis, and
206	lower extremity.

207	In patients with ASD, the muscle activity of the lower extremity muscles (GM, RF, and BF) were
208	significantly changed during anterior bending after surgery compared to that pre-operatively (Figs. 5 and
209	6). A fixed spine that has lost its ability to compensate might place a load on the GM and BF to maintain
210	an anterior flexion posture. Regarding the proximal junction, the patients with ASD showed a decrease in
211	TES activity during anterior flexion (Fig. 5); on the contrary, a significant increase in TES activity was
212	observed after fusion surgery (Fig. 6). The thoracic spine has a compensatory mechanism to maintain
213	standing posture by reducing thoracic kyphosis [11], which results in an increase in the TES activity in the
214	standing position. Taking the anterior flexion position seemed to cancel this compensation mechanism and
215	reduce the muscle activity. However, after surgery, mechanical stress was concentrated on the proximal
216	junction due to the fixed lumbar spine, thereby causing a proximal junctional failure, which was reported
217	as one of the major complications after long spinal fusion surgery [19]. Proximal junctional failure has been
218	reported to be caused by multiple factors, including age, fusion to the pelvis, preoperative thoracic kyphosis,
219	low bone mineral density, lower muscularity, and excessive correction [19-22]. We showed that, after
220	corrective fusion surgery, TES required a high muscle activity to maintain the anterior flexion position.
221	Greater trunk extensor muscle activation, which may increase the spinal load, was reported to contribute to
222	vertebral fracture [13]. Our finding may partly help to explain the mechanisms of vertebral fracture around
223	the upper instrumented vertebra, leading to proximal junctional failure after long fusion surgery. Therefore,
224	after corrective fusion surgery, patients should be prohibited to perform anterior flexion to prevent the

225 concentration of mechanical stress on the proximal junction.

226	This study has several limitations. First, participants were asked to maintain the posture during surface
227	electromyography measurements. The patients maintaining their position due to pain were excluded
228	because accurate measurement was not possible. However, these actions could be limited due to pain in
229	ASD patients. Second, we normalized the muscle activity using %MVC. Although this method is the
230	most widely used reference point for normalization, it is often subjective and potentially limited by
231	sensation of pain in injured individuals [23]. Third, we evaluated trunk muscles only in one side. These
232	muscle activities could be different in patients with scoliosis. Finally, the sample size was relatively small,
233	and these results might diminish the statistical relevance of the inter-group comparisons.
234	In conclusion, patients with ASD required a higher activity of the lower extremity and trunk muscles to
235	maintain a standing position than normal controls. After corrective fusion surgery, a significant increase in
236	the muscle activity of the lower extremity muscles (GM, BF) and TES was observed during anterior bending,
237	suggesting the presence of mechanical stress concentration caused by the fixed lumbar spine.

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290	Figure	legends
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291 Figure 1

- a: The attachment of surface electrodes
- 293 ① thoracic erector spinae (TES)
- 294 ② lumbar erector spinae (LES)
- 295 ③ external oblique (EO)
- 296 ④ gluteus maximus (GM)
- 297 ⑤ rectus femoris (RF)
- 298 6 biceps femoris (BF)
- 299
- 300 Measurement of maximum voluntary contraction using a fixed trunk dynamometer
- 301 (b: flexion, c: extension)
- 302 Measurement of maximum voluntary contraction by manual resistance
- 303 (d: gluteus maximus, e: rectus femoris, f: biceps femoris)

- 305 Figure 2
- 306 Representative radiographs
- 307 a: A 71-year-old woman in control group

308	b: A 63-year-old	woman with	spinal defor	mity (pre-op	eration)
	)		1		,

309	c:	post-o	peration
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- 311 Figure 3
- 312 EMG wave pattern of each muscle at rest in a standing position
- 313 Left: patients with ASD; right: controls

#### 314

- 315 Figure 4
- 316 The comparison of muscle activity between at rest in a standing position and anterior flexion in the control
- 317 group
- 318
- 319 Figure 5
- 320 The comparison of muscle activity between at rest in a standing position and anterior flexion in patients
- 321 with ASD (pre-operation)

