EFFECT OF LUMBAR LORDOTIC ANGLE ON LUMBOSACRAL JOINT DURING ISOKINETIC EXCERCISE

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The purpose of this study was to to analyze the biomechanical impact of the level of lumbar lordosis angle during isokinetic exercise through dynamic analysis using a 3-dimensional musculoskeletal model. We made each models for normal lordosis, excessive lordosis, lumbar kyphosis, and hypo-lordosis according to lordotic angle and inputted experimental data as initial values to perform inverse dynamic analysis. Comparing the joint torques, the largest torque of EL was 16.6% larger than that of NL, and LK was 11.7% less than NL. There existed no significant difference in the compressive intervertebral forces of each lumbar joint ($p>0.05$), but statistically significant difference in the anterioposterior shear force (LK>HL>EL>NL, $p<0.05$). For system energy, LK required the least and most energy during flexion and extension respectively. Therefore during the rehabilitation process, more efficient training will be possible by taking into consideration not simply weight and height but biomechanical effects on the skeletal muscle system according to lumbar lordosis angles.

KEY WORDS: lumbar lordotic angle, musculoskeletal model, isokinetic exercise

INTRODUCTION: Lumbar lordosis is especially known to be an important and decisive factor in flexibility during lifting, lowering and other movements. There are various factors affecting lumbar lordosis. Pre-existing studies discovered that the level of lumbar lordosis is affected by age and sex, and it is reportedly largely affected by movement in the center of mass (COM) such as pregnancy or obesity. Muscle imbalance and expected back pain caused by disorder in the lumbar lordosis has been disputable. In the case of rehabilitation exercises for lumbar lordosis disorder, muscle-building exercises are usually carried out, and these exercises are subcategorized into static and dynamic muscle-building exercises, actualized by isometric and isokinetic exercises. There have been reports made by previous researchers claiming that lumbar lordosis is only related to static muscle power in upright posture and statistically non-related to dynamic muscle power, but as reports on statistical irrelevance of static muscle power have been made, exercises strengthening dynamic muscle power for rehabilitation exercise for lumbar lordosis disorder have been developed. However, many exercise guides on muscle-building exercise devices take only body weight and height into consideration, not age and sex. Therefore if one carries out inappropriate muscle building through a training protocol that does not take lumbar lordosis into consideration, unexpected posture deviation and back pain could be caused due to using incorrect positions. Therefore this study intends to analyze the biomechanical impact of the level of lumbar lordosis curvature during isokinetic exercise through dynamic analysis using a 3-dimensional musculoskeletal model according to the curvature.

METHODS: Four healthy males (171.8 ± 4.0 cm, 70.5 ± 9.0 kg) were selected as subjects who have normal lordosis by radiography. These males were ordinary people with no pathological diagnosis of the nervous and skeletal muscle systems, and who do not perform any periodic muscle building exercises. In order to materialize the musculoskeletal model of each subject's entire body, 35 Helen Hayes marker sets (16 on the upper body, 19 on the lower body) were attached to each subject's body, and their static poses were shot by camera; then the full body musculoskeletal models were acquired through a conversion program (Motion module & SIMM ver. 4.2, Motion Analysis Inc., CA, USA). Due to the purpose of the study, the neck spine and lumbar spine were made to operate separately, especially when modeling the skeletal muscle. The muscles around the lumbar spine are composed of six pairs – one pair of flexors and five pairs of extensors. Rectus abdominis was defined as a flexor, and iliocostalis lumborum, longissimus thoracis, spinalis thoracis, quadratus lumborum (L1), quadratus lumborum (L2) were selected as extensors. A governing equation composed of Hill-type functions was applied to each muscle, and existing research data were used for each muscle variable. In addition, to apply the activation mechanism of the muscles, a 1st degree differential equation was used in modeling, and muscle activation levels were set at maximum values of each, in accordance to isokinetic exercise.

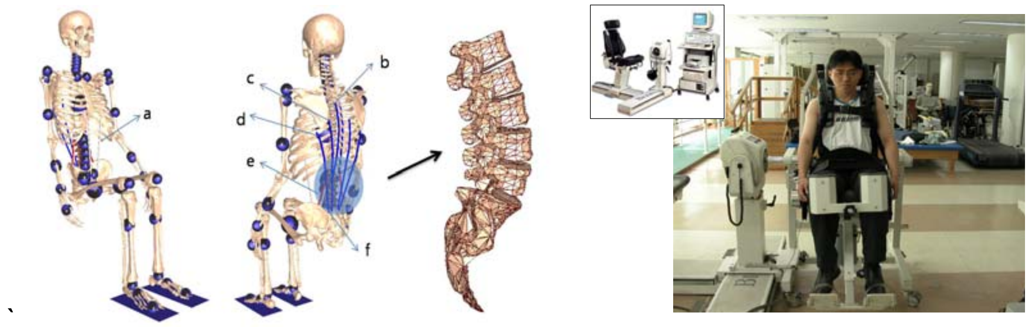

Fig. 1 Fullbody model with back muscles (left) and Isokinetic testing with Multi-Joint System 3:

