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Magnetic Resonance Imaging of Trunk Musculature and Intervertebral Discs in Patients with Spinal Cord Injury with Thoracolumbar Vertebral Fractures: A Prospective Study

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Study Design: This study is a prospective clinical study.

Purpose: This study aims to evaluate the characteristics of trunk musculature and intervertebral discs by using magnetic resonance imaging in patients with spinal cord injuries (SCIs) with thoracic and lumbar fractures.

Overview of Literature: Muscle atrophy is an immediate consequence of SCI and is associated with secondary complications. At present, there are limited clinical data on muscle and disc responses to fractures of the thoracic and lumbar spine.

Methods: A total of 51 patients with a mean age of 31.75±10.42 years who suffered traumatic SCI were included in this study. Complete neurological examinations (American Spinal Injury Association grading) and magnetic resonance imaging (MRI) were performed at the time of admission and at 3–6 months after injury to study the neurological status and disc and trunk parameters. The type of management (operative or conservative) was decided on the basis of clinical, radiological, and MRI evaluations, and a robust rehabilitation program was initiated.

Results: Disc parameters including disc angle, skin angle, cross-sectional area (CSA), and disc height and trunk parameters (mean trunk width, mean trunk depth, and CSA of the lumbar muscles) decreased significantly ($p<0.001$) during the first 3 months after SCI. However, improvements were observed in disc and muscle parameters at the 6-month follow-up, but these parameters did not return to normal levels. Neither initial neurological status (complete vs. incomplete) nor type of management (operative vs. conservative) had a significant effect on these parameters.

Conclusions: Spinal trauma leads to alterations in the morphology of the vertebral column, spinal cord, intervertebral discs, and paraspinal muscles in the initial phase of injury. The extent of these changes may determine the initial neurological deficit and subsequent recovery. Although this study did not identify any statistically significant effect of neurological status or management strategy on these parameters, rehabilitation was found to result in the improvement of these parameters in the later phase of recovery. Future studies are required to evaluate the exact causes of these alterations and the potential benefits of rehabilitation strategies and to minimize these changes.

Keywords: Spinal fractures; Muscles; Magnetic resonance imaging; Spinal cord injuries; Intervertebral disc; Rehabilitation

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Introduction

Acute traumatic spinal cord injury (SCI) is one of the most devastating injuries for the human body. This injury causes immediate and, in some areas, permanent gravitational unloading, thus resulting in structural changes due to disuse and associated metabolic consequences. Osteoporosis and muscle atrophy are the frequently encountered complications of SCI [1,2], and these conditions occur rapidly after injury and are associated with several secondary complications. Inactivation and extreme unloading following SCI can lead to marked atrophy of the leg and thigh skeletal muscles within a few months of injury [3].

A number of studies have evaluated the utility of various magnetic resonance imaging (MRI) parameters in relation to neurological performance following SCI; however, there is little information available on the response of intervertebral disc and paravertebral muscles to spinal trauma. The present study was conducted to evaluate the MRI data of trunk musculature and discs in patients who had suffered SCI with thoracic and lumbar vertebral fractures. We hypothesized that spinal trauma affects the trunk musculature and intervertebral discs and suggest that the information presented here deepens our understanding of muscular wasting, appropriate rehabilitation strategies, and approaches for improving the ultimate outcome of SCI.

Materials and Methods

This prospective study was performed from June 2015 to December 2017 and included patients who presented to our tertiary care institution with posttraumatic SCI. Owing to time constraints and the paucity of previous data related to the present research question, this study was conducted as a pilot study with 51 subjects recruited prospectively on the basis of the availability of patients undergoing treatment. The study and all its protocols were approved by the institutional review board and ethical committee (IRB approval no., Endst. No. Surg/Dean/16/1640-45; dated 08/06/2016). Written informed consent was obtained from all individual participants. We recruited all adult patients who suffered posttraumatic SCI. After emergency stabilization, a detailed history was taken from each patient in chronological order, and a thorough general physical and neurological examination was performed.

Each patient underwent a thorough clinical examination including spinal X-ray and MRI. The 1.5 Tesla machine was used to obtain MRI data with the patient lying comfortably in the supine position with knees and hips extended. Multislice sagittal and transverse sections were taken with MRI sequences. The locations of vertebral levels for MRI were determined from pilot parasagittal sections. Measurements were performed using on-screen calipers. Various parameters (detailed in Table 1) were measured at the L1–L2, L2–L3, L3–L4, L4–L5, and L5–S1 level of the intervertebral disc (as per the institutional protocol published previously [4]).

The clinical assessments of sensory score, motor score, and zone of partial preservation were performed at the time of admission and at 3 days, 7 days, 3 months, and 6 months postadmission according to the international scoring system of the American Spinal Injury Association (ASIA) [5]. Deep anal pressure (DAP), voluntary anal contraction (VAC), and any anal sensations were noted during each clinical assessment. The neurological level of injury (sensory and motor) was evaluated and defined as complete or incomplete. SCI was classified into five categories (A to E) according to the ASIA impairment scale (AIS) [6].

Plain roentgenogram examinations (lateral images, anteroposterior film) were conducted. Routine laboratory investigations including hemoglobin level, bleeding

Table 1. Various quantitative parameters measured with section at level of intervertebral discs

	Variable	Description
1	Trunk dimensions	Width (maximum width was be taken)
		Depth (anteroposterior diameter of trunk at mid-sagittal section)
2	CSA of muscle	Erector spinae
		Multifidus
		Psoas major
		Quadratus lumborum
		Rectus abdominis
		Obliques
3	Disc angle	The angle between the vertical line and the midplane of each lumbar disc
4	Skin angle	The angle between the vertical line and the line tangent to the overlying skin
5	CSA of disc	

CSA, cross-sectional area.

time, clotting time, complete urine examination, blood urea, blood sugar, serum electrolytes, electrocardiogram, and chest roentgenogram were performed in all cases. We performed MRI within 48 hours of injury in all cases. Patients who required surgery for unstable vertebral column injuries were operated on according to the requirements. Spinal stability was evaluated for thoracolumbar injuries according to lumbar spinal stenosis [7], and the thoracolumbar injury classification system [8]. Unstable spine was considered an indication for spinal surgery (either stabilization alone or stabilization with decompression). The type of surgery was decided on the basis of the characteristics of the fracture. Patients with stable spinal injuries were advised to stay on bed rest until pain subsided and were later mobilized with the use of braces. Patients who underwent surgical stabilization were usually mobilized on the third day after surgery following dressing change unless there were any contraindications. Rehabilitation for early mobilization and active/assisted limb and paraspinal muscle strengthening exercises were initiated as soon as possible for all patients.

Patients attended follow-up appointments at 3 and 6 months postinjury. Clinical evaluations and plain radiography examinations were performed at each follow-up, and MRI was performed at the 3- and 6-month follow-up appointments. Neurological recovery was documented on the basis of AIS.

The collected data were compiled and entered into spreadsheets. Statistical analysis was performed using the statistical software IBM SPSS for Windows ver. 20.0 (IBM Corp., Armonk, NY, USA). Continuous variables are presented as mean and standard deviation, and categorical variables are presented as proportions. The independent Student *t*-test was used to analyze statistical differences in continuous variables between two independent groups. To compare more than two independent groups or ordinal dependent variables, we used one-way analysis of variance (ANOVA). For repeated-measures analysis, repeated-measures ANOVA, Friedman's ANOVA, and Cochran's Q test were used on the basis of whether the dependent variable being measured was continuous, ordinal, or categorical, respectively. The level of significance was taken as 5% with 95% confidence intervals.

Results

Fifty-one patients (40 males, 11 females) were included in this study. The mean age of the study population was 31.75±10.42 years (range, 18–65 years), and the modal group was 21–30 years (n=27, 52.9%).

Table 2 shows the symptomatology at admission and subsequent evaluations. All symptoms decreased significantly over time (p<0.001), except in two patients wherein incontinence persisted at 6 months postadmission.

Table 3 shows the neurological involvement and improvement over time. Neurological involvement showed a statistically significant improvement (p<0.001).

