



TITLE:

Association of Pain History and Current Pain With Sagittal Spinal Alignment and Muscle Stiffness and Muscle Mass of the Back Muscles in Middle-aged and Elderly Women

AUTHOR(S):

Masaki, Mitsuhiro; Ikezoe, Tome; Yanase, Ko; Ji, Xiang; Umehara, Jun; Aoyama, Junichi; Minami, Seigo; ... Watanabe, Yuya; Kimura, Misaka; Ichihashi, Noriaki

CITATION:

Masaki, Mitsuhiro ...[et al]. Association of Pain History and Current Pain With Sagittal Spinal Alignment and Muscle Stiffness and Muscle Mass of the Back Muscles in Middle-aged and Elderly Women. *Clinical spine surgery* 2019, 32(7): E346-E352

ISSUE DATE:

2019-08

URL:

<http://hdl.handle.net/2433/265250>

RIGHT:

This is a non-final version of an article published in final form in *Clinical Spine Surgery*: August 2019 - Volume 32 - Issue 7 - p E346-E352.; The full-text file will be made open to the public on 01 August 2020 in accordance with publisher's 'Terms and Conditions for Self-Archiving'; This is not the published version. Please cite only the published version. この論文は出版社版ではありません。引用の際には出版社版をご確認ご利用ください。

1 Association of pain history and current pain with sagittal spinal alignment and muscle stiffness and
2 muscle mass of the back muscles in middle-aged and elderly women

3

4 Mitsuhiro Masaki^{1,2}, Tome Ikezoe³, Ko Yanase³, Xiang Ji³, Jun Umehara³, Junichi Aoyama⁴,

5 Seigo Minami⁵, Yoshihiro Fukumoto⁶, Yuya Watanabe⁷, Misaka Kimura⁸ and Noriaki Ichihashi³

6

7 ¹Department of Physical Therapy, Niigata University of Health and Welfare, Niigata

8 1398 Shimami-cho, Kita-ku, Niigata 950-3198, Japan.

9 ²Institute for Human Movement and Medical Sciences, Niigata University of Health and Welfare,

10 Niigata.

11 1398 Shimami-cho, Kita-ku, Niigata 950-3198, Japan.

12 ³Department of Physical Therapy, Human Health Sciences, Graduate School of Medicine, Kyoto

13 University, Kyoto

14 53 Kawahara-cho, Shogoin, Sakyo-ku, Kyoto 606-8507, Japan.

15 ⁴Department of Rehabilitation, Ikoi no Ie 26, Nara

16 1082-1 Kami-machi, Ikoma 630-0131, Japan.

17 ⁵Department of Occupational Therapy, Faculty of Allied Health Sciences, Yamato University, Osaka

18 2-5-1 Katayama-cho, Suita 564-0082, Japan.

- 1 ⁶Department of Physical Therapy, Faculty of Rehabilitation, Kobe Gakuin University, Hyogo
- 2 518 Arise, Ikawadani-cho, Nishi-ku, Kobe 651-2180, Japan.
- 3 ⁷Faculty of Health and Sports Science, Doshisha University, Kyoto
- 4 1-3 Tatara Miyakodani, Kyotanabe 610-0394, Japan.
- 5 ⁸Faculty of Health and Medical Science, Kyoto Gakuen University, Kyoto
- 6 1-1 Nanjyo-Otani, Sogabe-cho, Kameoka 621-8555, Japan.
- 7
- 8 Corresponding author
- 9 Mitsuhiro Masaki, R.P.T., PhD.
- 10 Department of Physical Therapy, Niigata University of Health and Welfare
- 11 Institute for Human Movement and Medical Sciences, Niigata University of Health and Welfare
- 12 1398 Shimami-cho, Kita-ku, Niigata 950-3198, Japan.
- 13 E-mail: masaki@nuhw.ac.jp
- 14 Office phone: +81-25-257-4312
- 15 Office fax: +81-25-257-4312
- 16
- 17
- 18

1 **Acknowledgments**

2 We would like to thank Wakako Inoue (Human Health Sciences, Graduate School of Medicine,
3 Kyoto University) for the practical and technical assistance. We also thank all of the individuals who
4 participated in this study.

5

6 **Funding**

7 No funding sources were disclosed for the study.

8

9 **Conflicts of interest**

10 On behalf of all authors, the corresponding author states that there is no conflict of interest.

11

12 **Ethical approval**

13 All study participants provided informed consent to participate, and the study design was
14 approved by the Ethics Committee of the Kyoto University Graduate School and Faculty of
15 Medicine.

16

17 **Device Status/Drug Statement**

18 The Manuscript submitted does not contain information about medical device(s)/drug(s).

1 **Study Design:** A cross-sectional study.

2 **Objective:** To investigate the association of low back pain history (LBPH) and LBP with sagittal
3 spinal alignment, stiffness assessed using ultrasonic shear wave elastography (SWE), and mass of
4 the back muscle in community-dwelling middle-aged and elderly women.

5 **Summary of Background Data:** The association of LBPH and LBP with sagittal spinal alignment,
6 stiffness, and mass of the back muscles remains unclear in middle-aged and elderly women.