- 323 Figure 6
- 324 The comparison of muscle activity between at rest in a standing position and anterior flexion in patients
- 325 with ASD (post-operation)

	controls	ASD patients		$P^{I}$	$P^2$
		pre-op	2y post-op		
SVA (mm)	$29.1 \pm 17.5$	$98.3 \pm 13.7$	$45.2 \pm 11.6$	0.006**	0.009 <sup>††</sup>
PT (°)	$16.1 \pm 3.0$	$36.4 \pm 2.3$	$24.3 \pm 3.6$	<0.001**	0.003 <sup>††</sup>
PI (°)	$53.5 \pm 3.7$	$53.4 \pm 3.3$	$51.3 \pm 3.4$	0.973	1.000
LL (°)	$52.3 \pm 4.6$	$6.7 \pm 3.6$	$39.5 \pm 3.2$	<0.001**	< 0.001**
TK (°)	$28.6 \pm 3.5$	$14.6 \pm 4.0$	$38.1 \pm 3.0$	<0.042*	< 0.001**

Table 1. Radiographic parameters of controls and patients with adult spinal deformity

Mean values are presented as  $\pm$  standard error.  $p^{1}$ : control vs pre-op, p<0.05, p<0.01, Mann-Whitney U test  $p^{2}$ : pre-op vs 2y post-op,  $^{\dagger\dagger}p<0.01$ , Wilcoxon test

Rest	control	ASD patients		$P^{I}$	$P^2$	$P^3$
standing		pre-op	post-op			
TES	$34.0\pm9.9$	$40.7 \pm 5.1$	$41.5 \pm 4.7$	0.297	0.975	0.165
LES	$31.5 \pm 7.3$	$62.5 \pm 11.2$	$33.6 \pm 4.3$	0.029*	$0.006^{\dagger \dagger}$	0.714
EO	$18.5 \pm 3.3$	$16.9 \pm 2.8$	$21.8 \pm 3.6$	0.764	0.300	0.815
GM	$16.4 \pm 6.0$	$13.1 \pm 4.1$	$8.4 \pm 3.1$	0.330	0.363	0.188
RF	$9.4 \pm 2.9$	$9.8 \pm 1.5$	$16.8 \pm 3.1$	0.714	0.026†	0.165
BF	$3.9 \pm 2.2$	$11.7 \pm 3.1$	$5.0 \pm 1.2$	0.035*	0.140	0.127

Table 2 Muscle activit	v of each	muscle at res	t in a sta	inding r	position
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Mean values are presented as  $\pm$  standard error.  $p^{1}$ : control vs pre-op, \*p<0.05, \*\*p<0.01, Mann-Whitney U test  $P^{2}$ : pre-op vs post-op,  $^{\dagger}p<0.05$ ,  $^{\dagger\dagger}p<0.01$ , Wilcoxon test  $P^{3}$ : control vs post-op, \*p<0.05, \*\*p<0.01, Mann-Whitney U test

Anterior	control	ASD patients		$P^{I}$	$P^2$	$P^3$
flexion		pre-op	post-op			
TES	$26.2 \pm 6.9$	$17.6 \pm 4.2$	$76.4 \pm 9.0$	0.330	0.001**	0.001**
LES	$49.5 \pm 15.0$	$46.5 \pm 12.6$	$43.1 \pm 8.3$	0.714	0.975	0.092
EO	$28.6 \pm 9.6$	$22.8\pm8.2$	$30.0 \pm 4.8$	0.441	0.056	0.616
GM	$22.8 \pm 6.6$	$15.8 \pm 4.5$	$21.6 \pm 3.8$	0.441	0.331	0.092
RF	$4.7 \pm 0.8$	$5.1 \pm 1.1$	$5.7 \pm 1.1$	0.714	0.433	0.868
BF	$24.1 \pm 6.2$	$33.6 \pm 10.1$	$28.4 \pm 3.6$	0.920	0.638	0.441

Table 3. Muscle activity of each muscle at anterior flexion

Mean values are presented as  $\pm$  standard error.  $p^{1}$ : control vs pre-op, \*p < 0.05, \*\*p < 0.001, Mann-Whitney U test  $P^{2}$ : pre-op vs post-op,  $^{\dagger}p < 0.05$ ,  $^{\dagger\dagger}p < 0.001$ , Wilcoxon test  $P^{3}$ : control vs post-op, \*p < 0.05, \*\*p < 0.001, Mann-Whitney U test







1 sec