There was no significant difference in the distribution of initial clinical assessment values (VAC, motor index score, and sensory index score), and DAP was managed operatively and conservatively. The superficial abdominal reflex was initially absent in 45.1% (23) of patients but remained absent in only 31.4% (16) of patients at the 6-month follow-up (p=0.001). The Babinski reflex was initially absent and remained absent throughout the follow-up for all patients. Knee and ankle reflexes were initially absent in 92.2% (47) of patients but remained absent in only 25.5% (13) of patients at the 6-month follow-up; this

Table 2. Distribution of subjects according to their symptomatology (n=51)

Symptoms	Initial	3 mo	6 mo	p-value
Pain				<0.001[a)]
Absent	0	34 (66.7)	49 (96.1)	
Mild	0	17 (33.3)	2 (3.9)	
Moderate	0	0	0	
Severe	51 (100.0)	0	0	
Swelling				<0.001[a)]
Absent	0	48 (94.1)	51 (100.0)	
Mild	0	3 (5.9)	0	
Moderate	20 (39.2)	0	0	
Severe	31 (60.8)	0	0	
Deformity				<0.001[a)]
Absent	0	33 (64.7)	46 (90.2)	
Mild	2 (3.9)	18 (35.3)	5 (9.8)	
Moderate	38 (74.5)	0	0	
Severe	11 (21.6)	0	0	
Weakness upper limb	0	0	0	-
Weakness lower limb	49 (96.1)	18 (35.3)	12 (23.5)	<0.001[b)]
Incontinence	0	0	2 (3.9)	0.135[b)]
Retention	46 (90.2)	16 (31.4)	10 (19.6)	<0.001[b)]

Values are presented as number (%).
[a)]By Friedman analysis of variance test. [b)]By Cochran's Q test.

decrease was statistically significant (p<0.001). The median neurological grade at initial presentation was D. The grade improved to E in the first 3 months after admission and remained as E for the next 3 months. Neurological recovery was found to be highly significant (p<0.001) by the Friedman ANOVA test. Initially, more than half of the study population (56.9%, 29 patients) were classified as grade D, 19.6% (10) of patients were classified as grade A (complete injury), 15.7% (8) of patients were classified as grade C, and 3.9% (2) of patients were classified as grades B and E each. At the 6-month follow-up, the majority of patients exhibited no deficit (74.5%, 38 patients), whereas 19.6% (10) were classified as grade C. Thirty-five (68.6%) patients were managed conservatively, and 16 patients (31.37%) were managed operatively. There was no significant difference in the distribution of the initial ASIA score between these two groups.

The mean trunk widths at various levels of the spinal cord decreased at the 3-month follow-up compared with that at the initial recordings but increased at the 6-month follow-up. Posthoc analysis revealed that this change is statistically significant (p<0.001) at all disc levels of the lumbar spinal cord from L1–S1 and at all time points (Table 4).

Table 5 shows the mean trunk depths at various levels of the spinal cord. Except at the L2–L3 disc levels, mean trunk depth at all levels decreased at the 3-month follow-up compared with that at the initial recordings. However, the mean trunk depth increased between the 3- and 6-month follow-up. Posthoc analysis revealed that this change is statistically significant (p<0.001) at all disc levels and at all time points, except for L3–L4 (p=0.049, initial versus 3 months) and L4–L5 (p=1.000, 3- versus 6-month

Table 3. Distribution of subjects according to their neurological assessment (n=51)

Neurological assessment	Initial	3 mo	6 mo	p-value
Decreased muscle tone	49 (96.1)	18 (35.3)	13 (25.5)	<0.001[a]
Mean MIS-upper limb	50	50	50	-
Mean MIS-lower limb	27.28±17.30	40.51±14.96	44.33±10.88	<0.001[b]
Voluntary anal contraction (absent)	26 (51.0)	18 (35.3)	10 (19.6)	<0.001[a]
SIS-light touch	96.0±23.33	105.84±12.58	109.18±6.91	<0.001[b]
SIS-pin prick	95.69±23.79	105.10±14.96	109.49±6.23	<0.001[b]
Temperature sense (absent)	11 (21.6)	4 (7.8)	4 (7.8)	0.001[a]
Deep anal pressure (absent)	17 (33.3)	11 (21.6)	5 (9.8)	<0.001[a]
Clonus (absent)	51 (100.0)	51 (100.0)	51 (100.0)	1.000[a]
Zone of partial preservation	0	0	0	-
Bladder-bowel involvement	49 (96.1)	16 (31.4)	11 (21.6)	<0.001[a]

Values are presented as number (%) or mean±standard deviation.
MIS, Motor Index Score; SIS, Sensory Index Score.
[a]By Cochran's Q test. [b]By repeated measures analysis of variance.

Table 4. Trunk width at various levels of lumbar discs initially and on follow-up (n=51)

Vertebral level	Trunk width (mm)			Intergroup comparisons: p-value[a] (post hoc analysis)		
	Initial (A)	3 mo (B)	6 mo (C)	A-B	A-C	B-C
L1–2	297.06±13.35	282.25±13.39	290.06±14.08	0.000	0.000	0.000
L2–3	299.33±11.21	287.55±11.15	294.31±12.14	0.000	0.000	0.000
L3–4	303.24±10.79	291.43±11.05	297.31±11.65	0.000	0.000	0.000
L4–5	305.16±9.17	291.55±8.08	299.78±9.49	0.000	0.000	0.000
L5–S1	306.04±8.97	292.27±13.76	299.53±11.07	0.000	0.000	0.000

Values are presented as mean±standard deviation. A-B means initial versus 3 months; B-C means 3 months versus 6 months; A-C means initial versus 6 months.
[a]By repeated measures analysis of variance test.

follow-up data).

The mean disc angle at all disc levels of the vertebral column (except for L2–L3 and L4–L5) was significantly decreased (p<0.001) at the 6-month follow-up. At the L2–L3 and L4–L5 levels, the mean disc angle was significantly decreased at the 3-month follow-up compared with the initial recordings but significantly increased at the 6-month follow-up (p<0.001) (Table 6). Posthoc analysis showed that this change is not statistically significant at the L2–L3, L3–L4, or L4–L5 at the 3-month follow-up versus the 6-month follow-up.

The mean skin angle was decreased at follow-up compared with the initial values at all lumbar vertebral levels. Posthoc analysis showed that this change was not statistically significant at the L2–L3 (p=0.194) or L4–L5 lumbar spine levels at the 3-month follow-up compared with the 6-month follow-up (Table 7).

Table 8 shows the mean cross-sectional area (CSA) of the disc at various levels of the lumbar spine at the time of admission and at follow-up. Posthoc analysis showed that

Table 5. Trunk depth at various levels of lumbar discs initially and on follow-up (n=51)

Vertebral level	Trunk depth (mm)			Intergroup comparisons: p-value[a)] (post hoc analysis)		
	Initial (A)	3 mo (B)	6 mo (C)	A-B	A-C	B-C
L1–2	198.47±16.92	176.65±12.00	195.55±16.25	0.000	0.019	0.000
L2–3	195.61±10.17	190.63±13.04	178.29±8.03	0.002	0.000	0.000
L3–4	198.71±16.54	179.18±13.58	196.18±15.29	0.000	0.049	0.000
L4–5	202.55±15.48	189.84±19.75	193.98±16.17	0.016	0.000	1.00
L5–S1	197.41±16.79	185.76±15.95	191.88±15.55	0.000	0.000	0.000

Values are presented as mean±standard deviation. A-B means initial versus 3 months; B-C means 3 months versus 6 months; A-C means initial versus 6 months.
[a)]By repeated measures analysis of variance test.

Table 6. Disc angle at various levels of lumbar discs initially and on follow-up (n=51)

Vertebral level	Disc angle (°)			Intergroup comparisons: p-value[a)] (post hoc analysis)		
	Initial (A)	3 mo (B)	6 mo (C)	A-B	A-C	B-C
L1–2	6.98±0.81	6.27±0.53	6.02±0.86	0.000	0.000	0.003
L2–3	6.76±0.79	5.98±0.93	6.12±1.01	0.000	0.000	0.579
L3–4	1.75±0.44	1.02±0.86	0.84±0.81	0.000	0.000	0.870
L4–5	-6.88±0.86	-6.06±0.86	-6.18±1.05	0.000	0.000	0.729
L5–S1	-21.35±2.90	-19.37±2.91	-20.00±3.30	0.000	0.000	0.000

Values are presented as mean±standard deviation. A-B means initial versus 3 months; B-C means 3 months versus 6 months; A-C means initial versus 6 months.
[a)]By repeated measures analysis of variance test.

Table 7. Skin angle at various levels of lumbar spine initially and on follow-up (n=51)

Vertebral level	Skin angle (°)			Intergroup comparisons: p-value[a)] (post hoc analysis)		
	Initial (A)	3 mo (B)	6 mo (C)	A-B	A-C	B-C
L1–2	-96.02±3.04	-93.02±4.53	-93.41±3.83	0.000	0.000	0.009
L2–3	-99.67±3.90	-97.00±4.36	-97.33±3.72	0.000	0.000	0.194
L3–4	-105.33±1.26	-103.00±1.43	-104.00±1.65	0.000	0.000	0.000
L4–5	-115.67±2.52	-111.00±2.97	-113.00±2.97	0.000	0.000	NA
L5–S1	-112.00±2.47	-108.67±0.95	-110.00±1.43	0.000	0.000	0.000

Values are presented as mean±standard deviation. A-B means initial versus 3 months; B-C means 3 months versus 6 months; A-C means initial versus 6 months.
[a)]By repeated measures analysis of variance test.

this change was not statistically significant at the L3–L4 (p=0.275, 3- versus 6-month follow-up), L4–L5 (p=0.492, initial versus 3-month follow-up), or L5–S1 levels (p=1.000, initial versus three-month follow-up; p=0.075, initial versus 6-month follow-up). There was no significant change in mean muscle disc ratio at any disc level, except L5–S1 (p=0.000, initial versus 3-month follow-up; p=0.011, 3- versus 6-month follow-up) (Table 9).

The mean intervertebral disc height was significantly decreased at the 3-month follow-up compared with the initial recordings at all levels, but this value was increased at the 6-month follow-up. Posthoc analysis showed that this change was not statistically significant at the L1–L2 (p=1.000, initial versus 3-month follow-up) or L4–L5 levels (p=0.151, 3- versus 6-month follow-up) (Table 10).