7 **Methods:** The study comprised 19 asymptomatic middle-aged and elderly women [control (CTR)
8 group], 16 middle-aged and elderly women with LBPH (LBPH group), and 23 middle-aged and
9 elderly women with LBP (LBP group). Sagittal spinal alignment in the standing and prone positions
10 (kyphosis angle in the thoracic spine, lordosis angle in the lumbar spine, and anterior inclination
11 angle in the sacrum) was measured using a Spinal Mouse. The stiffness of the back muscles (lumbar
12 erector spinae and multifidus) in the prone position was measured using ultrasonic SWE. The mass
13 of the back muscles (thoracic and lumbar erector spinae, lumbar multifidus, and quadratus
14 lumborum) was also measured.

15 **Results:** Multiple logistic regression analysis with a forward selection method showed that the
16 stiffness of the lumbar multifidus muscle was a significant and independent factor of LBPH. The
17 stiffness of the lumbar multifidus muscle was significantly higher in the LBPH group than in the
18 CTR group. Multiple logistic regression analysis also indicated that lumbar lordosis angle in the

1 standing position was a significant and independent factor of LBP. The lumbar lordosis angle was
2 significantly smaller in the LBP group than in the CTR group.

3 **Conclusions:** Our results suggest that LBPH is associated with increased stiffness of the lumbar
4 multifidus muscle in the prone position, and that LBP is associated with the decreased lumbar
5 lordosis in the standing position in community-dwelling middle-aged and elderly women.

6

7 Keywords: Low back pain; Posture; Paraspinal muscles; Muscle stiffness; Muscle thickness;

8

9

10

11

12

13

14

15

16

17

18

19

1 Introduction

2 Approximately 80% of adults experience low back pain (LBP) within their lifetime,¹ and LBP
3 frequently develops in middle-aged and elderly people. Intervertebral discs, intervertebral joints,
4 ligaments, nerves, vertebral body, and lumbar back muscles can all be implicated in LBP.
5 Clarification of the specific cause of LBP is critical for rehabilitation.
6 Age-related shifts in posture include increased thoracic kyphosis² and decreased lumbar lordosis and
7 sacral anterior inclination³ in the standing position. The incidence rate of hyperkyphosis is 20–40%
8 among elderly people.⁴ In terms of the association of low back pain with the alignment of the spine
9 in the standing position, one systematic review⁵ demonstrated no difference in the occurrence of
10 lumbar lordosis between healthy subjects and LBP patients. However, the age and sex of the subjects
11 are unspecified in many previous studies. The aforementioned decreased lumbar lordosis with aging
12 puts stress on the intervertebral discs of the lumbar spine, which may contribute to LBP occurrence.
13 In light of the increased risk of osteoporotic fracture in middle-aged and elderly women compared to
14 that in middle-aged and elderly men⁶, lumbar lordosis decreases with vertebral body deformity⁴ and
15 decreased lumbar lordosis puts stress on the anterior part of the intervertebral discs, which may
16 contribute to LBP occurrence in that population. Therefore, an investigation of the association of
17 LBP with alignment of the spine in the standing position that focuses on middle-aged and elderly
18 women is necessary.

1 Thus far, quantitative assessment of the stiffness of individual muscles isolating subcutaneous fat
2 and fibrous tissue has proved difficult. However, the assessment of muscle stiffness has recently
3 become possible by the use of ultrasonic shear wave elastography (SWE).⁷⁻⁹ Ultrasonic SWE is a
4 safe, non-invasive ultrasound imaging technique. The shear elastic modulus is an index of muscle
5 stiffness that is evaluated by measuring the shear wave propagation speed in the tissues generated by
6 ultrasonic SWE. Our previous study¹⁰ using ultrasonic SWE demonstrated that the stiffness of the
7 lumbar multifidus muscle in the prone position is high among young and middle-aged medical
8 workers with LBP. Spasm of the lumbar multifidus muscle due to LBP may contribute to further
9 increased muscle stiffness and secondary LBP occurrence. However, the association of LBP with the
10 stiffness of the back muscles has not been clarified in middle-aged and elderly women who are not
11 medical workers. Furthermore, there is an approximately 60% recurrence rate in individuals who
12 once experienced LBP.¹¹ Thus, the elucidation of particular physical and motion characteristics is
13 needed not only in LBP patients, but also in individuals with history of LBP (LBPH) who had LBP
14 in the past and have no LBP at the present time. Physical and motion characteristics after recovery
15 from LBP, which is the condition that the subject feel no pain during their activities, may contribute
16 to LBP recurrence in individuals with LBPH. Increased stiffness of the back muscles such as the
17 lumbar erector spinae and multifidus muscles is an important factor, which may be associated with
18 LBP recurrence. However, no previous studies have reported on the stiffness of the back muscles in

1 individuals with LBPH.

2 In terms of the association of LBP with the mass of the back muscles, studies using computed
3 tomography and magnetic resonance imaging images demonstrated decreased mass of the multifidus
4 muscle in LBP patients.¹²⁻¹⁷ The lumbar multifidus muscle, which is a deep muscle of the trunk,
5 contributes to stability in the lumbar spine by increasing the compressive force^{18,19}. Accordingly, it is
6 assumed that decreased muscle mass of the lumbar multifidus muscle results in instability in the
7 lumbar spine, which in turn puts stress on the intervertebral discs or intervertebral joints, which may
8 contribute to either LBP occurrence or recurrence. Furthermore, the mass of the lumbar erector spinae
9 and quadratus lumborum muscles also decreases in LBP patients^{20,21}. However, it is unclear whether
10 the sagittal spinal alignment, stiffness, or mass of the back muscles is associated with LBP and LBPH
11 in middle-aged and elderly women.

