SHORT REPORT

Massage manipulation vs. low back muscle exercise for lumbar intervertebral instability: A preliminary randomized clinical trial

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Abstract

This is a preliminary randomized clinical trial on patients conducted at Wuxi Hospital Affiliated with Nanjing University of Chinese Medicine from September 2015 to December 2016. The patients with intervertebral instability were randomized 1:1 for massage (20 min/day for 6 days) or exercise (3 sessions/day for 15 days). Japanese Orthopaedic Association (JOA) score, Oswestry disability score, and quantitative fluoroscopy (QF) were performed before and after the treatment and at 1 and 3 months thereafter. Improvement rates were noted to be 86.7% and 40.0% in the massage and exercise groups, respectively. Massage group showed significant changes in the JOA and Oswestry disability scores ($p < 0.001$ and $p = 0.002$), while the exercise group did not show any significant change ($p > 0.05$). Changes in the JOA and Oswestry disability scores were more important in the massage group ($p < 0.05$). All dynamic imaging parameters were improved in the massage group (all $p < 0.05$) but not in the exercise group (all $p>0.05$). These results suggest that the massage manipulation could be an appropriate way to treat intervertebral instability.

Keywords: Intervertebral instability, Massage, Exercise, Japanese Orthopaedic Association score, Oswestry disability score.

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Introduction

Primary clinical manifestations of intervertebral instability include local pain and motion disorders (i.e., abnormal activity between vertebrae as revealed by passive lumbar extension test, instability catch sign, painful catch sign and apprehension sign).[1,2] The presence of clinical symptoms of lumbar intervertebral instability, namely 'functional abnormality', is inescapably accompanied with abnormal lumbar motion, namely 'structural abnormality', but current imaging examinations only detect static abnormalities. Indeed, a plain X-ray, computed tomography (CT), and magnetic resonance imaging (MRI) film can reveal anatomical changes.[3] Changes in flexion-extension on X-ray film are common findings. Whole-range dynamic observations and precise measurements of each irregular inter-segmental motion is a prerequisite for quantitative analysis of the motion property of the unstable lumbar spine. Quantitative fluoroscopy (QF) enables optimized noise reduction and results in loss-less image editing to calculate the pattern of lumbar vertebral movement, hence, it overcomes various disadvantages of previous approaches. Low-dose X-ray acquires consecutive dynamic digital images of the subject in motion and automatically calculates them to achieve precise quantitative results.[4]

According to the traditional Chinese medicine (TCM), massage manipulation is the key treatment for intervertebral instability.[5] Manipulative adjustment of the vertebrae effectively improves abnormal stress distribution and reconstructs cervical stability.[6,7] It remains unclear how manipulation helps lumbar stability, however, it could result from the relaxation of muscles that corrects the abnormal potential of paravertebral muscles.[8] Another possibility is that manipulation improves clinical symptoms via the facilitation of the central nervous system to enhance central pain tolerance.[9] Therefore, we aim to examine the changes in clinical features after manipulation for lumbar intervertebral instability.

Methods

This is a preliminary randomized clinical trial of patients with lumbar intervertebral instability, randomized 1:1 to formal manipulation or exercise (Wuxi Hospital Affiliated with Nanjing University of Chinese Medicine, Wuxi, China; from September 2015 to December 2016). According to preliminary experiments, it was assumed that the mean AZ value after treatment in the massage and exercise groups were -0.002 ± 0.02 and -0.03 ± 0.02, respectively; the mean BZ after treatment in the massage and exercise groups were -0.01 ± 0.03 and -0.06 ± 0.03, respectively;

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the mean RX of the massage and exercise groups were -0.02 ± 0.04 and 0.03 ± 0.04, respectively. Power was set at 1-β = 0.80 and alpha at 0.05. We used the inequality test for two means using differences (i.e., two-sample t-test) in the PASS 8.0 software. Based on the AZ, BZ, and RX values after treatment, the sample size was 10, 7, and 12 patients/group based on the calculations AZ (translation of lower point A in the Z direction), BZ (translation of lower point A in the Z direction), and RX (vertebral relaxation), respectively. Considering potential drop-out of 10%, we determined that the required sample size was 15 patients/group.

Inclusion criteria were patients with age 40-65 years and symptoms of lumbar intervertebral instability for less than 3 months.[1] Exclusion criteria were patients with either lumbar spondylolisthesis, structural scoliosis, severe osteoporosis (T-score above -2.5), history of spinal fractures or history of lumbar surgery.

Patients were recruited by their treating physicians when the patient was first consulted for low back pain and was simultaneously diagnosed with lumbar intervertebral instability. The physician then presented the study to the participant and allowed time for reading the informed consent form. If the patient agreed to participate in the study all his queries were addressed and the consent form was then signed. There was no monetary incentive, except that the study intervention (massage or exercise) was provided free of charge.

Patients were randomized 1:1 to the massage and exercise groups using sequential sealed envelopes prepared by an independent statistician.

Massage techniques include loosening manipulation and fine-tuning techniques (Supplementary Material). All massage methods were performed by two professional massage therapists with more than 5 years of work experience at the hospital.

Low back muscle exercises for the treatment of lumbar intervertebral instability included standard exercises presented in the supplementary material.

Japanese Orthopaedic Association (JOA) score, Oswestry disability score, and quantitative fluoroscopy (QF) examinations were performed before and after treatment and at 1 and 3 months thereafter.

The JOA score for low back pain[10] and the Oswestry disability score[11] were used. QF examinations were performed routinely.

Observation indexes: The JOA score for low back pain[7] and the Oswestry disability score[8] were used. QF examinations were performed routinely (Supplementary Material).

Statistical analysis: Sample size estimation is presented in the supplementary material. All data were entered using EPIDATA 3.0 and analysed using SPSS 13.0. One-way ANOVA and the Tukey's post hoc test were used for multi-group comparison. The student t-test was used for inter-group comparisons under normal distribution, while the rank-sum test was used for non-normal distribution. Two-sided $p < 0.05$ indicated statistical significance.

Table-1: Characteristics of the patients.

	Massage	Exercise	P
n	15	15	
Gender (n)			0.456
Male	7	5	
Female	8	10	
Age (years)	56.1 ± 5.5	53.2 ± 7.3	0.433
JOA score	12.4 ± 3.7	14.3 ± 5.5	0.745
Oswestry disability score	25.1 ± 2.8	25.7 ± 3.1	0.387
JOA score before treatment	12.4 ± 3.7	14.3 ± 5.5	0.276
JOA score after treatment	23.0 ± 5.0	15.9 ± 5.2	<0.001
P	<0.001	0.266	
Oswestry disability score before treatment	24.7 ± 2.6	25.3 ± 2.7	0.540
Oswestry disability score after treatment	13.9 ± 4.7	22.3 ± 3.0	<0.001
P	0.002	0.303	
Cured (n, %)	2 (13.3)	3 (20.0)	0.66
Significantly effective, n (%)	5 (33.3)	1 (6.7)	0.169
Effective, n (%)	6 (40.0)	2 (13.3)	0.215
Non-effective, n (%)	2 (13.3)	9 (60.0)	0.021

Supplementary Table S1: Changes in vertebral sagittal rotation and displacement after massage or exercise treatment.

	L4	P	L5	P
Massage group				
△AZ	0.0289±0.0462	0.030	0.0338±0.0437	0.010
△BZ	0.0341±0.0480	0.016	0.0494±0.0695	0.015
△RX	0.0055±0.1104	0.851	-0.0219±0.0393	0.048
Exercise group				
△AZ	-0.0020±0.0521	0.885	-0.0052±0.0532	0.711
△BZ	-0.0160±0.0899	0.503	0.0740±0.1062	0.017
△RX	0.0655±0.1342	0.080	0.0174±0.0477	0.179

Paired t test.
AZ: translation of lower point A in the Z direction; BZ: translation of the upper point B in the Z direction; RX: angle of rotation around the X axis.

Supplementary Table S2: Intergroup comparison of L4 sagittal vertebral rotation and displacement between the two groups.