Table 11 shows the mean CSA of lumbar muscles at all disc levels of the lumbar spine at the time of admission and follow-up. Intergroup comparisons were performed to investigate the changes over different periods of time. The results revealed a significant decrease in the mean

Table 8. Mean cross-sectional area of disc at various levels of lumbar spine initially and on follow-up (n=51)

Vertebral level	Cross-sectional area (cm^2)			Intergroup comparisons: p-value[a)] (post hoc analysis)		
	Initial (A)	3 mo (B)	6 mo (C)	A-B	A-C	B-C
L1–2	14.82±0.61	14.50±0.58	14.67±0.58	0.000	0.005	0.000
L2–3	14.85±0.59	14.53±0.26	14.60±0.22	0.000	0.001	0.000
L3–4	14.89±0.57	14.70±0.30	14.73±0.35	0.003	0.010	0.275
L4–5	14.88±0.58	14.69±0.21	14.78±0.18	0.048	0.492	0.000
L5–S1	14.80±0.61	14.80±0.38	14.90±0.52	1.000	0.075	0.000

Values are presented as mean±standard deviation. A-B means initial versus 3 months; B-C means 3 months versus 6 months; A-C means initial versus 6 months.
[a)]By repeated measures analysis of variance test.

Table 9. Muscle disc ratio at various levels of lumbar spine initially and on follow-up (n=51)

Vertebral level	Muscle disc ratio (cm^2)			Intergroup comparisons: p-value[a)] (post hoc analysis)		
	Initial (A)	3 mo (B)	6 mo (C)	A-B	A-C	B-C
L1–2	0.55±0.05	0.56±0.05	0.54±0.05	1.000	1.000	0.491
L2–3	0.56±0.05	0.56±0.05	0.54±0.05	1.000	1.000	0.491
L3–4	0.55±0.05	0.54±0.05	0.54±0.05	1.000	1.000	0.491
L4–5	1.07±0.05	1.05±0.05	1.05±0.05	0.032	0.694	1.000
L5–S1	1.35±0.07	1.31±0.04	1.34±0.05	0.000	1.000	0.011

Values are presented as mean±standard deviation. A-B means initial versus 3 months; B-C means 3 months versus 6 months; A-C means initial versus 6 months.
[a)]By repeated measures analysis of variance test.

Table 10. Intervertebral disc height at various levels of lumbar spine initially and on follow-up (n=51)

Vertebral level	Intervertebral disc height (mm)			Intergroup comparisons: p-value[a)] (post hoc analysis)		
	Initial (A)	3 mo (B)	6 mo (C)	A-B	A-C	B-C
L1–2	11.87±0.42	11.73±0.45	11.73±0.50	0.000	0.000	1.000
L2–3	11.37±0.42	11.23±0.39	11.27±0.41	0.000	0.000	0.000
L3–4	11.73±0.29	11.57±0.17	11.60±0.25	0.000	0.000	0.047
L4–5	11.66±0.37	11.51±0.28	11.55±0.39	0.000	0.000	0.151
L5–S1	10.92±0.10	10.77±0.10	10.80±0.08	0.000	0.000	0.016

Values are presented as mean±standard deviation. A-B means initial versus 3 months; B-C means 3 months versus 6 months; A-C means initial versus 6 months.
[a)]By repeated measures analysis of variance test.

Table 11. Cross-sectional area & fat content of lumbar muscles at disc level of lumbar spine initially and on follow-up (n=51)

Level	Lumbar muscles		Cross-sectional area (cm^2)				Intergroup comparisons
			Initial (A)	3 mo (B)	6 mo (C)	p-value[a)]	
L1–L2	Multifidus	Left	4.55±0.45	4.07±0.27	4.36±0.52	<0.001	-
		Right	4.33±0.42	3.89±0.39	4.05±0.55	<0.001	B-C= 0.153
	Erector spinae	Left	9.78±0.62	9.27±0.78	9.39±0.49	0.001	B-C=0.412
		Right	9.69±0.53	9.27±0.60	9.65±0.77	0.003	A-C=1.00
	Ilio-psoas	Left	6.65±0.39	6.71±0.93	6.57±0.36	0.378	A-B=1.00, B-C=0.798, C-A=0.318
		Right	6.54±0.37	6.12±0.37	6.19±0.48	<0.001	B-C=0.782
	Quadratus lumborum	Left	4.92±0.29	4.70±0.45	4.68±0.39	<0.001	B-C=1.00
		Right	4.74±0.35	4.45±0.46	4.54±0.33	0.002	B-C-=0.836
	Rectus abdominis	Left	4.94±0.38	4.57±0.44	4.69±0.47	<0.001	-
		Right	5.38±0.38	5.07±0.26	5.17±0.33	<0.001	B-C=0.192
	Obliques	Left	22.07±2.83	19.55±2.96	20.11±3.46	<0.001	B-C=0.893
		Right	22.92±3.00	18.87±2.92	21.17±2.48	<0.001	-
L2–L3	Multifidus	Left	4.55±0.44	4.10±0.29	4.37±0.50	<0.001	-
		Right	4.31±0.43	3.92±0.38	4.05±0.55	<0.001	B-C=0.354
	Erector spinae	Left	10.09±1.02	9.30±2.27	9.51±0.73	0.058	A-B=0.187, B-C=1.00
		Right	10.29±1.19	8.98±1.26	10.01±0.95	<0.001	A-C=0.188
	Ilio-psoas	Left	6.66±0.39	6.37±0.61	6.57±0.36	0.374	B-C=0.066, C-A=0.220
		Right	6.55±0.37	6.16±0.36	6.21±0.48	<0.00	B-C=1.00
	Quadratus lumborum	Left	4.93±0.29	4.68±0.40	4.68±0.40	<0.001	B-C=1.00
		Right	4.76±0.34	4.47±0.40	4.57±0.30	0.002	B-C=0.398
	Rectus abdominis	Left	4.94±0.38	4.53±0.45	4.69±0.48	<0.001	-
		Right	5.38±0.38	5.06±0.28	5.16±0.33	<0.001	B-C=0.164
	Obliques	Left	22.14±2.99	18.12±3.26	20.54±3.17	<0.001	-
		Right	23.15±3.21	18.73±3.57	21.91±2.19	<0.001	-
L3–4	Multifidus	Left	4.56±0.43	4.08±0.27	4.33±0.52	<0.001	-
		Right	4.33±0.42	3.89±0.39	4.05±0.55	<0.001	B-C=0.153
	Erector spinae	Left	12.42±3.13	12.27±3.60	12.09±3.21	0.325	A-B=1.00, B-C=1.00, A-C=0.073
		Right	12.62±3.54	11.75±3.03	11.77±2.86	<0.001	B-C=1.00
	Ilio-psoas	Left	6.66±0.40	6.39±0.69	6.57±0.36	0.374	B-C=0.155, A-C=0.206
		Right	6.54±0.37	6.11±0.37	6.20±0.47	<0.00	B-C=0.332
	Quadratus lumborum	Left	4.92±0.29	4.68±0.45	4.68±0.39	<0.001	B-C=1.00
		Right	4.74±0.35	4.46±0.45	4.55±0.33	0.002	-
	Rectus abdominis	Left	4.94±0.37	4.56±0.45	4.69±0.47	<0.001	-
		Right	5.40±0.35	5.01±0.30	5.16±0.32	<0.001	-
	Obliques	Left	21.87±2.89	18.58±3.14	19.92±3.82	<0.001	-
		Right	22.86±3.14	19.05±3.28	22.07±2.25	<0.001	-
L4–L5	Multifidus	Left	7.44±1.40	6.10±1.14	7.35±1.42	<0.001	A-C=1.00
		Right	7.12±1.41	6.31±1.27	7.00±1.42	<0.001	A-C=1.00
	Erector spinae	Left	9.79±0.62	9.27±0.55	9.38±0.50	0.001	B-C=0.376
		Right	9.72±0.53	9.32±0.50	9.50±0.52	0.003	B-C=0.176

(Continued on next page)

Table 11. Continued

Level	Lumbar muscles		Cross-sectional area (cm^2) Initial (A)	3 mo (B)	6 mo (C)	p-value[a)]	Intergroup comparisons
	Ilio-psoas	Left	6.65±0.39	6.47±0.61	6.58±0.38	0.373	B-C=0.354, A-C=0.541
		Right	6.54±0.36	6.11±0.37	6.20±0.38	<0.001	B-C=0.227
	Quadratus lumborum	Left	4.94±0.30	4.65±0.46	4.67±0.40	<0.001	B-C=1.00
		Right	4.76±0.33	4.47±0.45	4.53±0.33	0.003	B-C=1.00
	Rectus abdominis	Left	4.95±0.37	4.53±0.45	4.68±0.47	<0.001	-
		Right	5.37±0.39	5.05±0.29	5.17±0.33	<0.001	B-C=0.110
	Obliques	Left	22.22±2.85	19.36±2.66	19.95±3.51	<0.001	B-C=0.434
		Right	23.20±2.63	19.53±3.99	21.27±2.70	<0.001	-
L5–S1	Multifidus	Left	9.39±0.95	9.01±0.86	9.14±0.95	0.325	B-C=0.171
		Right	9.53±0.89	8.90±1.27	9.06±1.01	<0.001	B-C=0.876
	Erector spinae	Left	9.79±0.62	9.40±0.58	9.43±0.43	0.001	B-C=1.00
		Right	9.69±0.52	9.26±0.60	9.51±0.57	0.003	B-C=0.085, C-A=0.171
	Ilio-psoas	Left	16.37±1.18	14.77±1.13	14.74±1.47	<0.001	B-C=1.00
		Right	14.64±1.92	13.38±2.15	14.09±1.70	<0.001	-
	Rectus abdominis	Left	4.94±0.38	4.53±0.46	4.69±0.47	<0.001	-
		Right	5.38±0.38	5.00±0.31	5.15±0.33	<0.001	-

Values are presented as mean±standard deviation. A-B means initial versus 3 months; B-C means 3 months versus 6 months; A-C means initial versus 6 months. Intergroup comparisons are all significant except these below mentioned.
[a)]By repeated measures analysis of variance test.