12 Therefore, we aimed to examine the association of LBPH and LBP with those factors in community-
13 dwelling middle-aged and elderly women.

14

15 **Participants and methods**

16 **Participants**

17 Fifty-eight community-dwelling middle-aged and elderly women in Kyoto were included in the
18 present study. The subjects were classified into control (CTR) (n=19; mean age 72.4±5.4), LBPH

1 (n=16; mean age 70.3±6.5), and LBP groups (n=23; mean age 74.3±6.4) according to the presence of
2 LBPH and LBP. The subjects in the CTR group had no history of LBP lasting 3 or more months and
3 no LBP at the time of evaluation. The LBPH group consisted of subjects with bilateral/central or
4 unilateral LBP lasting for 3 months or more in the past and no LBP at the time of evaluation. The
5 LBP group consisted of subjects with bilateral/central or unilateral LBP lasting for 3 months or more
6 at the time of evaluation. The classification of LBPH^{22,23} and LBP^{24,25} was performed based on
7 previous studies. Participants were excluded if they had any severe orthopedic disorder other than
8 LBP; neurological, circulatory, or respiratory disorders in the present or past; or previous spinal
9 surgery.

10 The protocol of the present study was accepted by the Ethics Committee of the Kyoto University
11 Graduate School and Faculty of Medicine. All participants in the present study provided informed
12 consent.

13

14 Low back pain assessment

15 The distribution, duration, and degree of LBP, as well as impaired activities of daily living due to
16 LBP, were assessed in the LBP group using a questionnaire based on a previous study.¹⁰ LBP status
17 in the past was assessed in the LBPH group, and LBP status at the time of evaluation was assessed in
18 the LBP group. The degree of LBP was examined using the Numerical Rating Scale (NRS) in both

1 static (i.e., lying, sitting, or standing) and dynamic situations (i.e., moving or walking). Furthermore,
2 the disabilities of daily living due to LBP were assessed using the Oswestry Disability Index (ODI)
3 (excluding the sex life item). The summed score was expressed as a percentage of the total possible
4 score, and a high percentage was indicative of severe disabilities of daily living due to LBP.

5

6 Spinal alignment measurement

7 The Spinal Mouse (Index Ltd., Tokyo, Japan) was used to measure sagittal spinal alignment in the
8 standing position according to a previous study.¹⁰ The kyphosis angle in the thoracic spine, lordosis
9 angle in the lumbar spine, and anterior inclination angle in the sacrum were evaluated. Furthermore,
10 alignment of the spine in the prone position was also measured to identify whether the stiffness and
11 mass of the back muscles were influenced by the alignment of the spine in the position used for
12 ultrasound measurement. Spinal alignment in each position was measured 3 times, and the mean
13 value of the 3 measurements was utilized for statistical analyses.

14

15 Ultrasound measurement

16 Images of the back muscles were taken using an ultrasound device with SWE (Aixplorer, Supersonic
17 Imagine, Aix-en-Provence, France) based on a previous study.¹⁰
18 To assess the mass of the back muscles, longitudinal ultrasound images of the thoracic (longissimus

1 thoracis) and lumbar (iliocostalis lumborum) erector spinae, lumbar multifidus, and quadratus
2 lumborum muscles were taken bilaterally in the prone position using the B-mode of the ultrasound
3 imaging device with a linear array probe (SuperLinear 10-2), which was positioned parallel to the
4 muscle fibers (Fig. 1). We obtained ultrasound images for muscle thickness once bilaterally at the
5 following measurement sites. The site of the thoracic erector spinae muscle was 4 cm lateral to the
6 T9 spinous process.²⁶ The site of the lumbar erector spinae and quadratus lumborum muscles was 7
7 cm lateral to the L3 spinous process.¹⁰ The site of the lumbar multifidus muscle was 2 cm lateral to
8 the L4 spinous process.¹⁰ All measurements of the lumbar back muscles were performed with 58-dB
9 gain and 69-Hz dynamic range. Dynamic focus was set to the position of the back muscles. Time
10 gain compensation was also set to the neutral position in all subjects.

11 To assess the stiffness of the back muscles, the shear elastic modulus of the lumbar erector spinae
12 and multifidus muscles was evaluated once bilaterally by measuring the shear wave propagation
13 speed in the tissues generated using ultrasonic SWE in the prone position (Fig. 2). The shear elastic
14 modulus of the thoracic erector spinae, which is affected by the reflection of the bone, was not
15 measured. The shear elastic modulus of the quadratus lumborum muscle, which is located deep to
16 the body surface, was also not measured. A linear array probe was set parallel to the muscle fibers to
17 accurately measure the shear elastic modulus based on a previous study.¹⁰ The circular regions of
18 interest (ROIs) were set voluntarily in the color-coded box presentation on B-mode ultrasound

1 imaging with a scale from blue (soft) to red (hard) based on the magnitude of the shear wave speed.