	Massage	Exercise	P
Before treatment			
AZ	-0.0314±0.0297	-0.0280±0.0503	0.820
BZ	-0.0506±0.0743	-0.0382±0.1208	0.736
RX	-0.0278±0.106	-0.0350±0.0856	0.840
After treatment			
AZ	-0.0026±0.0375	-0.0300±0.0323	0.041
BZ	-0.0166±0.0326	-0.0541±0.0558	0.035
RX	-0.0223±0.0765	0.0304±0.0509	0.034

AZ: translation of lower point A in the Z direction; BZ: translation of the upper point B in the Z direction; RX: angle of rotation around the X axis.

Supplementary Table S3: Intergroup comparison of L5 sagittal vertebral rotation and displacement between the two groups.

	Massage	Exercise	P
Before treatment			
AZ	-0.0483±0.0461	-0.0421±0.0615	0.760
BZ	-0.0752±0.0560	-0.0414±0.0942	0.242
RX	0.0274±0.0473	0.0136±0.0488	0.437
After treatment			
AZ	-0.0144±0.0420	-0.0473±0.0444	0.046
BZ	-0.0257±0.0541	0.0327±0.0797	0.026
RX	0.0055±0.0158	0.0310±0.0374	0.021

AZ: translation of lower point A in the Z direction; BZ: translation of the upper point B in the Z direction; RX: angle of rotation around the X axis.

Results

There were 12 males and 18 females of ages 40-65 years. Gender, age, baseline JOA score, and baseline Oswestry disability score were similar between the two groups (Table-1).

Supplementary Table S4: Intergroup comparison of dynamic parameters in extension between the two groups before and after treatment.

		Mean	SD	P
L3 anterior AZ	Massage	-0.0318	0.0301	0.8151
	Exercise	-0.0282	0.0507	
L3 posterior AZ	Massage	-0.0026	0.0370	0.0420
	Exercise	-0.0293	0.0316	
L4 anterior AZ	Massage	-0.0590	0.0563	0.7874
	Exercise	-0.0524	0.0764	
L4 posterior AZ	Massage	-0.0123	0.0358	0.0163
	Exercise	-0.0531	0.0499	
L5 anterior AZ	Massage	-0.0455	0.0434	0.7520
	Exercise	-0.0395	0.0577	
L5 posterior AZ	Massage	-0.0133	0.0388	0.0428
	Exercise	-0.0446	0.0419	
L3 anterior BZ	Massage	-0.0751	0.1102	0.6803
	Exercise	-0.0534	0.1690	
L3 posterior BZ	Massage	-0.0209	0.0412	0.0266
	Exercise	-0.0746	0.0769	
L4 anterior BZ	Massage	-0.00215	0.0614	0.056
	Exercise	0.0498	0.1216	
L4 posterior BZ	Massage	-0.0215	0.0614	0.0490
	Exercise	0.0433	0.1057	
L5 anterior BZ	Massage	-0.0068	0.0100	0.7028
	Exercise	-0.0050	0.0157	
L5 posterior BZ	Massage	-0.0021	0.0042	0.0336
	Exercise	-0.0070	0.0073	
L3 anterior HA	Massage	28.6118	4.7874	0.8287
	Exercise	29.2031	9.3342	
L3 posterior HA	Massage	21.8482	4.2379	0.0167
	Exercise	28.6396	9.1273	
L4 anterior HA	Massage	38.7338	3.9701	0.7078
	Exercise	39.4155	5.7296	
L4 posterior HA	Massage	31.7306	3.2744	0.0077
	Exercise	37.8118	7.2256	
L5 anterior HA	Massage	34.7977	3.5667	0.3900
	Exercise	33.4393	4.8609	
L5 posterior HA	Massage	26.2850	2.7124	0.002
	Exercise	32.4569	6.2023	
L3 anterior HC	Massage	17.1930	2.4302	0.5417
	Exercise	18.1489	5.4783	
L3 posterior HC	Massage	13.4805	1.5539	0.0041
	Exercise	16.0726	2.8107	
L4 anterior HC	Massage	17.0645	2.9196	0.5469
	Exercise	18.0806	5.7541	
L4 posterior HC	Massage	14.5081	2.7151	0.0107
	Exercise	17.6880	3.5920	
L5 anterior HC	Massage	25.5817	4.3769	0.4880
	Exercise	27.3507	8.7042	
L5 posterior HC	Massage	21.0170	3.9331	0.0080
	Exercise	25.8555	5.2506	
L3 anterior IPX	Massage	0.0284	0.0262	0.9747
	Exercise	0.0287	0.0219	
L3 posterior IPX	Massage	0.0039	0.0359	0.0157
	Exercise	0.0319	0.0222	

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L3 anterior IPY	Massage	0.0481	0.0260	0.7830
	Exercise	0.0454	0.0270	
L3 posterior IPY	Massage	0.0281	0.0242	<0.001
	Exercise	0.0848	0.0399	
L4 anterior IPX	Massage	0.0058	0.0076	0.2714
	Exercise	0.0103	0.0134	
L4 posterior IPX	Massage	0.00067	0.00088	0.046
	Exercise	0.00274	0.0036	
L4 anterior IPY	Massage	0.0068	0.0104	0.6617
	Exercise	0.0086	0.0116	
L4 posterior IPY	Massage	0.0010	0.0015	0.0006
	Exercise	0.0074	0.0056	
L5 anterior IPX	Massage	0.0039	0.0058	0.6392
	Exercise	0.0049	0.0067	
L5 posterior IPX	Massage	0.0005	0.0008	0.0005
	Exercise	0.0042	0.0032	
L5 anterior IPY	Massage	0.0033	0.0050	0.6361
	Exercise	0.0042	0.0057	
L5 posterior IPY	Massage	0.0004	0.0006	0.0010
	Exercise	0.0023	0.0018	
L3 anterior RX	Massage	0.0046	0.0177	0.8439
	Exercise	0.0058	0.0141	
L3 posterior RX	Massage	-0.0435	0.0749	0.4809
	Exercise	-0.0264	0.0550	
L4 anterior RX	Massage	0.0070	0.0121	0.4338
	Exercise	0.0035	0.0124	
L4 posterior RX	Massage	0.0006	0.0018	0.0120
	Exercise	0.0067	0.0081	
L5 anterior RX	Massage	0.0040	0.0153	0.9987
	Exercise	0.0040	0.0098	
L5 posterior RX	Massage	-0.0216	0.0373	0.2098
	Exercise	-0.0080	0.0166	
L3 anterior relaxation	Massage	-0.4690	0.2923	0.7697
	Exercise	-0.4238	0.5146	
L3 posterior relaxation	Massage	-0.2679	0.1856	0.2442
	Exercise	-0.1886	0.1793	
L4 anterior relaxation	Massage	-0.2436	0.1518	0.6140
	Exercise	-0.2052	0.2491	
L4 posterior relaxation	Massage	-0.1263	0.0875	0.1024
	Exercise	-0.0767	0.0729	
L5 anterior relaxation	Massage	-1.6236	1.0119	0.7291
	Exercise	-1.4410	1.7494	
L5 posterior relaxation	Massage	-0.6183	0.4283	0.0353
	Exercise	-1.4995	1.4253	
Anterior RXall	Massage	-2.0971	1.3070	0.4770
	Exercise	-1.6516	2.0051	
Posterior RXall	Massage	-0.8378	0.5803	0.0468
	Exercise	-1.8768	1.7840	

AZ: translation of lower point A in the Z direction; BZ: translation of the upper point B in the Z direction; RX: angle of rotation around the X axis; HA: anterior height of the intervertebral disc; HC: posterior height of the intervertebral disc; IPX: instantaneous center of rotation in the X direction; IPY: instantaneous center of rotation in the Y direction.

Supplementary Table S5: Changes in dynamic parameters in extension in the massage group.