CSA of the lumbar muscles at the follow-up compared with that at admission. When the CSA of the lumbar muscles was analyzed according to the type of management (operative/conservative), no significant differences were found in the majority of muscles, except for the right erector spinae and left rectus abdominis at the L1–L2 level at the 3-month follow-up compared with at admission (Table 12). When the CSA of the lumbar muscles was analyzed according to the severity of the initial injury, no significant differences were noted over time for most of the lumbar muscles according to posthoc analysis (Tables 13–17).

Fig. 1 shows measurements of cross sectional area of trunk muscles on axial T2 weighted images; fig. 2 shows measurements of trunk depth and width on axial T2 weighted images at lumbar disc levels.

Discussion

The asymmetry of the size and composition of the paraspinal muscle has been reported in patients with a clinical presentation of unilateral low back pain (LBP) with or without radiculopathy [6,7,9,10]. Singh et al. [4] observed that in patients with chronic LBP, trunk width, depth, and skin angle were comparable at the L3–L4, L4–L5, and L5–S1 disc levels. By contrast, significant differences were observed between patients with LBP and healthy volunteers regarding disc angle at the L3–L4 (p=0.005) and L4–L5 levels (p=0.02) and in the CSA of the disc at the L4–L5 level (p=0.01). The CSA of the paraspinal and abdominal oblique muscles tended to be smaller among patients, but this was not statistically different to that of healthy volunteers. These studies indicate that paravertebral muscles respond to changes in the normal biomechanics or anatomy of the vertebral column [4,6-10]. The present study supports these studies by providing corroborative data from patients with SCI in whom biomechanical and anatomical changes occurred after the traumatic event. We also highlight the fact that even normal discs distal to the lesion respond to the traumatic event, thus resulting in decreased disc angle, disc CSA, and skin angle. The factors underlying these changes may include altered biomechanics, abnormal stresses, and changes in the nutrition of the discs.

We observed significant decreases in trunk depth and

Table 12. CSA & fat content of lumbar muscles at disc level of lumbar spine initially and on follow-up according to their type of management (n=51)

Level	Mean CSA (cm^2) of lumbar muscles		Initial			3 mo			6 mo		
			Operative (n=35)	Conservative (n=16)	*p*-value[a)]	Operative (n=35)	Conservative (n=16)	*p*-value[a)]	Operative (n=35)	Conservative (n=16)	*p*-value[a)]
L1–L2	Multifidus	Left	4.55±0.44	4.54±0.47	0.972	4.08±0.27	4.06±0.29	0.860	4.39±0.48	4.31±0.60	0.605
		Right	4.38±0.48	4.21±0.22	0.100	3.96±0.41	3.74±0.31	0.055	4.15±0.59	3.84±0.37	0.066
	Erector spinae	Left	9.72±0.52	9.90±0.80	0.349	9.26±0.63	9.27±1.06	0.980	9.44±0.40	9.28±0.64	0.285
		Right	9.65±0.55	9.78±0.49	0.433	9.15±0.67	9.51±0.33	0.013	9.51±0.51	9.97±1.12	0.133
	Ilio-psoas	Left	6.62±0.41	6.71±0.33	0.482	6.73±1.09	6.66±0.43	0.717	6.55±0.30	6.61±0.48	0.562
		Right	6.55±0.39	6.53±0.33	0.855	6.14±0.37	6.09±0.40	0.646	6.21±0.52	6.16±0.41	0.738
	Quadratus lumborum	Left	4.89±0.27	5.00±0.32	0.204	4.66±0.44	4.79±0.49	0.333	4.65±0.41	4.76±0.37	0.360
		Right	4.74±0.36	4.73±0.33	0.888	4.46±0.50	4.44±0.36	0.924	4.56±0.36	4.51±0.27	0.615
	Rectus abdominis	Left	5.00±0.37	4.79±0.34	0.056	4.66±0.43	4.36±0.40	0.021	4.75±0.44	4.54±0.50	0.125
		Right	5.34±0.55	5.47±0.42	0.255	5.05±0.24	5.11±0.32	0.451	5.13±0.30	5.24±0.38	0.251
	Obliques	Left	22.53±2.78	21.06±2.75	0.085	19.61±2.74	19.40±3.48	0.815	20.74±3.42	18.73±0.48	0.053
		Right	22.78±3.10	18.66±2.99	0.638	18.66±2.99	19.31±2.80	0.466	21.14±2.56	21.23±2.39	0.911
L2–3	Multifidus	Left	4.55±0.43	4.56±0.45	0.972	4.09±0.28	4.11±0.31	0.812	4.40±0.48	4.32±0.53	0.605
		Right	4.35±0.49	4.23±0.20	0.100	3.98±0.43	3.80±0.22	0.125	4.15±0.59	3.84±0.37	0.066
	Erector spinae	Left	10.14±1.04	9.99±1.00	0.349	9.33±2.37	9.26±2.09	0.920	9.57±0.72	9.38±0.76	0.387
		Right	10.27±1.01	10.34±1.56	0.433	8.98±1.08	8.96±1.62	0.945	9.87±0.74	10.33±1.28	0.190
	Ilio-psoas	Left	6.63±0.41	6.73±0.34	0.482	6.28±0.69	6.56±0.34	0.121	6.56±0.31	6.58±0.48	0.869
		Right	6.55±0.39	6.54±0.33	0.855	6.13±0.37	6.23±0.35	0.366	6.20±0.51	6.22±0.39	0.898
	Quadratus lumborum	Left	4.90±0.28	5.00±0.32	0.204	4.63±0.35	4.78±0.48	0.199	4.65±0.41	4.75±0.38	0.403
		Right	4.77±0.35	4.73±0.33	0.888	4.48±0.41	4.44±0.36	0.783	4.60±0.31	4.51±0.27	0.322
	Rectus abdominis	Left	5.00±0.38	4.81±0.36	0.056	4.64±0.43	4.28±0.38	0.006	4.76±0.45	4.52±0.52	0.090
		Right	5.34±0.36	5.47±0.42	0.255	5.04±0.26	5.11±0.32	0.412	5.13±0.30	5.23±0.38	0.319
	Obliques	Left	22.72±2.90	20.88±2.89	0.085	18.44±3.10	17.42±3.60	0.306	21.03±2.98	19.48±3.42	0.105
		Right	22.79±3.17	23.95±3.25	0.638	17.70±3.04	20.99±3.67	0.002	21.60±2.18	22.60±2.11	0.131
L3–L4	Multifidus	Left	4.55±0.44	4.57±0.44	0.896	4.07±0.26	4.10±0.31	0.759	4.34±0.47	4.29±0.62	0.727
		Right	4.38±0.48	4.21±0.23	0.100	3.96±0.41	3.74±0.31	0.055	4.15±0.59	3.84±0.37	0.066
	Erector spinae	Left	12.83±3.39	11.51±2.32	0.112	12.55±3.86	11.65±2.98	0.369	12.46±3.50	11.28±2.34	0.162
		Right	13.15±3.84	11.46±2.51	0.069	12.25±3.35	10.66±1.83	0.034	12.23±3.16	10.75±1.78	0.038
	Ilio-psoas	Left	6.64±0.43	6.71±0.33	0.568	6.30±0.77	6.59±0.42	0.157	6.55±0.31	6.60±0.50	0.693
		Right	6.54±0.39	6.53±0.33	0.918	6.13±0.36	6.06±0.40	0.527	6.21±0.51	6.19±0.36	0.917
	Quadratus lumborum	Left	4.89±0.27	5.00±0.32	0.190	4.63±0.44	4.78±0.47	0.307	4.64±0.40	4.74±0.37	0.400
		Right	4.75±0.36	4.73±0.33	0.846	4.32±0.46	4.33±0.33	0.969	4.56±0.36	4.52±0.25	0.657
	Rectus abdominis	Left	5.01±0.38	4.79±0.34	0.051	4.66±0.43	4.34±0.41	0.016	4.76±0.45	4.53±0.50	0.109
		Right	5.34±0.35	5.52±0.32	0.095	4.99±0.31	5.07±0.29	0.365	5.12±0.29	5.24±0.38	0.198
	Obliques	Left	22.28±2.81	20.96±2.96	0.133	18.64±2.81	18.46±3.85	0.853	20.58±3.40	18.49±4.40	0.070
		Right	22.35±2.97	23.97±3.32	0.087	18.35±2.87	20.58±3.71	0.023	21.56±2.33	23.18±1.64	0.015
L4–L5	Multifidus	Left	7.43±1.51	7.46±1.14	0.959	6.23±1.27	5.83±0.76	0.169	7.45±1.50	7.11±1.23	0.430
		Right	7.25±1.56	6.85±1.00	0.353	6.48±1.42	5.93±0.78	0.083	7.11±1.54	6.77±1.13	0.434
	Erector spinae	Left	9.73±0.52	9.93±0.81	0.314	9.20±0.56	9.43±0.53	0.180	9.43±0.43	9.28±0.64	0.338
		Right	9.66±0.55	9.86±0.46	0.221	9.23±0.55	9.51±0.33	0.029	9.51±0.51	9.48±0.53	0.877
	Ilio-psoas	Left	6.62±0.42	6.71±0.33	0.453	6.41±0.68	6.59±0.42	0.338	6.56±0.33	6.63±0.48	0.559
		Right	6.54±0.39	6.53±0.32	0.917	6.14±0.36	6.05±0.39	0.425	6.21±0.38	6.18±0.40	0.755