2 Three ROIs with a diameter of 10 mm were set in the color-coded box, with 1 located at the center of

3 the box and the other 2 beside the initial ROI. The mean shear elastic modulus values in each ROI

4 and the mean of the 3 ROIs were computed. We computed the shear elastic modulus from the muscle

5 mass density and the shear wave propagation speed.²⁷ Enhanced elastic shear modulus indicates a

6 high muscle stiffness. Intraclass correlation coefficient (ICC 1.1) for the lumbar erector spinae

7 muscle and lumbar multifidus muscle in one measurement of muscle stiffness using ultrasonic SWE

8 were 0.784 and 0.913, respectively.¹⁰ One tester performed all the mass and stiffness assessment of

9 the back muscles.

10 The mean values of muscle thickness and the shear elastic modulus in one measurement each for the

11 right and left muscles were utilized for statistical analyses. The determination of the ROIs, and the

12 computation of muscle thickness and the shear elastic modulus were performed by one examiner

13 who was blinded to the group assignments.

14

15 Statistical analyses

16 We performed statistical analyses using SPSS version 21.0 (IBM Japan; Tokyo, Japan). The factors

17 associated with LBPH and LBP were investigated by multiple logistic regression analysis with a

18 forward selection method. These analyses were conducted using sagittal spinal alignment, the shear

1 elastic modulus and thickness of the back muscles, age, body height, and body weight as
2 independent variables.

3

4 **Results**

5 The characteristics, the LBPH/LBP status, spinal alignment, and stiffness and mass of the lumbar
6 back muscles in the CTR, LBPH, and LBP groups are shown in Tables 1 and 2.

7 Table 3 presents the factor associated with LBPH. Multiple logistic regression analysis showed that
8 the shear elastic modulus of the lumbar multifidus muscle (odds ratio, 1.75) was a significant and
9 independent factor of LBPH, but that the other factors were not. The shear elastic modulus of the
10 lumbar multifidus muscle was significantly higher in the LBPH group than in the CTR group.

11 Table 3 also presents the factor associated with LBP. Multiple logistic regression analysis also
12 showed that the lumbar lordosis angle in the standing position (odds ratio, 0.94) was a significant
13 and independent factor of LBP, but that the other factors were not. Lumbar lordosis angle was
14 significantly smaller in the LBP group than in the CTR group.

15

16 **Discussion**

17 This study investigated the association of LBPH and LBP with sagittal spinal alignment in the
18 standing position and stiffness and mass of the back muscles in the prone position. The present study

1 is the first to quantitatively assess the stiffness of the individual muscles and to examine the
2 association of LBP and LBPH with stiffness of the back muscles using ultrasonic SWE in
3 community-dwelling middle-aged and elderly women.

4 In terms of LBPH, multiple logistic regression analysis showed that the stiffness of the lumbar
5 multifidus muscle was significantly higher in the LBPH group than in the CTR group in the prone
6 position. MacDonald et al. revealed that the activity of the lumbar multifidus muscle delays²² or
7 decreases²³ during upper extremity motion in individuals with LBPH. However, the activity of the
8 lumbar multifidus muscle in the prone position was not clarified in their studies. The current results
9 of the LBPH group are consistent with those of our previous study¹⁰ that demonstrated increased
10 stiffness of the lumbar multifidus muscle in the prone position in young and middle-aged medical
11 workers, though our previous study examined the stiffness in the subjects who had LBP at the time of
12 evaluation. It is possible that the muscle spasm of the lumbar multifidus muscle that occurred at the
13 time of the LBP in the past was persisting in the LBPH group. It is assumed that erroneous movement
14 learning occurred in individuals with LBPH and that the stiffness of the lumbar multifidus muscle
15 remained even after recovery from LBP. The overuse caused by spasm of the lumbar multifidus muscle
16 can lead to circulatory difficulty within the muscle, which may contribute to LBP recurrence in the
17 future.

18 Any of the spinal alignment angles in the standing position or the mass of the back muscles were not

1 significant and independent factors of LBPH. The cause of LBP occurrence is varied among the
2 subjects. Thus, it is possible that the spinal alignment in the standing position and the mass of the
3 back muscles measured in the present study are not the cause of the LBP that occurred in the past.
4 Furthermore, the angles of spinal alignment in the prone position were not significant and
5 independent determinants of LBPH. Muscle stiffness and muscle mass of the back muscles were
6 assumed not to be influenced by the alignment of the spine in the prone position, which was the
7 position of the ultrasound measurement.

8 In terms of LBP, multiple logistic regression analysis showed that the lumbar lordosis angle in the
9 standing position was significantly smaller in the LBP group than in the CTR group. These results are
10 consistent with those of the previous study, which demonstrated that LBP is associated with lumbar
11 lordosis angle in the standing position.²⁸ Intervertebral discs of the lumbar spine degenerate with
12 aging,²⁹ and a previous study indicated that lumbar disc degeneration occurs in the majority of elderly
13 women.³⁰ Takeda³ et al. demonstrated that decreased lumbar lordosis with aging is associated with
14 anterior degeneration of the lumbar intervertebral discs. Since the subjects in the present study were
15 middle-aged and elderly women, it is possible that the lumbar lordosis angle in the standing position
16 was decreased due to osteoporotic deformity of the vertebral body. Such decreased lumbar lordosis
17 causes lumbar disc anterior degeneration and may contribute to LBP occurrence.