	Mean	SD	P
L3 difference in AZ	0.0293	0.0460	0.0273
L4 difference in AZ	0.0467	0.0490	0.0024
L5 difference in AZ	0.0322	0.0409	0.0087
L5 difference in IPX	0.0541	0.0763	0.0157
L3 difference in BZ	0.0682	0.0842	0.0073
L4 difference in BZ	0.0047	0.0066	0.0157
L5 difference in BZ	-6.7636	4.8142	0.0001
L3 difference in HA	-7.0032	5.2026	0.0001
L4 difference in HA	-8.5127	4.5291	<0.0001
L5 difference in HA	-3.7125	2.7639	0.0001
L3 difference in HC	-2.5564	2.4674	0.0013
L4 difference in HC	-4.5647	3.6507	0.0003
L5 difference in HC	-0.0245	0.0372	0.0229
L3 difference in IPX	-0.0201	0.0271	0.0125
L3 difference in IPY	-0.0051	0.0067	0.0103
L4 difference in IPX	-0.0059	0.0106	0.0494
L4 difference in IPY	-0.0034	0.0059	0.0458
L5 difference in IPY	-0.0029	0.0051	0.0452
L3 difference in RX	-0.0481	0.0834	0.0423
L4 difference in RX	-0.0064	0.0111	0.0418
L5 difference in RX	-0.0257	0.0455	0.0465
L3 difference in relaxation	0.2011	0.1803	0.0007
L4 difference in relaxation	0.1173	0.0965	0.0003
L5 difference in relaxation	1.0052	0.7136	0.0001
Difference in RXall	1.2593	0.9073	0.0001

AZ: translation of lower point A in the Z direction; BZ: translation of the upper point B in the Z direction; RX: angle of rotation around the X axis; HA: anterior height of the intervertebral disc; HC: posterior height of the intervertebral disc; IPX: instantaneous center of rotation in the X direction; IPY: instantaneous center of rotation in the Y direction.

Supplementary Table S6: Changes in dynamic parameters in extension in the exercise group.

	Mean	SD	P
L3 difference in AZ	-0.0011	0.0523	0.9359
L4 difference in AZ	-0.0007	0.0651	0.9654
L5 difference in AZ	-0.0051	0.0499	0.7004
L5 difference in IPX	-0.0212	0.1261	0.5254
L3 difference in BZ	0.1075	0.1563	0.0185
L4 difference in BZ	-0.0021	0.0117	0.5014
L5 difference in BZ	-0.5636	5.5160	0.6983
L3 difference in HA	-1.6037	6.1127	0.3268
L4 difference in HA	-0.9824	5.2326	0.4791
L5 difference in HA	-2.0764	4.0410	0.0665
L3 difference in HC	-0.3926	5.8309	0.7981
L4 difference in HC	-1.4952	8.7619	0.5194
L5 difference in HC	0.0033	0.0221	0.5754
L3 difference in IPX	0.0393	0.0462	0.0053
L3 difference in IPY	-0.0075	0.0099	0.0104
L4 difference in IPX	-0.0012	0.0087	0.5862
L4 difference in IPY	-0.0008	0.0050	0.5595

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L5 difference in IPY	-0.0019	0.0046	0.1350
L3 difference in RX	-0.0321	0.0570	0.0466
L4 difference in RX	0.0033	0.0117	0.3004
L5 difference in RX	-0.0120	0.0195	0.0317
L3 difference in relaxation	0.2352	0.4194	0.0475
L4 difference in relaxation	0.1285	0.2087	0.0318
L5 difference in relaxation	-0.0584	1.3495	0.8692
Difference in RXall	-0.2252	1.5845	0.5907

AZ: translation of lower point A in the Z direction; BZ: translation of the upper point B in the Z direction; RX: angle of rotation around the X axis; HA: anterior height of the intervertebral disc; HC: posterior height of the intervertebral disc; IPX: instantaneous center of rotation in the X direction; IPY: instantaneous center of rotation in the Y direction.

Supplementary Table S7: Intergroup comparison of dynamic parameters in flexion between the two groups before and after treatment.

		Mean	SD	P
L3 anterior AZ	Massage	-0.0637	0.0601	0.9038
	Exercise	-0.0598	0.1074	
L3 posterior AZ	Massage	-0.0046	0.0673	0.0306
	Exercise	-0.0592	0.0638	
L4 anterior AZ	Massage	-0.0690	0.0658	0.6387
	Exercise	-0.0865	0.1262	
L4 posterior AZ	Massage	-0.0190	0.0552	0.0126
	Exercise	-0.0881	0.0827	
L5 anterior AZ	Massage	-0.0388	0.0370	0.7103
	Exercise	-0.0329	0.0480	
L5 posterior AZ	Massage	-0.0110	0.0318	0.0388
	Exercise	-0.0375	0.0352	
L3 anterior BZ	Massage	-0.0714	0.1049	0.6601
	Exercise	-0.0497	0.1574	
L3 posterior BZ	Massage	-0.0182	0.0359	0.0206
	Exercise	-0.0713	0.0736	
L4 anterior BZ	Massage	-0.0091	0.0068	0.7367
	Exercise	-0.0075	0.0171	
L4 posterior BZ	Massage	-0.0020	0.0057	0.0355
	Exercise	-0.0158	0.0225	
L5 anterior BZ	Massage	-0.0682	0.1001	0.7036
	Exercise	-0.0497	0.1573	
L5 posterior BZ	Massage	-0.0021	0.0041	0.0027
	Exercise	-0.0706	0.0728	
L3 posterior HA	Massage	24.9959	4.1824	0.7389
	Exercise	25.7997	8.2464	
L3 anterior HA	Massage	18.6222	3.6122	0.0105
	Exercise	25.0153	7.9722	
L4 anterior HA	Massage	39.0166	3.9991	0.1550
	Exercise	36.5088	5.3071	
L4 posterior HA	Massage	31.5143	3.2520	0.0121
	Exercise	37.0769	7.0851	
L5 anterior HA	Massage	37.3848	3.8318	0.9449
	Exercise	37.5049	5.4519	
L5 posterior HA	Massage	30.2070	3.1171	0.0066
	Exercise	36.1610	6.9101	
L3 anterior HC	Massage	26.2948	3.7167	0.6767
	Exercise	27.2776	8.2339	
L3 posterior HC	Massage	19.2552	2.2195	0.0004
	Exercise	24.2670	4.2437	
L4 anterior HC	Massage	23.3943	4.0026	0.8485
	Exercise	22.9792	7.3130	
L4 posterior HC	Massage	16.4992	3.0877	0.0013
	Exercise	21.4244	4.3508	
L5 anterior HC	Massage	29.7349	5.0875	0.5046
	Exercise	31.7071	10.0906	
L5 posterior HC	Massage	24.3848	4.5634	0.0084
	Exercise	29.9469	6.0815	
L3 anterior IPX	Massage	0.0624	0.0575	0.9115
	Exercise	0.0602	0.0461	
L3 posterior IPX	Massage	0.0081	0.0753	0.0149
	Exercise	0.0676	0.0472	
L3 anterior IPY	Massage	0.2590	0.1401	0.5394
	Exercise	0.2277	0.1353	
L3 posterior IPY	Massage	0.0789	0.0681	0.0404
	Exercise	0.2587	0.3038	
L4 anterior IPX	Massage	0.0055	0.0072	0.4092
	Exercise	0.0084	0.0109	
L4 posterior IPX	Massage	0.0006	0.0008	0.0072
	Exercise	0.0037	0.0038	
L4 anterior IPY	Massage	0.0090	0.0136	0.9657
	Exercise	0.0088	0.0118	
L4 posterior IPY	Massage	0.0010	0.0016	0.0004
	Exercise	0.0095	0.0072	
L5 anterior IPX	Massage	0.0037	0.0052	0.4729
	Exercise	0.0025	0.0033	
L5 posterior IPX	Massage	-0.0008	0.0066	0.0387
	Exercise	0.0032	0.0025	
L5 anterior IPY	Massage	0.0338	0.0512	0.6506
	Exercise	0.0430	0.0577	
L5 posterior IPY	Massage	0.0042	0.0064	0.0009
	Exercise	0.0237	0.0180	
L3 anterior RX	Massage	0.0266	0.1020	0.9365
	Exercise	0.0292	0.0715	
L3 posterior RX	Massage	-0.2300	0.3959	0.5561
	Exercise	-0.1520	0.3171	
L4 anterior RX	Massage	0.0705	0.1217	0.4306
	Exercise	0.0346	0.1242	
L4 posterior RX	Massage	0.0060	0.0175	0.0117
	Exercise	0.0676	0.0814	
L5 anterior RX	Massage	0.0405	0.1553	0.9781
	Exercise	0.0392	0.0960	
L5 posterior RX	Massage	0.0401	0.1535	0.9946
	Exercise	0.0398	0.0973	
L3 anterior relaxation	Massage	1.0063	0.6272	0.5770
	Exercise	0.8330	1.0112	
L3 posterior relaxation	Massage	0.2729	0.1890	0.0964
	Exercise	0.7791	1.0881	
L4 anterior relaxation	Massage	1.0716	0.6679	0.4432
	Exercise	0.8290	1.0065	
L4 posterior relaxation	Massage	0.5031	0.3485	0.1486
	Exercise	0.3246	0.3086	
L5 anterior relaxation	Massage	1.4237	0.8873	0.5666
	Exercise	1.1725	1.4235	
L5 posterior relaxation	Massage	0.4528	0.3137	0.0231
	Exercise	1.2514	1.1895	
Anterior RXall	Massage	2.0472	1.2759	0.3365
	Exercise	1.4886	1.8072	
Posterior RXall	Massage	0.7305	0.5060	0.0355
	Exercise	1.7686	1.6812	