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Table 12. Continued

Level	Mean CSA (cm^2) of lumbar muscles		Initial			3 mo			6 mo		
			Operative (n=35)	Conservative (n=16)	*p*-value[a)]	Operative (n=35)	Conservative (n=16)	*p*-value[a)]	Operative (n=35)	Conservative (n=16)	*p*-value[a)]
	Quadratus lumborum	Left	4.91±0.29	5.00±0.33	0.330	4.63±0.43	4.69±0.51	0.642	4.63±0.41	4.75±0.39	0.346
		Right	4.76±0.36	4.77±0.27	0.860	4.45±0.50	4.49±0.35	0.773	4.55±0.35	4.49±0.27	0.554
	Rectus abdominis	Left	5.03±0.36	4.79±0.34	0.032	4.62±0.45	4.36±0.40	0.058	4.75±0.44	4.54±0.50	0.139
		Right	5.33±0.37	5.47±0.42	0.231	5.03±0.28	5.08±0.33	0.632	5.14±0.31	5.23±0.37	0.430
	Obliques	Left	22.64±2.79	21.29±2.86	0.116	19.69±2.47	18.63±2.99	0.189	20.56±3.47	18.63±3.33	0.067
		Right	22.71±2.40	24.28±2.87	0.047	19.19±3.55	20.28±4.86	0.370	21.15±2.45	21.52±3.26	0.660
L5–S1	Multifidus	Left	9.53±0.95	9.09±0.90	0.124	9.11±0.91	8.78±0.72	0.212	9.18±0.97	9.04±0.94	0.617
		Right	9.65±0.95	9.24±0.72	0.129	8.83±1.23	9.05±1.37	0.562	9.15±1.00	8.85±1.05	0.330
	Erector spinae	Left	9.73±0.52	9.93±0.80	0.284	9.32±0.54	9.56±0.64	0.172	9.43±0.43	9.43±0.44	0.984
		Right	9.65±0.54	9.78±0.49	0.451	9.15±0.66	9.50±0.33	0.014	9.51±0.52	9.51±0.70	0.977
	Ilio-psoas	Left	16.36±1.30	16.39±0.87	0.950	14.66±1.18	15.04±0.96	0.300	14.62±1.55	15.04±1.25	0.365
		Right	14.47±1.98	15.03±1.78	0.369	13.14±2.23	13.98±1.90	0.223	13.88±1.80	14.59±1.39	0.147
	Rectus abdominis	Left	5.01±0.37	4.79±0.34	0.047	4.64±0.44	4.29±0.41	0.008	4.76±0.45	4.54±0.50	0.123
		Right	5.34±0.35	5.47±0.42	0.273	4.99±0.31	5.03±0.32	0.635	5.11±0.30	5.23±0.38	0.237

Values are presented as mean±standard deviation.
CSA, cross-sectional area.
[a)]By independent Student *t*-test.

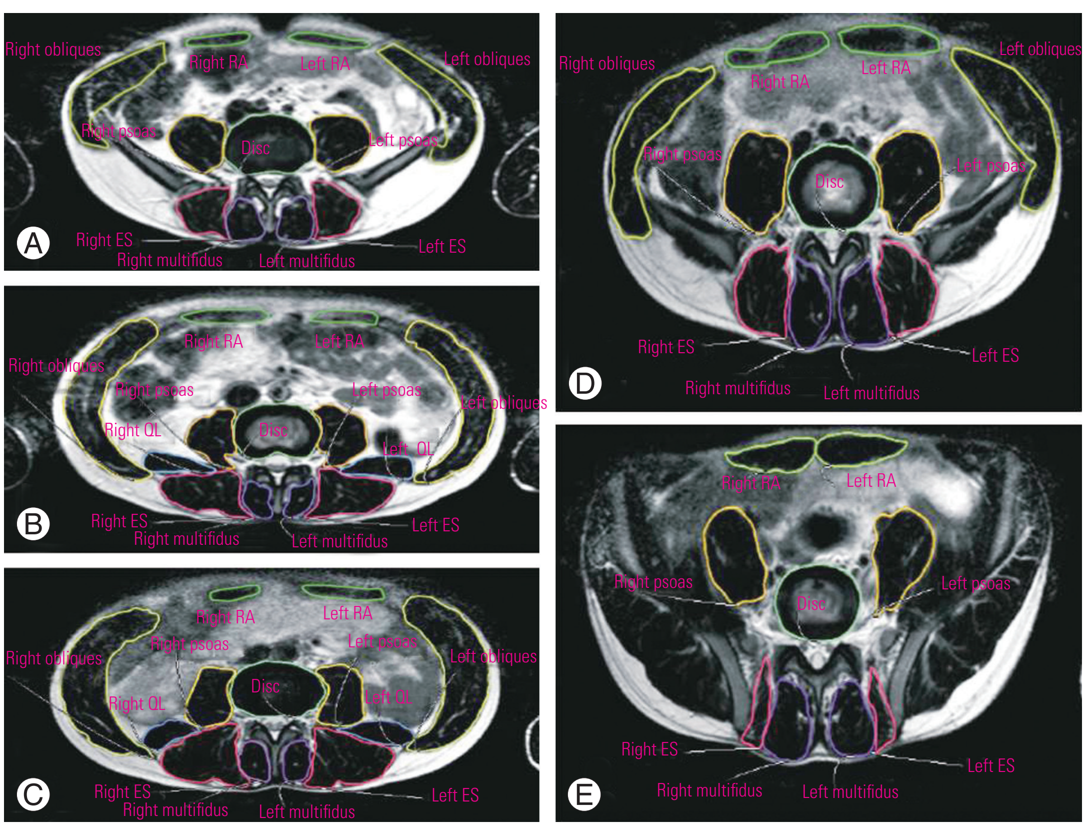

Fig. 1. Measurements of the cross-sectional areas of trunk muscles on axial T2-weighted images at the **(A)** L1–L2, **(B)** L2–L3, **(C)** L3–L4, **(D)** L4–L5, and **(E)** L5–S1 lumbar disc levels. RA, rectus abdominis; ES, erector spinae; QL, quadratus lumborum.

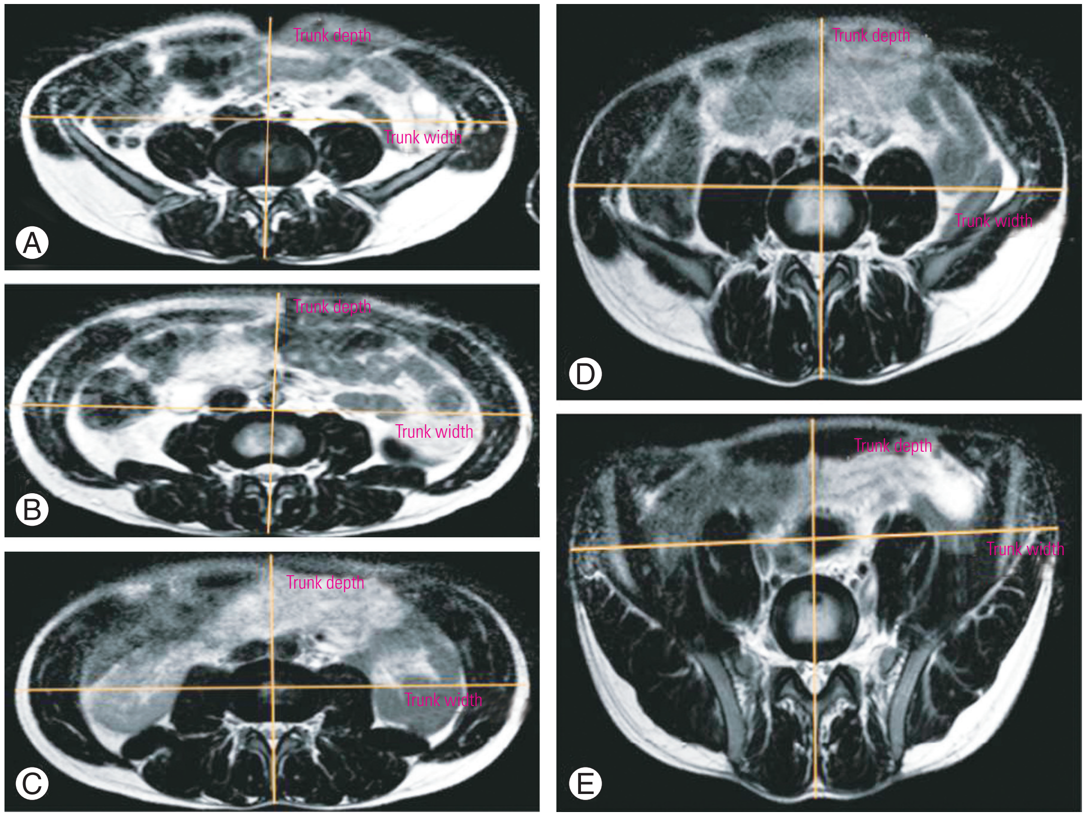

Fig. 2. Measurements of trunk depth and width on axial T2-weighted images at the **(A)** L1–L2, **(B)** L2–L3, **(C)** L3–L4, **(D)** L4–L5, and **(E)** L5–S1 lumbar disc levels.