18 Though the stiffness of the lumbar multifidus muscle was significantly higher in the LBPH group

1 than in the CTR group, the stiffness of the lumbar multifidus muscle was not significant and
2 independent determinant of LBP. Our previous study revealed that the stiffness of the lumbar
3 multifidus muscle in the LBP group was significantly higher in the prone position.¹⁰ The fact that no
4 significant association in the stiffness of the lumbar multifidus muscle was observed in the LBP
5 group in this study might be attributable to the differences in LBP status. LBP status was moderate to
6 severe in the LBPH group in the present study (NRS [static situation] 5.1 ± 2.5 , NRS [dynamic
7 situation] 6.1 ± 2.4 , ODI $30.0 \pm 24.7\%$) and in the LBP group in our previous study (NRS [static
8 situation] 5.0 ± 1.4 , NRS [dynamic situation] 5.0 ± 1.7 , ODI $19.6 \pm 7.8\%$),¹⁰ whereas LBP status was
9 relatively mild in the LBP group in the present study (NRS [static situation] 2.5 ± 1.9 , NRS
10 [dynamic situation] 3.2 ± 2.4 , ODI $13.2 \pm 8.5\%$). The absence of a significant association in the
11 stiffness of the lumbar multifidus muscle in the LBP group of this study may be due to the reduced
12 severity of LBP.

13 The mass of the back muscles was not significant and independent factor of LBP. In previous studies,
14 the mass of the back muscles either decreases³¹⁻³³ or does not decrease³⁴ in LBP patients. The results
15 of this study were consistent with those of the previous study,³⁴ which found that LBP is not associated
16 with the mass of the back muscles.

17 There are several limitations in this study. First, only some of the back muscles were targeted in the
18 measurements of muscle stiffness and muscle mass. Furthermore, because this study included only

1 middle-aged and elderly women, it is unclear whether the results in middle-aged and elderly men
2 would be similar. Second, whether increased stiffness of the lumbar multifidus muscle in the LBPH
3 group was caused by the continuation of muscle spasm that occurred at the time of previous LBP or
4 by other causes is unclear, since the activities of the lumbar back muscles were not measured using
5 electromyography during ultrasound measurement. Third, because a diagnosis of the cause of pain in
6 the subjects with LBPH and LBP was not made in the present study, subjects with nonspecific LBPH
7 and nonspecific LBP as well as subjects with specific LBPH and specific LBP (i.e., disease of the
8 lumbar spine, which frequently occurs in middle-aged and elderly women) might have been
9 included. However, we could not identify the specific cause of LBPH and LBP, such as lumbar
10 spondylosis, spondylolisthesis, or scoliosis. Fourth, though we used the Spinal Mouse to measure the
11 kyphosis angle in the thoracic spine, lordosis angle in the lumbar spine, and anterior inclination
12 angle in the sacrum in the standing position, we were unable to measure the pelvic incidence.
13 This study suggests that LBPH is associated with increased stiffness of the lumbar multifidus muscle
14 rather than sagittal spinal alignment, the stiffness of the lumbar erector spinae muscle, or the mass of
15 the back muscles in community-dwelling middle-aged and elderly women. Because muscle stiffness
16 of the lumbar multifidus muscle may contribute to LBP recurrence, future investigation is necessary
17 to clarify the cause of LBP recurrence and the optimal training for ameliorating the stiffness of the
18 lumbar multifidus muscle to prevent LBP recurrence. Furthermore, the present study also suggests

1 that LBP is associated with decreased lumbar lordosis in the standing position rather than the
2 stiffness and mass of the back muscles in community-dwelling middle-aged and elderly women. The
3 development of strategies for middle-aged and elderly women to prevent decreased lumbar lordosis
4 seems critical to preventing LBP occurrence.

5

6

7

8

9

10

11

12

13

14

15

16

17

18

1 References

- 2 1. Waddell G. A new clinical model for the treatment of low-back pain. *Spine (Phila Pa 1976)*.
3 1987;12:632-644.
- 4 2. Kado DM, Huang MH, Karlamangla AS, Cawthon P, Katzman W, Hillier TA, Ensrud K,
5 Cummings SR. Factors associated with kyphosis progression in older women: 15 years'
6 experience in the study of osteoporotic fractures. *J Bone Miner Res*. 2013;28:179-187.
- 7 3. Takeda N, Kobayashi T, Atsuta Y, Matsuno T, Shirado O, Minami A. Changes in the sagittal spinal
8 alignment of the elderly without vertebral fractures: a minimum 10-year longitudinal study. *J*
9 *Orthop Sci*. 2009;14:748-753.
- 10 4. Kado DM, Prenovost K, Crandall C. Narrative review: hyperkyphosis in older persons. *Ann*
11 *Intern Med*. 2007;147:330-338.
- 12 5. Laird RA, Gilbert J, Kent P, Keating JL. Comparing lumbo-pelvic kinematics in people with and
13 without back pain: a systematic review and meta-analysis. *BMC Musculoskelet Disord*.
14 2014;15:229.
- 15 6. Swezey RL. Osteoporosis: diagnosis, pharmacological, and rehabilitation therapies. *Crit Rev*
16 *Phys Rehabil Med*. 2000, 12, 229–269.
- 17 7. Maïsetti O, Hug F, Bouillard K, Nordez A. Characterization of passive elastic properties of the
18 human medial gastrocnemius muscle belly using supersonic shear imaging. *J Biomech*. 2012;