AZ: translation of lower point A in the Z direction; BZ: translation of the upper point B in the Z direction; RX: angle of rotation around the X axis; HA: anterior height of the intervertebral disc; HC: posterior height of the intervertebral disc; IPX: instantaneous center of rotation in the X direction; IPY: instantaneous center of rotation in the Y direction.

Supplementary Table S8: Changes in dynamic parameters in flexion in the massage group.

	Mean	SD	P
L3 difference in AZ	0.0590	0.0871	0.0200
L4 difference in AZ	0.0500	0.0606	0.0065
L5 difference in AZ	0.0278	0.0344	0.0074
L5 difference in IPX	0.0532	0.0751	0.0158
L3 difference in BZ	0.0071	0.0083	0.0050
L4 difference in BZ	0.0661	0.0966	0.0189
L5 difference in BZ	-6.3738	4.1663	<0.0001
L3 difference in HA	-7.1778	4.9936	0.0001
L4 difference in HA	-7.5022	5.2108	0.0001
L5 difference in HA	-7.0396	4.1535	<0.0001
L3 difference in HC	-6.8951	3.2037	<0.0001
L4 difference in HC	-5.3501	4.2406	0.0002
L5 difference in HC	-0.0543	0.0791	0.0187
L3 difference in IPX	-0.1801	0.1276	0.0001
L3 difference in IPY	-0.0049	0.0064	0.0103
L4 difference in IPX	-0.0080	0.0138	0.0419
L4 difference in IPY	-0.0044	0.0061	0.0136
L5 difference in IPY	-0.0297	0.0520	0.0442
L3 difference in RX	-0.2566	0.4458	0.0427
L4 difference in RX	-0.0645	0.1115	0.0418
L5 difference in RX	-0.2059	0.3545	0.0411
L3 difference in relaxation	-0.7334	0.4880	<0.0001
L4 difference in relaxation	-0.5685	0.4389	0.0002
L5 difference in relaxation	-0.9708	0.6613	0.0001
Difference in RXall	-1.3167	0.9187	0.0001

AZ: translation of lower point A in the Z direction; BZ: translation of the upper point B in the Z direction; RX: angle of rotation around the X axis; HA: anterior height of the intervertebral disc; HC: posterior height of the intervertebral disc; IPX: instantaneous center of rotation in the X direction; IPY: instantaneous center of rotation in the Y direction.

Supplementary Table S9: Changes in dynamic parameters in flexion in the exercise group.

	Mean	SD	P
L3 difference in AZ	0.0006	0.1095	0.9834
L4 difference in AZ	-0.0016	0.1076	0.9538
L5 difference in AZ	-0.0047	0.0416	0.6713
L5 difference in IPX	-0.0216	0.1169	0.4861
L3 difference in BZ	-0.0083	0.0338	0.3595
L4 difference in BZ	-0.0209	0.1171	0.5013
L5 difference in BZ	-0.7844	4.8498	0.5411
L3 difference in HA	-1.3439	5.8388	0.3878
L4 difference in HA	0.5681	5.9216	0.7158
L5 difference in HA	-3.0107	6.0687	0.0753
L3 difference in HC	-1.5547	7.3429	0.4259
L4 difference in HC	-1.7602	10.1559	0.5130
L5 difference in HC	0.0074	0.0465	0.5470
L3 difference in IPX	0.0310	0.3906	0.7630
L3 difference in IPY	-0.0046	0.0094	0.0753
L4 difference in IPX	0.0008	0.0085	0.7352
L4 difference in IPY	0.0007	0.0024	0.2902
L5 difference in IPY	-0.0193	0.0470	0.1350
L3 difference in RX	-0.1812	0.3262	0.0494
L4 difference in RX	0.0329	0.1172	0.2950
L5 difference in RX	-0.0808	0.1686	0.0847
L3 difference in relaxation	-0.0539	0.4034	0.6130
L4 difference in relaxation	-0.5044	0.8371	0.0350
L5 difference in relaxation	0.0789	1.1046	0.7862
Difference in RXall	0.2800	1.4515	0.4673

AZ: translation of lower point A in the Z direction; BZ: translation of the upper point B in the Z direction; RX: angle of rotation around the X axis; HA: anterior height of the intervertebral disc; HC: posterior height of the intervertebral disc; IPX: instantaneous center of rotation in the X direction; IPY: instantaneous center of rotation in the Y direction.

Supplementary Table S10: Intergroup comparison of dynamic parameters in side bending between the two groups before and after treatment.

		Mean	SD	P
L3 anterior AZ	Massage	3.0082	1.1662	0.4062
	Exercise	2.3760	2.6364	
L3 posterior AZ	Massage	2.0160	0.7382	0.0083
	Exercise	3.5687	1.8910	
L4 anterior AZ	Massage	3.9613	1.5357	0.3554
	Exercise	3.0524	3.3869	
L4 posterior AZ	Massage	2.5338	0.9278	0.0070
	Exercise	4.5702	2.4218	
L5 anterior AZ	Massage	2.4472	0.9487	0.4276
	Exercise	1.9523	2.1663	
L5 posterior AZ	Massage	1.5355	0.5623	0.0093
	Exercise	2.6825	1.4215	
L3 anterior BZ	Massage	7.7539	3.0060	0.4613
	Exercise	6.2804	6.9686	
L3 posterior BZ	Massage	4.4789	1.6401	0.0093
	Exercise	7.8238	4.1458	
L4 anterior BZ	Massage	6.6295	2.5701	0.4381
	Exercise	5.3143	5.8966	
L4 posterior BZ	Massage	3.7251	1.3640	0.0080
	Exercise	6.6202	3.5081	
L5 anterior BZ	Massage	5.8644	2.2735	0.4392
	Exercise	4.7033	5.2187	
L5 posterior BZ	Massage	3.7218	1.3628	0.0056
	Exercise	6.8942	3.6532	
L3 anterior IPX	Massage	0.0245	0.0104	0.4590
	Exercise	0.0215	0.0113	
L3 posterior IPX	Massage	0.0111	0.0065	0.0006
	Exercise	0.0255	0.0129	
L3 anterior IPY	Massage	0.0332	0.0142	0.2947
	Exercise	0.0276	0.0146	
L3 posterior IPY	Massage	0.0136	0.0079	0.0003
	Exercise	0.0332	0.0168	
L4 anterior IPX	Massage	0.0027	0.0017	0.4435
	Exercise	0.0021	0.0024	
L4 posterior IPX	Massage	0.0009	0.0006	0.0296
	Exercise	0.0116	0.0180	
L4 anterior IPY	Massage	0.0278	0.0177	0.5590
	Exercise	0.0230	0.0259	
L4 posterior IPY	Massage	0.0089	0.0058	0.0294
	Exercise	0.1159	0.1803	

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L5 anterior IPX	Massage	0.0031	0.0045	0.4797
	Exercise	0.0021	0.0029	
L5 posterior IPX	Massage	-0.0006	0.0053	0.0336
	Exercise	0.0027	0.0021	
L5 anterior IPY	Massage	0.0217	0.0328	0.6963
	Exercise	0.0267	0.0358	
L5 posterior IPY	Massage	0.0025	0.0038	0.0007
	Exercise	0.0169	0.0128	
L3 anterior RX	Massage	6.5629	1.7984	0.9823
	Exercise	6.5366	4.1404	
L3 posterior RX	Massage	4.3045	1.3688	0.0002
	Exercise	8.7298	3.4814	
L4 anterior RX	Massage	5.5549	1.5222	0.7330
	Exercise	5.2293	3.3123	
L4 posterior RX	Massage	3.3647	1.0700	0.0004
	Exercise	6.4742	2.5818	
L5 anterior RX	Massage	2.3965	0.3624	0.2069
	Exercise	2.7315	0.9228	
L5 posterior RX	Massage	1.9168	0.4528	0.0026
	Exercise	2.6800	0.7498	
Anterior RXall	Massage	5.5917	0.4013	0.0693
	Exercise	5.1965	0.6947	
Posterior RXall	Massage	4.7508	0.1189	0.0018
	Exercise	5.1985	0.4472	

AZ: translation of lower point A in the Z direction; BZ: translation of the upper point B in the Z direction; RX: angle of rotation around the X axis; HA: anterior height of the intervertebral disc; HC: posterior height of the intervertebral disc; IPX: instantaneous center of rotation in the X direction; IPY: instantaneous center of rotation in the Y direction.