In order to do a dynamics analysis using a whole-body musculoskeletal model, the lengths and weights of the subjects were measured, then the mass, center of mass, and moment of inertia needed for dynamics analysis were calculated by referencing existing research results. Measurement of the isokinetic muscular strength of the lumbar spine joint was carried out using the Multi-Joint System 3 pro (BIODEX, U.S.A.). (Fig.1) The dynamic variables on each part of the subject were put in, and after appropriately modifying the operating range on each joint, an equation of motion was induced using the Dynamic Pipeline Module (Ver3.2.1, Motion Analysis, USA) and SD/FAST (B2.8, PTC Inc, USA), a dynamics analysis program for mechanical systems. The initial values for all joints were set at the angular value of each joint of the subject during isokinetic exercise, and since this is an analysis on isokinetic exercise, all joint motions except spinal joints at sagittal plane were restricted. Also, the simulations were performed after putting in the pre-measured joint angles and angular velocity measured over time during isokinetic exercise as prescribed motions. For verification on the whole-body musculoskeletal model, an inverse dynamics analysis using SIMM was used to calculate lumbar joint torque, to be compared with torque value measured through isokinetic experiment on actual subjects. The results showed a small difference in the size of the lumbar torque in extension and flexion, but the overall torque patterns were similar to each other. (Fig. 2) Lumbar lordosis is defined by the angle between the upper plane of the L1 lumbar vertebrae and the upper plane of the S1 sacral vertebrae.

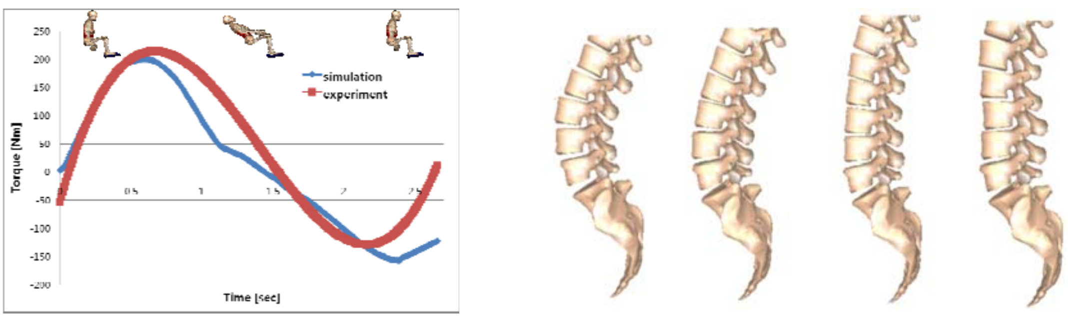

Fig. 2 Result of inverse dynamic analysis for validation(left) and Lumbosacral Joint model with respect to lordosis(right) (a) EL, (b) NL, (c) HL (d) LK

Normal lordosis (NL) is in the 31◦~50◦ range, excessive lordosis (EL) is over 70◦, lumbar kyphosis (LK) is less than 10◦, and hypo-lordosis (HL) is set at 11◦~30◦ to materialize the musculoskeletal model of lumbar lordosis for each case. Their whole-body musculoskeletal model for various lumbar lordosis angles can be arbitrarily modified using bone editing tool in SIMM. In order to take into consideration the impact of pelvic movement due to lumbar lordosis, 3 degrees of freedom was applied to the pelvic movement of the L5 lumbar vertebrae in redefining the skeletal parts. (Fig.2)

RESULTS: Comparing the joint torques when the trunk is flexed and extended, the largest torque was created in the case of EL, then in NL, HL and LK in that order. In the case of EL, the torque amount was 16.6% larger than that of NL, and LK was 11.7% less than NL. The results from calculating compressive force in the normal direction and shear force in the anterioposterior direction showed that there existed no significant difference in the compressive forces of each joint in the vertical direction at each lordosis angle. ($p>0.05$) Also, in shear force in the anterioposterior direction, LK showed the largest force in all lumbar joints, followed by HL, El and NL; there existed a statistically significant difference ($p<0.05$). However, in the pelvic and L5 lumbar there was no statistically significant difference in both compressive and shear forces. During trunk flexion, LK required the least energy, but had no statistically significant difference ($p>0.05$), and during trunk extension, NL and HL required the least energy, while LK required the most energy, with statistically significant differences ($p<0.05$).