- 1 45:978-984.
- 2 8. Koo TK, Guo JY, Cohen JH, Parker KJ. Relationship between shear elastic modulus and
3 passive muscle force: an ex-vivo study. *J Biomech.* 2013;46:2053-2059.
- 4 9. Ateş F, Hug F, Bouillard K, Jubeau M, Frappart T, Couade M, Bercoff J, Nordez A. Muscle
5 shear elastic modulus is linearly related to muscle torque over the entire range of isometric
6 contraction intensity. *J Electromyogr Kinesiol.* 2015;25:703-708.
- 7 10. Masaki M, Aoyama T, Murakami T, Yanase K, Ji X, Tateuchi H, Ichihashi N. Association of
8 low back pain with muscle stiffness and muscle mass of the lumbar back muscles, and sagittal
9 spinal alignment in young and middle-aged medical workers. *Clin Biomech (Bristol, Avon).*
10 2017;49:128-133.
- 11 11. Croft PR, Macfarlane GJ, Papageorgiou AC, Thomas E, Silman AJ. Outcome of low back pain
12 in general practice: a prospective study. *BMJ.* 1998;316:1356-1359.
- 13 12. Hides JA, Richardson CA, Jull GA. Multifidus musculerecovery is not automatic after resolution
14 of acute, first-episode low back pain. *Spine (Phila Pa 1976).* 1996;21:2763-2769.
- 15 13. Hides JA, Stanton WR, McMahon S, Sims K, Richardson CA. Effect of stabilization training
16 on multifidus muscle crosssectional area among young elite cricketers with low back pain. *J*
17 *Orthop Sports Phys Ther.* 2008;38:101-108.
- 18 14. Cooper RG, St Clair Forbes W, Jayson MI. Radiographic demonstration of paraspinal muscle

- 1 wasting in patients with chronic low back pain. *Br J Rheumatol.* 1992;31:389-394.
- 2 15. Barker KL, Shamley DR, Jackson D. Changes in the crosssectional area of multifidus and
3 psoas in patients with unilateral back pain: the relationship to pain and disability. *Spine (Phila*
4 *Pa 1976).* 2004;29:E515-519.
- 5 16. Keller A, Brox JI, Gunderson R, Holm I, Friis A, Reikerås O. Trunk muscle strength, cross-
6 sectional area, and density in patients with chronic low back pain randomized to lumbar
7 fusion or cognitive intervention and exercises. *Spine (Phila Pa 1976).* 2004;29:3-8.
- 8 17. Hodges P, Holm AK, Hansson T, Holm S. Rapid atrophy of the lumbar multifidus follows
9 experimental disc or nerve root injury. *Spine (Phila Pa 1976).* 2006;31:2926-2933.
- 10 18. Bergmark A. Stability of the lumbar spine. A study in mechanical engineering. *Acta Orthop*
11 *Scand Suppl.* 1989;230:1-54.
- 12 19. MacDonald DA, Moseley GL, Hodges PW. The lumbar multifidus: does the evidence support
13 clinical beliefs? *Man Ther.* 2006;11:254-263.
- 14 20. Kamaz M, Kireşi D, Oğuz H, Emlik D, Levendoğlu F. CT measurement of trunk muscle areas
15 in patients with chronic low back pain. *Diagn Interv Radiol.* 2007;13:144-148.
- 16 21. Lee HI, Song J, Lee HS, Kang JY, Kim M, Ryu JS. Association between cross-sectional areas
17 of lumbar muscles on magnetic resonance imaging and chronicity of low back pain. *Ann*
18 *Rehabil Med.* 2011;35:852-859.

- 1 22. MacDonald D, Moseley GL, Hodges PW. Why do some patients keep hurting their back?
2 Evidence of ongoing back muscle dysfunction during remission from recurrent back pain. *Pain*.
3 2009;142:183-188.
- 4 23. MacDonald D, Moseley GL, Hodges PW. People with recurrent low back pain respond
5 differently to trunk loading despite remission from symptoms. *Spine (Phila Pa 1976)*.
6 2010;35:818-824.
- 7 24. Tsao H, Hodges PW. Immediate changes in feedforward postural adjustments following
8 voluntary motor training. *Exp Brain Res*. 2007;181:537-546.
- 9 25. Tsao H, Druitt TR, Schollum TM, Hodges PW. Motor training of the lumbar paraspinal
10 muscles induces immediate changes in motor coordination in patients with recurrent low back
11 pain. *J Pain*. 2010;11:1120-1128.
- 12 26. Ikezoe T, Mori N, Nakamura M, Ichihashi N. Effects of age and inactivity due to prolonged bed
13 rest on atrophy of trunk muscles. *Eur J Appl Physiol*. 2012;112:43-48.
- 14 27. Aubry S, Risson JR, Kastler A, Barbier-Brion B, Siliman G, Runge M, Kastler B.
15 Biomechanical properties of the calcaneal tendon in vivo assessed by transient shear wave
16 elastography. *Skeletal Radiol*. 2013;42:1143-1150.
- 17 28. Tsuji T, Matsuyama Y, Sato K, Hasegawa Y, Yimin Y, Iwata H. Epidemiology of low back pain
18 in the elderly: correlation with lumbar lordosis. *J Orthop Sci*. 2001;6:307-311.