width at most levels of the spinal cord at the 3-month follow-up after SCI compared with that at admission, thus demonstrating the response of the paraspinal muscles to SCI. The decrease in mean CSA of all the lumbar muscles and subsequent increase might be due to the neurological improvement and active rehabilitation of the patient. As weight bearing begins and neurological improvement occurs, the observed changes may begin to revert to normal levels in response to the restoration of the normal biomechanics and anatomical alignment of the vertebral column. Many previous studies have highlighted the need for early rehabilitation and weight bearing (if possible) after the initial management of vertebral column injuries [11,12]. The limited strength observed in patients with SCI may be due to neurological factors or the insufficient muscle mass (more accurately, insufficient physiological muscle CSA) of neurally intact muscles. The neurologically intact muscles of a person with SCI are likely to respond to strength in the same way as those of an able-bodied person [5]. Indeed, clinical trials involving patients with SCI have demonstrated that progressive resistance training for nonparalyzed muscles increases the strength and quality of life of the patients [13,14]. It is not clear why partially paralyzed muscles are directly affected by SCI, although there is strong evidence to indicate that people who suffer partial paralysis following SCI become stronger over time [15].

Clinical trials and nonrandomized studies have consistently demonstrated that the strength of partially paralyzed muscles increases over time. It is generally assumed that this is due to a combination of central and peripheral factors. Peripheral factors include muscle hypertrophy, whereas central factors include adaptations either at the site of SCI or within the brain. It is unclear how much of the observed increase in the strength of partially paralyzed muscles can be attributed to physiotherapy intervention as opposed to natural recovery [5]. It has been reported that reversing the changes in muscles or at least restoring the normal proportions of fat and contractile tissue in the cervical spine muscles may contribute to the improvement of the functional rate of recovery in chronic whiplash injury [5]. The reinnervation of denervated paraspinal muscles has been reported following posterior spinal surgery in patients with lumbar degenerative

Table 13. CSA & fat content of lumbar muscles at L1–L2 disc level of lumbar spine according to neurological status in terms of complete and incomplete injury (n=51)

Duration	CSA (cm^2) of lumbar muscles (initially)		Severity of initial injury: Complete SCI (ASIA grade A) (n=10)	Incomplete SCI (ASIA grade B, C, D) (n=39)	No deficit (ASIA grade E) (n=2)	*p*-vale[a)]	Intergroup comparisons
Initial	Multifidus	Left	4.67±0.42	4.52±0.46	4.40±0.28	0.655	Insignificant
		Right	4.38±0.41	4.30±0.43	4.65±0.35	0.411	Insignificant
	Erector spinae	Left	10.36±0.86	9.64±0.47	9.60±0.00	0.245	Insignificant
		Right	9.82±0.71	9.65±0.48	9.85±0.35	0.500	Insignificant
	Ilio-psoas	Left	6.63±0.44	6.65±0.39	6.70±0.00	0.279	Insignificant
		Right	6.34±0.50	6.539±0.32	6.55±0.50	0.679	Insignificant
	Quadratus lumborum	Left	4.81±0.23	4.97±0.30	4.65±0.07	0.205	Insignificant
		Right	4.46±0.38	4.80±0.31	4.90±0.28	0.261	Insignificant
	Rectus abdominis	Left	4.95±0.43	4.92±0.37	5.10±0.00	0.117	Insignificant
		Right	5.35±0.18	5.36±0.41	5.90±0.00	0.145	Insignificant
	Obliques	Left	21.44±3.27	22.21±2.79	22.50±1.70	0.377	Insignificant
		Right	23.17±3.08	22.57±2.81	22.92±3.00	0.851	Insignificant
3 mo	Multifidus	Left	3.99±0.18	4.10±0.29	3.95±0.35	0.256	Insignificant
		Right	3.87±0.23	3.90±0.43	3.95±0.21	0.816	Insignificant
	Erector spinae	Left	8.98±1.15	9.33±0.68	9.50±0.00	0.519	Insignificant
		Right	9.34±0.55	9.24±0.64	9.45±0.21	0.036	A-B=0.031
	Ilio-psoas	Left	6.49±1.12	6.75±0.90	6.95±0.78	0.903	Insignificant
		Right	5.98±0.55	6.16±0.32	6.20±0.28	0.993	Insignificant
	Quadratus lumborum	Left	4.66±0.34	4.74±0.46	4.10±0.57	0.347	Insignificant
		Right	4.81±0.43	4.36±0.43	4.40±0.42	0.042	A-B=0.039
	Rectus abdominis	Left	4.72±0.55	4.53±0.42	4.50±0.00	0.040	B-C=0.035
		Right	5.03±0.16	5.09±0.29	4.85±0.07	0.033	A-C=0.034
	Obliques	Left	19.18±2.61	19.49±3.06	22.50±0.14	0.796	Insignificant
		Right	19.80±2.37	18.63±2.71	18.90±9.19	0.320	Insignificant
6 mo	Multifidus	Left	4.22±0.21	4.41±0.58	4.15±0.07	0.559	Insignificant
		Right	4.02±0.77	4.06±0.51	4.10±0.14	0.259	Insignificant
	Erector spinae	Left	9.16±0.65	9.44±0.44	9.60±0.00	0.898	Insignificant
		Right	9.44±0.56	9.73±0.82	9.25±0.78	0.346	Insignificant
	Ilio-psoas	Left	6.45±0.30	6.59±0.38	6.70±0.14	0.002	B-C=0.002, A-C=0.002
		Right	5.85±0.54	6.27±0.44	6.25±0.50	0.880	Insignificant
	Quadratus lumborum	Left	4.33±0.56	4.78±0.29	4.45±0.07	0.233	Insignificant
		Right	4.41±0.38	4.57±0.32	4.60±0.28	0.553	Insignificant
	Rectus abdominis	Left	4.81±0.40	4.65±0.48	4.85±0.78	0.020	B-C=0.017, A-C=0.031
		Right	5.13±0.16	5.16±0.36	5.50±0.00	0.227	Insignificant
	Obliques	Left	20.66±2.52	19.90±3.73	21.50±2.26	0.481	Insignificant
		Right	21.00±2.56	21.03±2.43	24.65±0.50	0.288	Insignificant

Values are presented as mean±standard deviation. A-B means complete SCI versus incomplete SCI; B-C means incomplete SCI versus no deficit; A-C means complete SCI versus no deficit. Intergroup comparisons are all significant except below mentioned.
CSA, cross-sectional area; SCI, spinal cord injury; ASIA, American Spinal Injury Association.
[a)]By one way analysis of variance test.

Table 14. CSA & fat content of lumbar muscles at L2–L3 disc level of lumbar spine according to initial neurological status in terms of complete and incomplete injury (n=51)