Supplementary Table S11: Changes in dynamic parameters in side bending in the massage group.

	Mean	SD	P
L3 difference in AZ	-0.9922	1.5109	0.0234
L4 difference in AZ	-1.4275	1.9607	0.0136
L5 difference in AZ	-0.9117	1.2043	0.0109
L5 difference in IPX	-3.2750	3.7268	0.0043
L3 difference in BZ	-2.9044	3.1629	0.0032
L4 difference in BZ	-2.1425	2.8958	0.0125
L5 difference in BZ	-0.0134	0.0093	0.0001
L3 difference in IPX	-0.0196	0.0125	<0.0001
L3 difference in IPY	-0.0018	0.0017	0.0010
L4 difference in IPX	-0.0189	0.0172	0.0008
L4 difference in IPY	-0.0038	0.0050	0.0117
L5 difference in IPY	-0.0192	0.0333	0.0420
L3 difference in RX	-2.2584	2.3358	0.0022
L4 difference in RX	-2.1902	1.9215	0.0006
L5 difference in RX	-0.4797	0.3013	<0.0001
Difference in RXall	-0.8410	0.4200	<0.0001

AZ: translation of lower point A in the Z direction; BZ: translation of the upper point B in the Z direction; RX: angle of rotation around the X axis; HA: anterior height of the intervertebral disc; HC: posterior height of the intervertebral disc; IPX: instantaneous center of rotation in the X direction; IPY: instantaneous center of rotation in the Y direction.

Supplementary Table S12: Changes in dynamic parameters in side bending in the exercise group.

	Mean	SD	P
L3 difference in AZ	1.1926	2.3843	0.0732
L4 difference in AZ	1.5178	3.0611	0.0754
L5 difference in AZ	0.7302	1.9295	0.1648
L5 difference in IPX	1.5434	6.1394	0.3468
L3 difference in BZ	1.3060	5.1949	0.3468
L4 difference in BZ	2.1909	4.6974	0.0924
L5 difference in BZ	0.0040	0.0171	0.3783
L3 difference in IPX	0.0056	0.0221	0.3437
L3 difference in IPY	0.0095	0.0186	0.0693
L4 difference in IPX	0.0928	0.1875	0.0758
L4 difference in IPY	0.0006	0.0021	0.3212
L5 difference in IPY	-0.0098	0.0284	0.2048
L3 difference in RX	2.1932	5.2282	0.1265
L4 difference in RX	1.2449	4.0612	0.2549
L5 difference in RX	-0.0515	0.7122	0.7834
Difference in RXall	.00202161	.726128989	0.9915

AZ: translation of lower point A in the Z direction; BZ: translation of the upper point B in the Z direction; RX: angle of rotation around the X axis; HA: anterior height of the intervertebral disc; HC: posterior height of the intervertebral disc; IPX: instantaneous center of rotation in the X direction; IPY: instantaneous center of rotation in the Y direction.

Supplementary Table S13: Correlations between the changes in the Oswestry disability score and changes in dynamic parameters in extension.

	Massage (r)	P	Exercise (r)	P
L3 difference in AZ	0.829	<0.001	0.066	0.816
L4 difference in AZ	0.593	0.020	0.417	0.122
L5 difference in AZ	0.577	0.002	0.122	0.665
L5 difference in IPX	0.623	0.013	0.357	0.192
L3 difference in BZ	0.789	<0.001	0.062	0.826
L4 difference in BZ	0.729	0.002	0.356	0.192
L5 difference in BZ	0.728	0.002	0.365	0.181
L3 difference in HA	0.703	0.003	0.286	0.302
L4 difference in HA	0.591	0.020	0.193	0.490
L5 difference in HA	0.599	0.018	0.179	0.522
L3 difference in HC	0.791	<0.001	0.251	0.366
L4 difference in HC	0.706	0.003	0.362	0.184
L5 difference in HC	0.651	0.009	0.413	0.126
L3 difference in IPX	0.792	<0.001	0.318	0.249
L3 difference in IPY	0.991	<0.001	0.264	0.341
L4 difference in IPX	0.829	<0.001	0.066	0.816
L4 difference in IPY	0.593	0.020	0.417	0.122
L5 difference in IPY	0.707	0.003	0.122	0.665
L3 difference in RX	0.929	<0.001	0.357	0.192
L4 difference in RX	0.789	<0.001	0.062	0.826
L5 difference in RX	0.729	0.002	0.356	0.192
L3 difference in relaxation	0.728	0.002	0.365	0.181
L4 difference in relaxation	0.703	0.003	0.286	0.302
L5 difference in relaxation	0.591	0.020	0.193	0.490
Difference in RXall	0.599	0.018	0.179	0.522

AZ: translation of lower point A in the Z direction; BZ: translation of the upper point B in the Z direction; RX: angle of rotation around the X axis; HA: anterior height of the intervertebral disc; HC: posterior height of the intervertebral disc; IPX: instantaneous center of rotation in the X direction; IPY: instantaneous center of rotation in the Y direction.

Supplementary Table S14: Correlations between the changes in the JOA score and changes in dynamic parameters in extension.

	Massage (r)	P	Exercise (r)	P
L3 difference in AZ	0.635	0.011	0.415	0.124
L4 difference in AZ	0.714	0.003	0.390	0.151
L5 difference in AZ	0.748	0.001	0.098	0.729
L5 difference in IPX	0.709	0.003	0.137	0.626
L3 difference in BZ	0.707	0.003	0.057	0.841
L4 difference in BZ	0.991	<0.001	0.253	0.363
L5 difference in BZ	0.982	<0.001	0.312	0.258
L3 difference in HA	0.713	0.003	0.180	0.522
L4 difference in HA	0.703	0.003	0.415	0.124
L5 difference in HA	0.725	0.002	0.325	0.237
L3 difference in HC	0.709	0.003	0.237	0.395
L4 difference in HC	0.707	0.003	0.039	0.889
L5 difference in HC	0.603	0.017	0.057	0.839
L3 difference in IPX	0.993	<0.001	0.183	0.515
L4 difference in IPX	0.788	<0.001	0.046	0.871
L5 difference in IPX	0.635	0.011	0.415	0.124
L4 difference in IPY	0.714	0.003	0.390	0.151
L5 difference in IPY	0.748	0.001	0.098	0.729
L3 difference in RX	0.709	0.003	0.137	0.626
L4 difference in RX	0.707	0.003	0.057	0.841
L5 difference in RX	0.573	0.026	0.253	0.363
L3 difference in relaxation	0.982	<0.001	0.312	0.258
L4 difference in relaxation	0.713	0.003	0.180	0.522
L5 difference in relaxation	0.658	0.008	0.415	0.124
Difference in RXall	0.725	0.002	0.325	0.237

AZ: translation of lower point A in the Z direction; BZ: translation of the upper point B in the Z direction; RX: angle of rotation around the X axis; HA: anterior height of the intervertebral disc; HC: posterior height of the intervertebral disc; IPX: instantaneous center of rotation in the X direction; IPY: instantaneous center of rotation in the Y direction.