- 1 29. Hangai M, Kaneoka K, Kuno S, Hinotsu S, Sakane M, Mamizuka N, Sakai S, Ochiai N.
2 Factors associated with lumbar intervertebral disc degeneration in the elderly. *Spine J.* 2008;8:
3 732-740.
- 4 30. Powell MC, Wilson M, Szypryt P, Symonds EM, Worthington BS. Prevalence of lumbar disc
5 degeneration observed by magnetic resonance in symptomless women. *Lancet.* 1986;2:1366-
6 1367.
- 7 31. Wallwork TL, Stanton WR, Freke M, Hides JA. The effect of chronic low back pain on size and
8 contraction of the lumbar multifidus muscle. *Man Ther.* 2009;14:496-500.
- 9 32. Lee HI, Song J, Lee HS, Kang JY, Kim M, Ryu JS. Association between cross-sectional areas
10 of lumbar muscles on magnetic resonance imaging and chronicity of low back pain. *Ann Rehabil*
11 *Med.* 2011;35:852-859.
- 12 33. Kamaz M, Kireşi D, Oğuz H, Emlik D, Levendoğlu F. CT measurement of trunk muscle areas
13 in patients with chronic low back pain. *Diagn Interv Radiol.* 2007;13:144-148.
- 14 34. Danneels LA, Vanderstraeten GG, Cambier DC, Witvrouw EE, De Cuyper HJ. CT imaging of
15 trunk muscles in chronic low back pain patients and healthy control subjects. *Eur Spine J.*
16 2000;9:266-272.
- 17
- 18

1 Table 1. Characteristics and LBPH/ LBP status in the CTR, LBPH, and LBP groups.

	CTR group (n=19)		LBPH group (n=16)		LBP group (n=23)	
	Mean±SD	Range	Mean±SD	Range	Mean±SD	Range
Characteristics						
Age (years)	72.4±5.4	64.0–82.0	70.3±6.5	57.0–82.0	74.3±6.4	62.0–88.0
Height (cm)	152.0±5.9	140.5–159.6	152.4±4.8	145.7–161.8	150.1±5.4	139.4–159.2
Weight (kg)	47.8±7.2	37.0–60.0	49.7±5.7	40.2–57.7	51.1±7.1	39.7–63.4
LBPH/ LBP status						
Distribution						
(bilateral or central /unilateral)	—	—	6/10	—	9/14	—
Duration (months)	—	—	58.7±113.0	3.0–360.0	67.3±86.3	3.0–360.0
NRS (static)	—	—	5.1±2.5	0–8.0	2.5±1.9	0–6.0
NRS (dynamic)	—	—	6.1±2.4	1.0–10.0	3.2±2.4	0–8.0
ODI (%)	—	—	30.0±24.7	2.2–97.8	13.2±8.5	2.2–28.9

CTR: control; LBPH: low back pain history; LBP: low back pain; NRS: Numerical Rating Scale; ODI: Oswestry Disability Index;

SD: standard deviation.

1

2 Table 2. Spinal alignment and stiffness and mass of the back muscles in the CTR, LBPH, and LBP

3 groups.

	CTR group (n=19)		LBPH group (n=16)		LBP group (n=23)	
	Mean±SD	Range	Mean±SD	Range	Mean±SD	Range
Spinal alignment (standing) (°)						
Thoracic kyphosis	39.6±10.3	22.0–57.0	37.3±13.1	17.0–63.0	38.8±10.4	21.0–59.0
Lumbar lordosis	22.7±9.2	3.0–38.0	18.9±7.5	8.0–30.0	12.8±14.7	–15.0–34.0
Sacral anterior inclination	8.4±5.1	1.0–20.0	7.4±6.0	–3.0 to 19.0	2.4±11.1	–19.0–25.0
Spinal alignment (prone) (°)						
Thoracic kyphosis	34.7±11.3	10.0–57.0	27.9±12.2	7.0–47.0	31.6±7.0	21.0–45.0
Lumbar lordosis	18.6±6.8	6.0–30.0	15.8±10.4	–4.0 to 34.0	13.9±7.9	–3.0–29.0
Sacral anterior inclination	100.4±5.5	86.0–109.0	99.1±6.1	91.0–110.0	98.4±5.6	90.0–107.0
Shear elastic modulus (prone) (kPa)						
Lumbar erector spinae	3.1±0.8	2.0–4.7	3.2±0.8	2.1–5.0	3.8±1.1	1.6–6.3

Lumbar multifidus	4.6±1.1	2.5–6.5	5.6±1.7	3.3–9.8	5.1±1.3	2.7–9.2
Muscle thickness (cm)						
Thoracic erector spinae	0.75±0.25	0.37–1.24	0.66±0.19	0.31–1.12	0.70±0.19	0.41–1.05
Lumbar erector spinae	1.41±0.24	1.03–1.99	1.51±0.29	1.09–2.37	1.46±0.43	0.79–2.64
Lumbar multifidus	2.29±0.38	1.46–2.97	2.39±0.51	1.76–3.33	2.56±0.65	1.65–4.16
Quadratus lumborum	0.80±0.25	0.52–1.52	0.77±0.20	0.48–1.15	0.84±0.16	0.62–1.26

CTR: control; LBPH: low back pain history; LBP: low back pain; SD: standard deviation.