Duration	CSA (cm^2) of lumbar muscles (initially)		Severity of initial injury				Intergroup comparison
			Complete SCI (ASIA grade A) (n=10)	Incomplete SCI (ASIA grade B, C, D) (n=39)	No deficit (ASIA grade E) (n=2)	p-value[a)]	
Initial	Multifidus	Left	4.67±0.42	4.53± 0.45	4.40±0.28	0.655	Insignificant
		Right	4.37± 0.40	4.28± 0.43	4.65±0.35	0.729	Insignificant
	Erector spinae	Left	10.36±0.86	10.11± 0.99	10.45± 1.63	0.796	Insignificant
		Right	9.82±0.71	10.42± 1.29	10.35±0.07	0.278	Insignificant
	Ilio-psoas	Left	6.63±0.44	6.66± 0.39	6.70±0.00	0.266	Insignificant
		Right	6.34±0.50	6.60±0.32	6.55±0.50	0.689	Insignificant
	Quadratus lumborum	Left	4.81±0.23	4.97±0.30	4.65±0.07	0.238	Insignificant
		Right	4.57± 0.40	4.80±0.31	4.90±0.28	0.272	Insignificant
	Rectus abdominis	Left	4.95±0.43	4.93± 0.38	5.10±0.00	0.115	Insignificant
		Right	5.35±0.18	5.36±0.41	5.90±0.00	0.145	Insignificant
	Obliques	Left	21.83± 3.75	22.20± 2.89	22.50±1.70	0.472	Insignificant
		Right	23.17±3.08	22.88± 3.13	28.35± 0.07	0.987	Insignificant
3 mo	Multifidus	Left	4.08± 0.25	4.11± 0.30	3.95± 0.35	0.370	Insignificant
		Right	3.87± 0.23	3.93± 0.42	3.95±0.21	0.483	Insignificant
	Erector spinae	Left	8.98± 1.15	9.13± 1.98	14.25±6.72	0.105	Insignificant
		Right	9.34± 0.55	8.85± 1.39	14.60± 0.00	0.001	A-B=0.034, B-C=0.003, A-C=0.038
	Ilio-psoas	Left	6.49± 1.12	6.34± 0.43	6.35± 0.07	0.455	Insignificant
		Right	5.97± 0.54	6.20±0.30	6.20± 0.28	0.976	Insignificant
	Quadratus lumborum	Left	4.63± 0.35	4.72± 0.39	4.10± 0.57	0.205	Insignificant
		Right	4.73± 0.40	4.40±0.38	4.40±0.42	0.069	Insignificant
	Rectus abdominis	Left	4.63± 0.60	4.50± 0.42	4.50±0.00	0.054	Insignificant
		Right	5.03± 0.16	5.08± 0.30	4.85± 0.07	0.048	A-C=0.049
	Obliques	Left	18.92± 3.51	17.75± 3.18	21.35± 1.77	0.780	Insignificant
		Right	18.18± 2.83	18.95± 3.65	17.35±7.00	0.224	Insignificant
6 mo	Multifidus	Left	4.25± 0.23	4.42± 0.55	4.15±0.07	0.527	Insignificant
		Right	4.02± 0.77	4.06± 0.51	4.10± 0.14	0.259	Insignificant
	Erector spinae	Left	9.16± 0.65	9.57± 0.72	10.25±0.92	0.665	Insignificant
		Right	9.44±0.56	10.17± 1.00	9.80±0.00	0.043	Insignificant
	Ilio-psoas	Left	6.50± 0.34	6.58± 0.38	6.70± 0.14	0.001	B-C=0.003, A-C=0.001
		Right	5.84± 0.54	6.30±0.42	6.25± 0.50	0.918	Insignificant
	Quadratus lumborum	Left	4.33±0.56	4.78± 0.30	4.45± 0.07	0.236	Insignificant
		Right	4.48± 0.34	4.59± 0.29	4.60±0.28	0.348	Insignificant
	Rectus abdominis	Left	4.81± 0.40	4.65± 0.49	4.85± 0.78	0.024	B-C=0.021, A-C=0.034
		Right	5.13±0.16	5.15± 0.36	5.50± 0.00	0.259	Insignificant
	Obliques	Left	21.03± 4.01	20.37± 3.02	21.50± 2.26	0.697	Insignificant
		Right	21.80± 2.16	21.80± 2.18	24.65±0.50	0.379	Insignificant

Values are presented as mean±standard deviation. A-B means complete SCI versus incomplete SCI; B-C means incomplete SCI versus no deficit; A-C means complete SCI versus no deficit.
CSA, cross-sectional area; SCI, spinal cord injury; ASIA, American Spinal Injury Association.
[a)]By one way analysis of variance test.

Table 15. CSA & fat content of lumbar muscles at L3–L4 disc level of spine according to initial neurological status in terms of complete and incomplete injury (n=51)

Duration	CSA (cm^2) of lumbar muscles (initially)		Severity of initial injury				Intergroup comparison
			Complete SCI (ASIA grade A) (n=10)	Incomplete SCI (ASIA grade B, C, D) (n=39)	No deficit (ASIA grade E) (n=2)	*p*-value[a)]	
Initial	Multifidus	Left	4.67±0.42	4.54±0.45	4.40±0.28	0.740	Insignificant
		Right	4.38±0.41	4.30±0.43	4.65±0.35	0.411	Insignificant
	Erector Spinae	Left	10.74±1.05	12.74±3.30	14.50±5.09	0.308	Insignificant
		Right	9.82±0.71	13.23±3.61	14.70±5.09	0.057	Insignificant
	Ilio-psoas	Left	6.63±0.44	6.65±0.39	6.95±0.35	0.273	Insignificant
		Right	6.35±0.50	6.59±0.32	6.55±0.50	0.708	Insignificant
	Quadratus lumborum	Left	4.81±0.23	4.96±0.29	4.65±0.07	0.212	Insignificant
		Right	4.46±0.38	4.80±0.31	4.90±0.28	0.267	Insignificant
	Rectus abdominis	Left	4.95±0.43	4.93±0.38	5.10±0.00	0.114	Insignificant
		Right	5.35±0.18	5.39±0.37	5.90±0.00	0.281	Insignificant
	Obliques	Left	21.42±3.26	21.95±2.89	22.50±1.70	0.818	Insignificant
		Right	23.22±2.43	22.76±3.17	22.90±7.64	0.264	Insignificant
3 mo	Multifidus	Left	4.09±0.25	4.09±0.28	3.95±0.35	0.277	Insignificant
		Right	3.87±0.23	3.90±0.43	3.95±0.21	0.816	Insignificant
	Erector spinae	Left	10.17±1.13	12.77±3.87	12.90±3.82	0.103	Insignificant
		Right	9.34±0.55	12.30±3.12	13.00±3.82	0.071	Insignificant
	Ilio-psoas	Left	6.42± 1.08	6.37±0.59	6.65 ± 0.35	0.260	Insignificant
		Right	5.99± 0.53	6.14±0.33	6.20± 0.28	0.826	Insignificant
	Quadratus lumborum	Left	4.63± 0.32	4.73±0.46	3.95± 0.35	0.375	Insignificant
		Right	4.25±0.41	4.34±0.43	4.40±0.42	0.315	Insignificant
	Rectus abdominis	Left	4.73±0.54	4.52±0.43	4.50±0.00	0.044	B-C=0.039
		Right	4.98±0.23	5.03±0.32	4.85±0.07	0.601	Insignificant
	Obliques	Left	18.62±3.73	18.37±2.96	22.50±0.14	0.449	Insignificant
		Right	18.85±2.82	19.11±3.34	18.85±6.58	0.310	Insignificant
6 mo	Multifidus	Left	4.19±0.27	4.37±0.57	4.15±0.07	0.633	Insignificant
		Right	4.02±0.77	4.06±0.51	4.10±0.14	0.259	Insignificant
	Erector spinae	Left	9.72±0.95	12.61±3.30	13.75±4.45	0.135	Insignificant
		Right	9.44±0.56	12.32±2.95	12.65±3.18	0.072	Insignificant
	Ilio-psoas	Left	6.43±0.36	6.60±0.39	6.70±0.14	0.003	B-C=0.004, A-C=0.003
		Right	5.92±0.53	6.28±0.43	6.20±0.42	0.910	Insignificant
	Quadratus lumborum	Left	4.33±0.56	4.77±0.29	4.45±0.07	0.210	Insignificant
		Right	4.41±0.38	4.58±0.31	4.70±0.14	0.540	Insignificant
	Rectus abdominis	Left	4.80±0.41	4.65±0.48	4.85±0.78	0.021	B-C=0.018, A-C=0.033
		Right	5.13±0.16	5.15±0.35	5.50±0.00	0.248	Insignificant
	Obliques	Left	20.03±3.51	19.82±4.00	21.50±2.26	0.415	Insignificant
		Right	22.35±2.05	22.03±2.28	21.45±4.03	0.348	Insignificant

Values are presented as mean±standard deviation. A-B means complete SCI versus incomplete SCI; B-C means incomplete SCI versus no deficit; A-C means complete SCI versus no deficit.
CSA, cross-sectional area; SCI, spinal cord injury; ASIA, American Spinal Injury Association.
[a)]By one way analysis of variance test.

Table 16. CSA & fat content of lumbar muscles at L4–L5 disc level of spinal cord initially according to initial neurological status in terms of complete and incomplete injury (n=51)