Supplementary Table S15: Correlations between the changes in the Oswestry disability score and changes in dynamic parameters in flexion.

	Massage (r)	P	Exercise (r)	P
L3 difference in AZ	0.630	0.012	0.018	0.949
L4 difference in AZ	0.945	<0.001	0.435	0.105
L5 difference in AZ	0.618	0.014	0.082	0.771
L5 difference in IPX	0.621	0.013	0.115	0.683
L3 difference in BZ	0.957	<0.001	0.039	0.891
L4 difference in BZ	0.960	<0.001	0.128	0.651
L5 difference in BZ	0.946	<0.001	0.116	0.682
L3 difference in HA	0.867	<0.001	0.178	0.525
L4 difference in HA	0.543	0.040	0.016	0.955
L5 difference in HA	0.614	0.015	0.267	0.337
L3 difference in HC	0.948	<0.001	0.116	0.682
L4 difference in HC	0.950	<0.001	0.072	0.798
L5 difference in HC	0.920	<0.001	0.075	0.790
L3 difference in IPX	0.869	<0.001	0.127	0.652
L3 difference in IPY	0.613	0.015	0.128	0.650
L4 difference in IPX	0.630	0.012	0.367	0.178
L4 difference in IPY	0.534	<0.001	0.118	0.674
L5 difference in IPY	0.618	0.014	0.082	0.771
L3 difference in RX	0.621	0.013	0.115	0.683
L4 difference in RX	0.524	0.045	0.039	0.891
L5 difference in RX	0.960	<0.001	0.328	0.232
L3 difference in relaxation	0.946	<0.001	0.116	0.682
L4 difference in relaxation	0.867	<0.001	0.378	0.164
L5 difference in relaxation	0.935	<0.001	0.016	0.955
Difference in RXall	0.614	0.015	0.213	0.413

AZ: translation of lower point A in the Z direction; BZ: translation of the upper point B in the Z direction; RX: angle of rotation around the X axis; HA: anterior height of the intervertebral disc; HC: posterior height of the intervertebral disc; IPX: instantaneous center of rotation in the X direction; IPY: instantaneous center of rotation in the Y direction.

Supplementary Table S16: Correlations between the changes in the JOA score and changes in dynamic parameters in flexion.

	Massage (r)	P	Exercise (r)	P
L3 difference in AZ	0.873	<0.001	0.225	0.421
L4 difference in AZ	0.591	0.020	0.269	0.333
L5 difference in AZ	0.978	<0.001	0.220	0.431
L5 difference in IPX	0.829	<0.001	0.227	0.415
L3 difference in BZ	0.593	0.020	0.269	0.331
L4 difference in BZ	0.707	0.003	0.274	0.323
L5 difference in BZ	0.929	<0.001	0.091	0.746
L3 difference in HA	0.789	<0.001	0.119	0.672
L4 difference in HA	0.729	0.002	0.410	0.129
L5 difference in HA	0.728	0.002	0.272	0.327
L3 difference in HC	0.703	0.003	0.120	0.671
L4 difference in HC	0.591	0.020	0.188	0.503
L5 difference in HC	0.599	0.018	0.287	0.300
L3 difference in IPX	0.791	<0.001	0.061	0.829
L3 difference in IPY	0.706	0.003	0.410	0.129
L4 difference in IPX	0.873	<0.001	0.225	0.421
L4 difference in IPY	0.591	0.020	0.269	0.333
L5 difference in IPY	0.978	<0.001	0.220	0.431
L3 difference in RX	0.829	<0.001	0.227	0.415
L4 difference in RX	0.593	0.020	0.269	0.331
L5 difference in RX	0.707	0.003	0.274	0.323
L3 difference in relaxation	0.677	0.006	0.091	0.746
L4 difference in relaxation	0.789	<0.001	0.119	0.672
L5 difference in relaxation	0.729	0.002	0.410	0.129
Difference in RXall	0.628	0.012	0.272	0.327

AZ: translation of lower point A in the Z direction; BZ: translation of the upper point B in the Z direction; RX: angle of rotation around the X axis; HA: anterior height of the intervertebral disc; HC: posterior height of the intervertebral disc; IPX: instantaneous center of rotation in the X direction; IPY: instantaneous center of rotation in the Y direction.

JOA scores improved by 86.7% and 40.0% in the massage and exercise groups, respectively (Table-1). Massage group showed a significant change in the Oswestry disability score ($p = 0.002$), while the exercise group did not show any change ($p > 0.05$) (Table-1).

Dynamic imaging: The range of vertebral movement translation of lower point A in the Z direction (AZ) and translation of upper point B in the Z direction (BZ) improved at L4 and L5 (all $p < 0.05$) and vertebral

Supplementary Table S17: Correlations between the changes in the Oswestry disability score and changes in dynamic parameters in side bending.

	Massage (r)	P	Exercise (r)	P
L3 difference in AZ	0.606	0.017	0.188	0.503
L4 difference in AZ	0.697	0.004	0.287	0.300
L5 difference in AZ	0.770	0.001	0.061	0.829
L5 difference in IPX	0.806	<0.001	0.410	0.129
L3 difference in BZ	0.587	0.021	0.214	0.444
L4 difference in BZ	0.881	<0.001	0.121	0.667
L5 difference in BZ	0.529	0.043	0.364	0.182
L3 difference in HA	0.529	0.043	0.318	0.248
L4 difference in HA	0.587	0.021	0.061	0.828
L5 difference in HA	0.833	<0.001	0.122	0.665
L3 difference in HC	0.739	0.002	0.096	0.733
L4 difference in HC	0.994	<0.001	0.289	0.296
L5 difference in HC	0.593	0.020	0.214	0.444
L3 difference in IPX	0.879	<0.001	0.066	0.816
L3 difference in IPY	0.621	0.013	0.417	0.122
L4 difference in IPX	0.606	0.017	0.188	0.503
L4 difference in IPY	0.697	0.004	0.287	0.300
L5 difference in IPY	0.770	0.001	0.061	0.829
L3 difference in RX	0.806	<0.001	0.410	0.129
L4 difference in RX	0.587	0.021	0.214	0.444
L5 difference in RX	0.881	<0.001	0.121	0.667
L3 difference in relaxation	0.529	0.043	0.364	0.182
L4 difference in relaxation	0.529	0.043	0.318	0.248
L5 difference in relaxation	0.587	0.021	0.061	0.828
Difference in RXall	0.833	<0.001	0.122	0.665

AZ: translation of lower point A in the Z direction; BZ: translation of the upper point B in the Z direction; RX: angle of rotation around the X axis; HA: anterior height of the intervertebral disc; HC: posterior height of the intervertebral disc; IPX: instantaneous center of rotation in the X direction; IPY: instantaneous center of rotation in the Y direction.

Supplementary Table S18: Correlations between the changes in the JOA score and changes in dynamic parameters in side bending.

	Massage (r)	P	Exercise (r)	P
L3 difference in AZ	0.664	0.007	0.151	0.591
L4 difference in AZ	0.688	<0.001	0.151	0.590
L5 difference in AZ	0.650	0.009	0.415	0.124
L5 difference in IPX	0.867	<0.001	0.390	0.151
L3 difference in BZ	0.638	0.010	0.098	0.729
L4 difference in BZ	0.573	0.025	0.137	0.626
L5 difference in BZ	0.828	<0.001	0.057	0.841
L3 difference in HA	0.702	0.004	0.253	0.363
L4 difference in HA	0.825	<0.001	0.312	0.258
L5 difference in HA	0.824	<0.001	0.180	0.522
L3 difference in HC	0.634	0.011	0.415	0.124
L4 difference in HC	0.574	0.025	0.325	0.237
L5 difference in HC	0.881	<0.001	0.237	0.395
L3 difference in IPX	0.613	0.015	0.039	0.889
L3 difference in IPY	0.660	0.007	0.057	0.839
L4 difference in IPX	0.664	0.007	0.151	0.591
L4 difference in IPY	0.788	<0.001	0.151	0.590
L5 difference in IPY	0.650	0.009	0.415	0.124
L3 difference in RX	0.867	<0.001	0.390	0.151
L4 difference in RX	0.961	<0.001	0.098	0.729
L5 difference in RX	0.573	0.025	0.137	0.626
L3 difference in relaxation	0.828	<0.001	0.057	0.841
L4 difference in relaxation	0.702	0.004	0.253	0.363
L5 difference in relaxation	0.525	0.044	0.312	0.258
Difference in RXall	0.824	<0.001	0.478	0.071

AZ: translation of lower point A in the Z direction; BZ: translation of the upper point B in the Z direction; RX: angle of rotation around the X axis; HA: anterior height of the intervertebral disc; HC: posterior height of the intervertebral disc; IPX: instantaneous center of rotation in the X direction; IPY: instantaneous center of rotation in the Y direction.

relaxation (RX) improved at L5 ($p = 0.048$) in the massage group. After treatment, the relative ROM was smaller in L4 and L5 ($p < 0.05$). Exercise treatment did not induce any change in these parameters (all $p > 0.05$). After treatment, no significant difference ($p > 0.05$) in relative ROM was detected (Supplementary Table S1).