1

2

3

4

5

6

7

8

9

1

2

3 Table 3. Results of multiple logistic regression analysis.

Dependent variables	Independent variables	Non-standard			95% Confidence interval	
		partial regression coefficient	<i>P</i> value	Odds ratio	Lower	Upper
	Shear elastic modulus of the lumbar multifidus (kPa)	0.56	0.06	1.75	0.97	3.17
Low back pain history (Yes=1, No=0)						
χ^2 value <i>P</i> = 0.04						
	Lumbar lordosis angle (°)	-0.07	0.02	0.94	0.88	0.99
Low back pain (Yes=1, No=0)						
χ^2 value <i>P</i> = 0.01						

4

5

6

7

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19

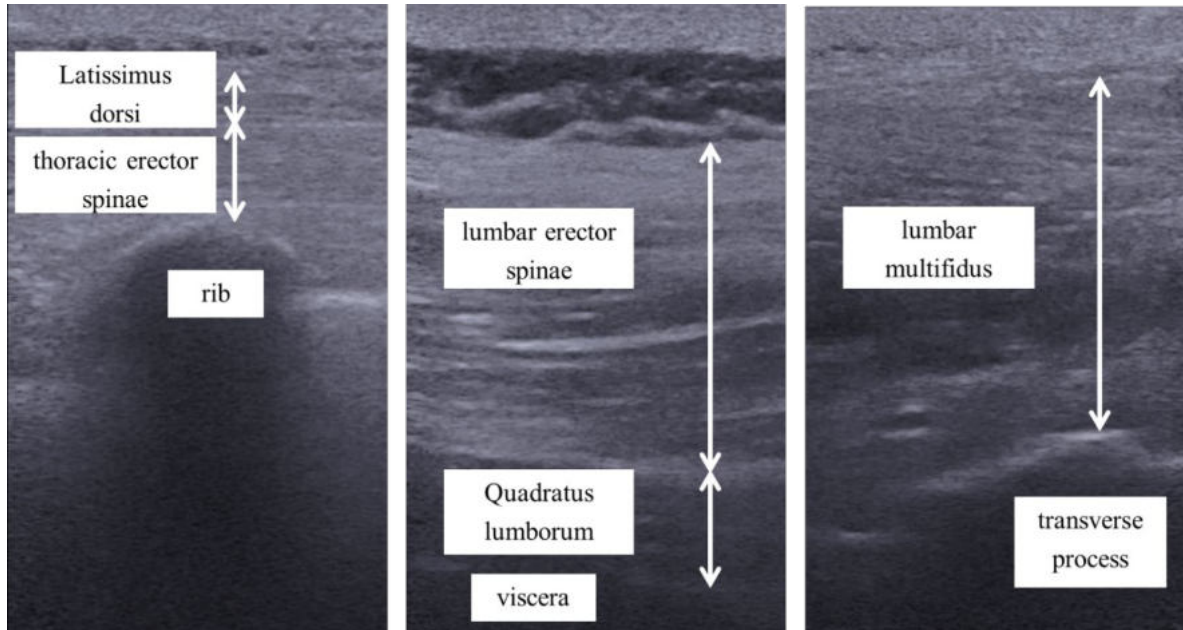


Fig. 1. Thickness measurement of the back muscles in community-dwelling middle-aged and elderly women.

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19

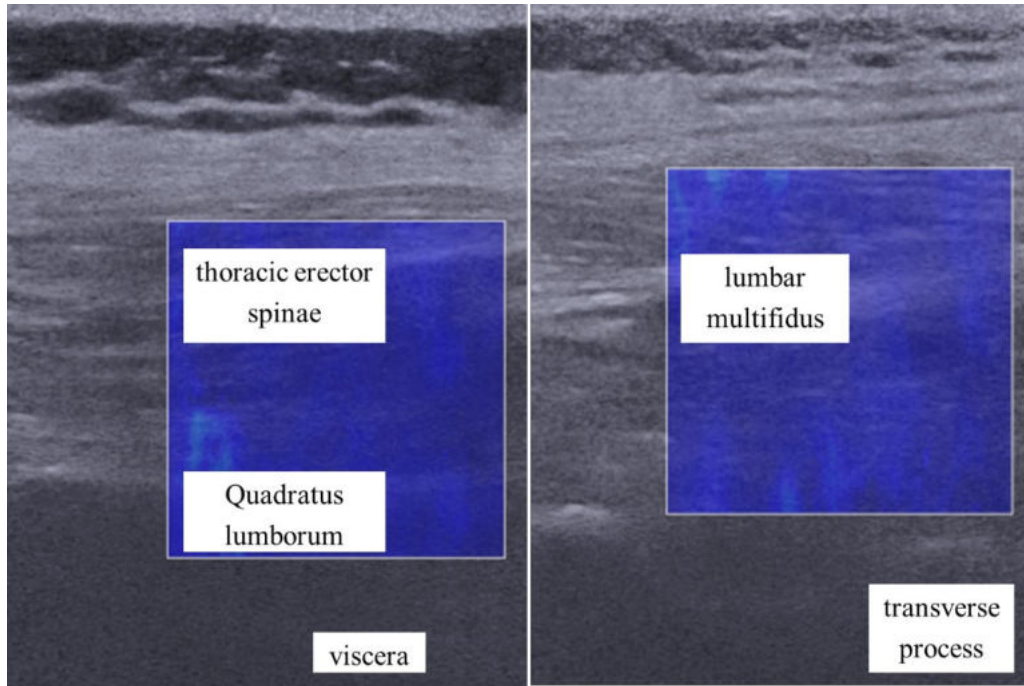


Fig. 2. Stiffness measurement of the back muscles in community-dwelling middle-aged and elderly women.

1

2