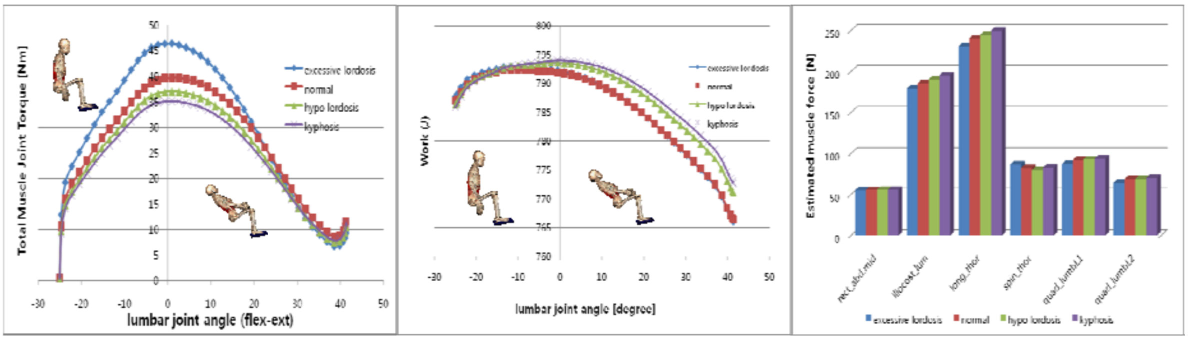

Fig. 3 Result of Total muscle joint torque (right), system energy (mid), and muscle forcess as lordosis curvature

The required muscle forces during isokinetic exercise for muscles surrounding the lumbar area - one pair of flexors and five pairs of extensors – were separately calculated. In the case of rectus abdominus, there were few differences in each case of lumbar lordosis angle. For spinalis thoracis, quadrates lumborum (L1,L2), EL showed a smaller value compared to other angles, but with no statistically significant difference.($p<0.05$) However, in cases of iliocostalis lumborum and longissimus thoracis, the muscle force dropped as the angle widened (EL), and led to lumbar kyphosis (LK), which increased muscle force.

Table 1. Intervertebral compressive and anterioposterior shear force from pelvic to thorax joint

	Pelvic-L5		L5-L4		L4-L3		L3-L2		L2-L1		L1-thorax	
	comp	shear	comp	shear	compr	shear	comp	shear	comp	shear	comp	shear
EL	791.8	240.1	1600.5	66.2*	1574.9	165.4*	1538.5	251.0*	1494.0	322.1*	1471.2	285.4
NL	790.3	241.4	1581.2	31.4	1553.1	112.4	1527.6	208.9	1513.8	291.0	1512.0	287.0
HL	783.7	246.9	1576.8	110.7*	1562.0	155.9*	1547.4	252.4*	1533.2	333.6*	1533.2	351.0*
LK	785.7	248.6*	1582.0	141.3*	1567.3	165.3*	1552.5	265.0*	1537.8	350.5*	1540.7	398.6*

* P-values < 0.05 revealed significant differences between NL and other cases through statistical analysis. (unit:newton)

DISCUSSION: Most cases of back pain are said to be caused by incorrect posture. This posture deviation is known to be caused by changes in muscle length and subsequent strength of muscles surrounding the skeleton over time. Change in muscle length directly affects posture alignment, and is known to cause excessive posture deviation such as lumbar lordosis, kyphosis, and scoliosis.[25] These changes in lumbar lordosis angle lead to back pain over time, but most physiotherapists overlook trunk muscle strength test when assessing spine-related data. This is due to the fact that good trunk muscle strength does not always mean the patient has a well-functioning spine. However, considering the fact that the results from this study showed that EL, HL and LK showed statistically significant differences in shear forces of front and rear lumbar, system energy and in some parts of extensors, there is a possibility these quantitative differences could ultimately lead to skeletal muscle disorders caused by posture imbalance. Most muscle building training devices do not take lumbar lordosis angle into consideration when setting up programs, which could lead to the possibility of additional problems due to trunk exercise over time.

The best model is to test and verify actual subjects according to various lumbar lordosis angle, but considering the range of lumbar lordosis angles, it is very difficult to find subjects who match the description. Also, in the case of subjects who fall away from normal lordosis angles, there is a possibility that various types of pain could be caused during exercise; therefore in this study is a whole-body musculoskeletal model on which the various lumbar lordosis angles can be arbitrarily modified. Due to the fact that not all muscles around lumbar area were modelled, however, while the overall lumbar flexing and extending torques showed similar tendencies during verification comparisons, quantitative difference existed between the experiment and calculated results. Further studies should include a more precise modeling of lumbar area muscle to heighten reality, and a more systemized verification process is considered necessary by comparing various clinical results on lumbar lordosis disorder.

CONCLUSION: During lumbar muscle strengthening training, in order to examine its impact according to lumbar lordosis angle, a 3-dimensional whole-body musculoskeletal model on EL, NL, HL and LK was used in a simulated experiment to examine biomechanical impact according to lordosis angles. In joint torques, EL showed the highest value, followed by NL, HL and LK, but in anterioposterior shear force, LK was the largest, followed by HL, EL then NL. The compressive intervertebral force inside the joint showed statistically to not be affected by lordosis angles. In terms of system energy, HL and LK required more energy than EL. Therefore, during the rehabilitation process, more efficient training will be possible by taking into consideration not simply weight and height but biomechanical effect on the skeletal muscle system according to lumbar lordosis angles.

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Acknowledgement

This study was supported by Ministry of Culture, Sports, and Tourism. Grant # S07-2008-03