There were no significant differences at baseline between the two groups (all $p > 0.05$) in AZ, BZ, and RX of L4 and L5. On the other hand, changes were significantly better in the massage group compared to the exercise group (all $p < 0.05$) (Supplementary Tables S2, S3). Supplementary Tables S4-S6 present the dynamic parameters of the two groups in extension. Supplementary Tables S7-S9 present the dynamic parameters of the two groups in flexion. Supplementary Tables S10-S12 present the dynamic parameters of the two groups in side bending.

Correlations analyses: The correlations analyses showed that the changes in Oswestry disability scores and JOA scores correlated with changes in dynamic parameters in the massage group (all $p < 0.05$), but not in the exercise group (all $p > 0.05$) (Supplementary Table S13-S18).

Discussion

The dynamic balance in lumbar motion is the key characteristic of lumbar stability. Clinical instability symptoms of pain and twisting are results of lumbar dynamic balance loss. Dynamic balance is not determined by a single factor but by multiple factors of lumbar facet joints, paravertebral muscles, and ligaments. Improvement of clinical symptoms by manipulation is potentially the result of reconstruction of the lumbar dynamic balance, and thus lumbar stability. Therefore, the mechanism of manipulation on lumbar intervertebral instability likely comprises correction of facet joint subluxation, improvement of irregular load on paravertebral muscles, and relaxation of paralumbar soft tissues. Nonetheless, eventual mechanism lies on the correction of irregular

intervertebral motion and restoration of lumbar dynamic balance, leading to lumbar stability. The changes induced by manipulation or exercise may be small and precise methods like QF are necessary to quantify them.

Using QF, the present study showed that the massage treatment (Supplementary Material) was successful in improving all dynamic parameters at L4 and L5, while the exercise treatment, despite being performed 3 times daily for 15 days (compared with once a day for 6 days for massage) did not induce any improvement in dynamic parameters. In addition, these changes correlate with the improvements in JOA and Oswestry scores. These results are supported by previous studies that showed that manipulative adjustment of vertebrae effectively improves abnormal stress distribution and reconstructs cervical stability.[3,4] Nevertheless, the present study adds to the literature by presenting quantitative data of dynamic improvements after massage manipulation.

The present study is not without limitations. Compared to X-ray films and CT examination, QF uses a lower radiation dose, but the drawback is that the images are less clear with more noise. Edge detection and enhancement were automatically performed by the software, but some issues need to be resolved, for instance automatic detection and calculation of vertebral corner in the coronal plane and poor tracking in the rotation state. These factors impact the study of lumbar coronal motion. Due to limitation of the vision field on the display of the electronic digital 3D C-arm X-ray system, this study selected only the L4-5 segments for investigation. In fact, occurrence of lumber intervertebral instability usually influences the adjacent segmental motion, which requires further study and improvement. In addition, the number of subjects included in the study were small and from a single centre. Finally, some data was not collected, including duration of symptoms, work description, drugs for pain relief, and active vs. sedentary lifestyle. Additional studies are necessary to address these issues.

Conclusion

The present study suggests that spinal massage manipulation is superior to low back muscle exercise in patients with lumbar intervertebral instability. The changes in intervertebral motion can be captured by QF, facilitating further illustration of the mechanism under spinal massage manipulation on lumbar intervertebral instability.

Supplementary Material

Massage manipulation: Massage techniques include loosening manipulation and fine-tuning techniques. Loosening techniques included rolling, pressing, kneading and plucking. Patient was in the lateral position and relaxing as much as possible for fine-tuning manipulation. Practitioner used one elbow and arm to stabilize the patient's pelvis, and the feet and middle fingers were respectively placed on the upper and lower interval space of the spinous process of the dislocated vertebra, and the other hand slowly pulled the patient's lower shoulder forward to make the upper spine gradually bend forward until the feet finger placed on the upper interval space started to feel the upward movement of the adjacent upper spinous process along with flexion of the spine. Once the spinous process space was widened, forward movement of the shoulder was instantly stopped. Then, the upper shoulder of the patient was stabilized by the practitioner's elbow and arm originally used to pull the patient's shoulder. The feet and middle fingers were apart and placed respectively on the lower and upper interval space of the spinous process of the dislocated vertebra. The other hand slowly pulled the lower leg of the patient forward to gradually bend the hip joint, driving the pelvic backward tilt and lumbar flexion, until the feet finger placed on the lower interval space started to feel the downward movement of the adjacent lower spinous process. Once the spinous process space was widened, forward movement of the lower leg was instantly ended and the pelvis was stabilized by the elbow and arm to maintain the flexion range of the lower spine. Then, the feet and middle fingers pushed against the spinous process in displacement or scoliosis. According to the operating essentials of the oblique flip method, "nimble force in abrupt eruption" was imposed, and a sudden and rapid flip was made with increased amplitude. At the same time, the feet and middle fingers forcefully pushed the spinous process to induce reduction, usually with a clicking sound. After adjustment, the patient was placed in the lateral position, and lumbar and abdominal muscles were loosened at both sides of the transverse process. Relaxing the muscles of the affected limb was also performed before the end of the treatment. The treatment lasted 20 minutes, once every day for 6 days as a complete treatment course.

Low back muscle exercise: Low back muscle exercise for the treatment of lumbar intervertebral instability included the following methods. 1) Five points support method: lying supine on the bed, with the five support points being the head, elbows, and feet, the patient body arched to make lumbar muscles contraction, 15 actions per session, and once every morning, noon, and evening. 2) Flying swallow touching water: lying prostrate on the bed, legs and arms straight on the sides, keeping the body straight, the head, upper limbs, and lower limbs of the

patient were simultaneously lifted above the bed to achieve the purpose of posterior body arch, 15 actions per session, and once every morning, noon, and evening. A complete treatment course was 15 days.

Quantitative fluoroscopy: For QF examinations, the machine was an electronic digital three-dimensional C-arm X-ray machine. Images were taken during motions of flexion extension, lateral flexion, and rotation in the standing and lying positions. The standing position was designed to simulate physiological activity while the lying position was to minimize the influence of muscular strength on movement. 1) Flexion extension position. The patient was measured at both the standing and lying positions. The pelvis and knee joints were fixed with a special brace to prevent compensation. Lumbar lateral images were acquired centered at the L3 vertebral body. The subject performed flexion and extension motion at a uniform rate, with the upright position as the neutral position, in the range of 60° of flexion, and 20° of extension. The subject bent forward from the neutral position to 60° at a uniform rate within 10 s, then resumed from flexion to the neutral position at the same speed. The subject extended backward from the neutral position to 20° at a uniform rate within 5 s, then resumed from extension to the neutral position at the same speed. A complete flexion and extension motion cycle was about 30 s. 2) Left-right lateral flexion position. Imaging was performed in both the standing and supine positions. During imaging, the subject was secured to the pelvis to prevent the pelvis from tilting. Images of lumbar vertebra positive side were acquired centered on the L3 vertebral body. The subject was subjected to left and right lateral flexion at a uniform speed, with the upright position as the neutral position, and the left or right lateral flexion was 40°. The subject bent laterally from the neutral position to 40° left at a uniform speed within 10 s, and then resumed from left flexion to the neutral position at the same speed. The same way was used for right lateral flexion. 3) Left-right rotation position. Imaging was performed in the standing position. The pelvis was immobilized during imaging to prevent rotation of the