Duration	CSA (cm^2) of lumbar muscles		Severity of initial injury				Intergroup comparison
			Complete SCI (ASIA grade A) (n=10)	Incomplete SCI (ASIA grade B, C, D) (n=39)	No deficit (ASIA grade E) (n=2)	*p*-value[a)]	
Initial	Multifidus	Left	8.31±0.66	7.12±1.38	9.35±1.34	0.130	Insignificant
		Right	7.31±0.84	7.00±1.50	8.70±1.27	0.690	Insignificant
	Erector spinae	Left	10.36±0.86	9.66±0.48	9.60±0.00	0.250	Insignificant
		Right	9.82±0.71	9.69±0.49	9.85±0.35	0.470	Insignificant
	Ilio-psoas	Left	6.63±0.44	6.65±0.39	6.70±0.00	0.287	Insignificant
		Right	6.34±0.50	6.59±0.31	6.55±0.50	0.465	Insignificant
	Quadratus lumborum	Left	4.81±0.29	4.98±0.30	4.65±0.07	0.192	Insignificant
		Right	4.50±0.39	4.81±0.30	4.90±0.28	0.260	Insignificant
	Rectus abdominis	Left	5.05±0.38	4.92±0.38	5.10±0.00	0.129	Insignificant
		Right	5.35±0.18	5.35±0.42	5.90±0.00	0.179	Insignificant
	Obliques	Left	21.47±3.30	22.40± 2.81	22.50±1.70	0.496	Insignificant
		Right	22.66±1.22	23.26±2.81	24.80±4.95	0.258	Insignificant
3 mo	Multifidus	Left	6.40±0.37	5.92±1.17	8.05±1.63	0.251	Insignificant
		Right	6.50±0.37	6.20±1.38	7.50±1.70	0.538	Insignificant
	Erector spinae	Left	9.44±0.47	9.22±0.58	9.50±0.00	0.434	Insignificant
		Right	9.29±0.57	9.32±0.50	9.45±0.21	0.525	Insignificant
	Ilio-psoas	Left	6.52±0.72	6.43±0.58	6.95±0.78	0.214	Insignificant
		Right	5.97±0.55	6.14±0.31	6.20±0.28	0.691	Insignificant
	Quadratus lumborum	Left	4.49±0.33	4.71±0.46	4.10±0.57	0.147	Insignificant
		Right	4.93±0.32	4.37±0.42	4.40±0.42	0.062	Insignificant
	Rectus abdominis	Left	4.72±0.55	4.48±0.42	4.50±0.00	0.051	Insignificant
		Right	5.03±0.16	5.06±0.33	4.85±0.07	0.021	Insignificant
	Obliques	Left	19.68±2.72	19.20±2.69	22.85±2.19	0.913	Insignificant
		Right	19.50±2.32	19.86±4.09	13.35±5.73	0.485	Insignificant
6 mo	Multifidus	Left	8.47±0.69	6.97±1.38	9.05±0.64	0.042	Insignificant
		Right	8.40±0.73	6.61±1.34	7.60±1.41	0.084	Insignificant
	Erector spinae	Left	9.16±0.65	9.43±0.47	9.60±0.00	0.707	Insignificant
		Right	9.42±0.57	9.53±0.50	9.25±0.78	0.599	Insignificant
	Ilio-psoas	Left	6.51±0.33	6.60±0.40	6.70±0.00	0.005	B-C=0.006, A-C=0.004
		Right	5.97±0.53	6.26±0.32	6.25±0.50	0.487	Insignificant
	Quadratus lumborum	Left	4.25±0.60	4.78±0.29	4.45±0.07	0.214	Insignificant
		Right	4.36±0.41	4.56±0.31	4.60±0.28	0.599	Insignificant
	Rectus abdominis	Left	4.81±0.40	4.63±0.48	4.85±0.78	0.020	B-C=0.016, A-C=0.044
		Right	5.13±0.16	5.16±0.37	5.50±0.00	0.139	Insignificant
	Obliques	Left	20.01±3.27	19.86±3.66	21.50±2.26	0.297	Insignificant
		Right	20.50±1.96	21.29±2.82	24.65±0.50	0.274	Insignificant

Values are presented as mean±standard deviation. A-B means complete SCI versus incomplete SCI; B-C means incomplete SCI versus no deficit; A-C means complete SCI versus no deficit.
CSA, cross-sectional area; SCI, spinal cord injury; ASIA, American Spinal Injury Association.
[a)]By one way analysis of variance test.

Table 17. CSA & fat content of lumbar muscles at L5–S1 disc level of spinal cord initially according to neurological status in terms of complete and incomplete injury (n=51)

Duration	CSA (cm^2) of lumber muscles		Severity of initial injury				Intergroup comparison
			Complete SCI (ASIA grade A) (n=10)	Incomplete SCI (ASIA grade B, C, D) (n=39)	No deficit (ASIA grade E) (n=2)	*p*-value[a)]	
Initial	Multifidus	Left	9.41±1.43	9.40±0.82	9.10±0.85	0.885	Insignificant
		Right	9.43±0.98	9.56±0.90	9.40±0.85	0.441	Insignificant
	Erector spinae	Left	10.36±0.86	9.66±0.48	9.60±0.00	0.212	Insignificant
		Right	9.82±0.71	9.65±0.48	9.85±0.35	0.481	Insignificant
	Ilio-psoas	Left	16.87±2.51	16.25±0.58	16.25±0.35	0.989	Insignificant
		Right	16.96±2.07	14.15±1.45	13.25±1.63	0.191	Insignificant
	Rectus abdominis	Left	4.95±0.43	4.93±0.37	5.10±0.00	0.107	Insignificant
		Right	5.35±0.18	5.36±0.41	5.90±0.00	0.130	Insignificant
3 mo	Multifidus	Left	8.70±1.17	9.07±0.77	9.20±0.99	0.466	Insignificant
		Right	8.72±1.42	8.99±1.25	8.00±0.00	0.881	Insignificant
	Erector spinae	Left	9.46±0.58	9.38±0.60	9.50±0.00	0.200	Insignificant
		Right	9.34±0.55	9.23±0.62	9.45±0.21	0.037	A-B=0.032
	Ilio-psoas	Left	15.92±2.15	14.51±0.46	14.40±0.28	0.437	Insignificant
		Right	15.76±1.81	12.84±1.87	12.85±1.91	0.461	Insignificant
	Rectus abdominis	Left	4.72±0.55	4.49±0.44	4.50±0.00	0.065	Insignificant
		Right	4.96±0.14	5.02±0.35	4.85±0.07	0.019	A-C=0.025
6 mo	Multifidus	Left	8.87±1.70	9.19±0.69	9.40±0.42	0.649	Insignificant
		Right	9.01±1.02	9.08±1.04	8.85±0.92	0.240	Insignificant
	Erector spinae	Left	9.40±0.33	9.43±0.46	9.60±0.00	0.677	Insignificant
		Right	9.39±0.48	9.55±0.60	9.25±0.78	0.666	Insignificant
	Ilio-psoas	Left	16.18±2.17	14.39±1.06	14.70±0.28	0.834	Insignificant
		Right	16.04±1.49	13.66±1.42	13.15±1.77	0.164	Insignificant
	Rectus abdominis	Left	4.81±0.40	4.65±0.48	4.85±0.78	0.021	B-C=0.017, A-C=0.032
		Right	5.13±0.16	5.14±0.36	5.50±0.00	0.277	Insignificant

Values are presented as mean±standard deviation. A-B means complete SCI versus incomplete SCI; B-C means incomplete SCI versus no deficit; A-C means complete SCI versus no deficit.
CSA, cross-sectional area; SCI, spinal cord injury; ASIA, American Spinal Injury Association.
[a)]By one way analysis of variance test.

disease [12]. Postoperative computed tomography (CT) and MRI imaging studies have shown that reductions in the CSA of the spinal muscles occur, as well as changes in muscular density. Gille et al. [16] reported that erector spinae muscle alterations mainly occur at locations distal to the posterior lumbar surgical procedures. Kim et al. [17] observed a significant decrease in the CSA of the multifidus muscle in patients who underwent open pedicle fixation. Fan et al. [10,18] reported that multifidus atrophy was reduced among patients who underwent minimally invasive treatment (p<0.001), with mean reductions in the CSA of 12.2% at the operative level and 8.5% at the adjacent levels compared with 36.8% and 29.3%, respectively, among patients who underwent conventional open surgery. Conversely, Keller et al. [19] observed that there was no decrease in spinal muscle CSA after surgery, but muscle density (determined by CT) was adversely affected.

The abovementioned studies indicate that surgical intervention with pedicle screws for the traumatic or degenerative disorders of the spine can lead to alteration in the CSA and fat contents of the paravertebral muscles [10,16-18]. In the present study, we were unable to clarify whether operative intervention with pedicle screws causes further damage to paravertebral muscles because no significant differences were observed in the CSAs of various muscles (except at the L1–L2 level, which was adjacent to the most commonly injured site, for the erector spinae and rectus abdominis) between groups divided according to conservative or operative management. However, all patients in this study underwent open pedicle screw fixation. Ntilikina et al. [20] compared the MRI findings of paravertebral muscles after implant removal in thoracolumbar fractures after open versus percutaneous instrumentation. They reported that percutaneous instrumentation led to decreased muscle atrophy compared with open surgery. The MRI signal differences for T12 and L1 fractures suggested reduced fat infiltration within the CSA of patients who received percutaneous treatment. A major difference between the study of Ntilikina et al. [20] and the present study was that none of the patients in the former had neurological deficits. Similarly, other studies (such as those of Gille et al. [16], Kim et al. [17], and Fan et al. [10,18]) reported differences in the pre- and postoperative CSA of muscles after lumbar spine surgery on patients without major neurological deficits. Anecdotal evidence from the literature suggests that further damage should be expected after open pedicle screw in previously paralyzed muscles [10,13,15-17].

The degree of neurological involvement has a significant effect on the wastage of the paravertebral muscle post-SCI [2]. We did not find any statistically significant differences between patients categorized as motor complete (ASIA A) and motor incomplete (ASIA B, C, or D) in the present study, and intergroup comparisons at different time points did not reveal any significant changes in the majority of the muscles studied. To the best of our knowledge, no study has reported such findings. This could be due to the short follow-up of the present study (6 months) and our robust post-SCI rehabilitation protocol irrespective of the degree of neurological involvement. Furthermore, the lack of significant differences could have been influenced by the small number of patients with complete SCI in the present cohort. Larger studies involving more patients and longer follow-up are required to verify these findings.

Conclusions

Spinal trauma leads to alterations in the vertebral column, spinal cord, intervertebral discs, and paraspinal muscle morphology in the initial phase after injury. The extent of these changes may determine the initial neurological deficit and subsequent recovery. Although the present study did not identify any statistically significant effects of neurological status or management strategy on these parameters, improvement in the later phase of recovery was observed in response to rehabilitation. Future studies are needed to evaluate the exact mechanisms underlying these alterations and the benefits of rehabilitation strategies with regard to these parameters.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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