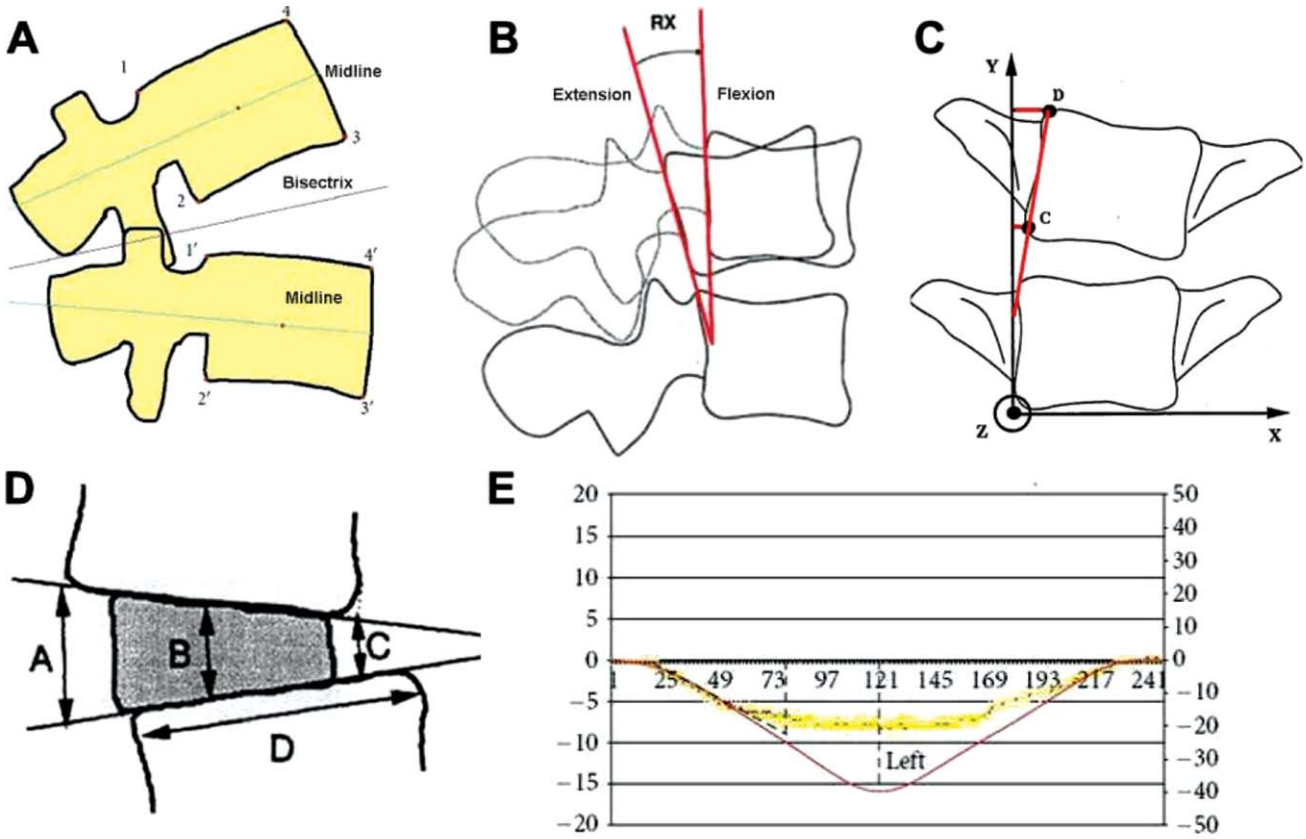

Figure-1: (A) Determination of the midpoint and vertical axis by the Frobin method. (**B**) Measurement of rotation and displacement in the sagittal plane of the vertebral body (RX referred to rotation, BZ and AZ referred to displacement). **(C**) Intervertebral rotation and displacement in the coronal plane. Distance between **C** and **D** at the X axis represented the displacement of the superior and inferior edges of the vertebral body. The angle between the CD line and the Y axis represented the angle of rotation. (**D**) Anterior and posterior heights of the intervertebral disk, marked in A and C. (**E**) The relaxation degree of the lumbar spine (taking L4/5 lateral flexion as an example).

hips and knees. Images of lumbar vertebra positive side were acquired, centered on the L3 vertebral body. The subject rotated left and right at a uniform speed. The upright position being the neutral position, the rotation angle was 60°. The subject rotated from the neutral position to 60° left at a uniform speed within 10 s, and resumed position at the same speed. The same was done on the right. The images were captured at 10 frames per second (FPS). Therefore, about 300-400 consecutive lumbar motion images were obtained for each movement.

First, acquired images were enhanced through a filter to highlight the boundary of the lumber vertebral body in the soft tissues. Then, the enhanced images were put into the MATLAV image analysis software (Matrix Laboratory, MathWorks, USA). The Frobin method was applied to determine the midpoint and vertical axis of the vertebral body (Figure-1A).[9] Vertebral rotation and displacement were measured on flexion extension images (Figure-1B). Vertebral rotation and displacement were measured on left and right lateral flexion images (Figure-1C). The specific heights were measured on flexion extension images in motion (Figure-1D). The relaxation degree of the lumbar spine was calculated as the ratio of the coronal rotation degree of each segment to the coronal rotation degree of the entire lumbar spine in lateral flexion while as the ratio of the sagittal rotation degree of each segment to the sagittal rotation degree of the entire lumbar spine in flexion extension. The higher the ratio, the greater the relaxation degree was. As shown in Figure-1E, taking the left flexion of L4/5 for an example, the left vertical axis displayed the coronal rotation degree of L4/5, the right vertical axis revealed the coronal rotation degree of the entire lumbar spine, and the horizontal axis reflected the frame number of images. L4/5 rotation degree was shown in the yellow line while the red line represented the lumbar rotation degree, and their ratio indicated the relaxation degree of L4/5 vertebral segments. Lateral flexion symmetry was quantitatively indicated by the root mean square (RMS) of the difference in coronal displacement and rotation between the two sides of the vertebral body (separated by the center of the vertebral body) in motion of left and right lateral flexion. Rotation symmetry was quantified by the ratio of the rotation degree between the two sides of the vertebral body (separated by the center of the vertebral body) in motion of left and right rotation. Vertebral rotation was evaluated by the Nash-Moe method,[10] which is regularly applied for the assessment of vertebral rotation in scoliosis.

Lateral flexion rotation axis was reflected by the instantaneous rotation axis geometrically calculated as the intersection point of the vertical middle lines of two lines, which were formed by connecting two vertebral apexes on the top of two sequentially adjacent images (A-A' and B-B') in motion of left and right lateral flexion. The flexion extension rotation axis was reflected by the instantaneous rotation axis geometrically calculated as the intersection point of the vertical middle lines of two lines, which were formed by connecting two vertebral apexes on two sequentially adjacent images, inferior position on the previous image and superior position on the following, in motion of forward flexion and backward extension. The calculation methods for lumbar dynamic balance comprised lateral flexion symmetry and rotation symmetry in lumbar motion, as well as symmetry of the lumbar instantaneous axis in motion of left and right lateral flexion.

Sample size estimation: According to preliminary experiments, it was assumed that the mean AZ value after treatment in the massage and exercise groups are -0.002 ± 0.02 and -0.03± 0.02, respectively; the mean BZ after treatment in the massage and exercise groups are -0.01 ± 0.03 and -0.06 ± 0.03, respectively; the mean RX of the massage and exercise groups were -0.02 ± 0.04 and 0.03 ± 0.04, respectively. The power was set to $1-\beta = 0.80$ and alpha at 0.05. Sample size estimation was performed using the PASS 8.0 software according to the following formula:

$$n_1 = n_2 = 2[(t_\alpha + t_\beta)^2 s / \delta]^2$$

According to the preset parameters, we used the inequality tests for two means using differences (i.e., two-sample t-test) in the PASS 8.0 software Means menu to calculate the sample size. Based on the AZ, BZ and RX after treatment, sample size needed is 10, 7, and 12 cases/group when basing the calculations on AZ, BZ, and RX, respectively. Considering potential drop-out of 10%, we determined that the required sample was 15 cases per group.

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