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LUMBAR SPINE SYSTEM: BIOMECHANICAL MODEL EVALUATION

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1. Abstract

Considering lumbar spine injuries, investigations were pointed in many different directions. Our approach in case of lumbar spine under external mechanical load is to propose approach that can offer better understanding of lumbar spine functionality. For this purpose, this paper describes hypothetic model of lumbar spine mechanism, reduced on sagittal mid plane. As found in our previous investigations, there is principle that can explain response of lumbar spine to applied external mechanical load. Our findings are compared with experimental results. Beside comparison of our findings, comparison with other authors shows even more similarities. Conclusion of this paper comes through noticeable dependence of lumbar spine extension torque and trunk inclination. Connection between lumbar spine responses and applied external mechanical load can be defined as regulative system, however very complex. Used approach can have implications in further biomechanical modelling. For evaluation of reliable relations between lumbar spine responses and applied external mechanical load further investigations are needed.

2. Introduction

To decrease lumbar spine injuries occurrence, it is of importance to understand its functionality. As found up to date, lumbar spine functionality depends on many mechanical parameters. Lumbar spine is considered as regulative mechanical mechanism that has ability to deal with applied mechanical loads, mostly presented as torque. Proper evaluation of acceptable loads upon the spine is important, especially for health care and ergonomic purposes. In manual material handling operations (tasks), biomechanical model analysis of each task should be preformed for evaluation of present external mechanical loads, which causes response loads within lumbar spine system that we are searching for. If we are about to solve this problem experimentally, we should create conditions and movement similar to analyzed manual material handling operation. Finally, if we are aimed to understand the lumbar spine system functionality, then for both approaches and their results should be comparable if not similar conclusion, which can be used in general.

The purpose of the present study is to found facts that are in common for any movement that includes activation of lumbar spine system, with intention to correlate its functionality path. General idea is, if lumbar spine system can be considered as regulative system, than we can explain mechanical response of each subsystem. This approach attends to create understanding to some extent of lumbar spine system functionality.

To found answers that lead to a better perspective of lumbar spine functionality, extension torque of lumbar spine is introduced as our approach. In this study, experimental results for lumbar spine extension torque offer possibility to apply them on any case of trunk motion, through range of motion in sagittal mid-plane.

2.1 Theory

During everyday activities an increase in the intra-abdominal pressure is commonly observed when a large load is applied on the spine, recognized as forces in the muscles and joints. A forceful contraction of abdominal muscles is necessary to generate intra-abdominal pressure, since the abdominal cavity volume decrease. Pressure produced within the abdominal cavity exerted a resultant hydrostatic force down on the pelvic floor and up on the diaphragm, but also on the spine and abdominal wall. Assumed reduction in spine compression was absent, so it seems that the spine compressive force, arising from a contraction of abdominal wall muscles, cancels out the beneficial action of the hydrostatic intra-abdominal pressure forces acting on the spine. Currently prevailing hypothesis for duty of intra-abdominal pressure increase is in providing mechanical stability of the lumbar spine, obtained by absence of evidence for other contributions. Mechanical stability of the lumbar spine must be maintained during physical activities when the spine is loaded, mostly to prevent buckling and uncontrolled motion of spine segments. Furthermore, it is well established that skeletal muscle stiffness is proportional to the produced muscle force, so the contraction of muscles that surround the lumbar spine can also increase its stiffness and stability. That means that there are two ways for achieving the lumbar spine mechanical stability and stiffness. Also, activation levels of all trunk muscles determine the stability of the spine, regardless the magnitude of generated intra-abdominal pressure. In this case, intra-abdominal pressure increase and trunk muscle activation create synergy in achieving the lumbar spine stability, yet not well explored.

Mechanical stability of spine should be accomplished prior to any spine activity, especially if external trunk loads are to be applied. Lumbar spine and its parts form a system, surrounded by trunk muscles, nerves, tendons and nearby placed inner organs, which can be considered as very complex system with its own regulation, providing physiological functionality of lumbar spine area.

Everyday working activities, such as pushing, pulling, lifting, carrying or manual material handling in general, mostly requires two types of muscle contractions, static and dynamic. Applied load, most frequently presented as torque, consists from the external load itself and the posture effect on the human body. It can be divided into mass and inertia forces that create applied torque, respectively. For lumbar spine system, load is any force that lumbar spine system muscles should produce or prevail to complete designed task. The initial part of the lift can be considered static till activated muscles doesn't overcome static equilibrium of the applied forces on the muscles. Since the muscle length in the first phase doesn't change, it is considered isometric load, after which the lift may become dynamic as a result of change in involved muscle length. During this activity, activated muscles are contracted to some level, forming optimal intensity level for every one. This is well known answer of the body, which intends to reduce activation of few to as much as possible muscles, preferably biggest. This is human body prevention mechanism for overexertion of involved muscles, but it is still possible. Some of the tasks and their starting postures prevent effective regulation; the activation level of each muscle depends directly, so the overexertion can easily occur. Manual material handling tasks, especially those with loads to be carried, raised to high positions or similar are considered as very dangerous. When considering acceptable loads to be evaluated, we should keep in mind all factors that can change true estimation, if we want to avoid overexertion of lumbar spine system.

3. Experimental procedure

Results obtained by dynamic lift measurements, or in many cases isometric, show that there is significant difference between them, and from our point of view, are just inadequate. We want to obtain results that can be used for both static and dynamic analysis, and obtained in procedure that allows comparing with other results, considering different sex and anthropometric groups. Also, this request is recommended to achieve excluding all but the lumbar spine system muscles as much as possible. For this purpose, isokinetic lumbar extension measurement device MedX was chosen, providing isolation for lumbar spine muscle activation, counterbalance for trunk and accurate control for range of motion. Subjects should for set range of motion, from starting to full extension prevail static equilibrium and in modest isokinetic motion complete the lift. Detailed description and procedure are available [13]. For our purpose we are using only one group results, men aged 36 to 59, since similarities are quantitative and for our analysis are important only to find explanation of obtained results.

4. Results

Since the experiment procedure makes available trunk counterbalance during the extension, results presented in Figure 1 show complete lumbar spine extension torque.

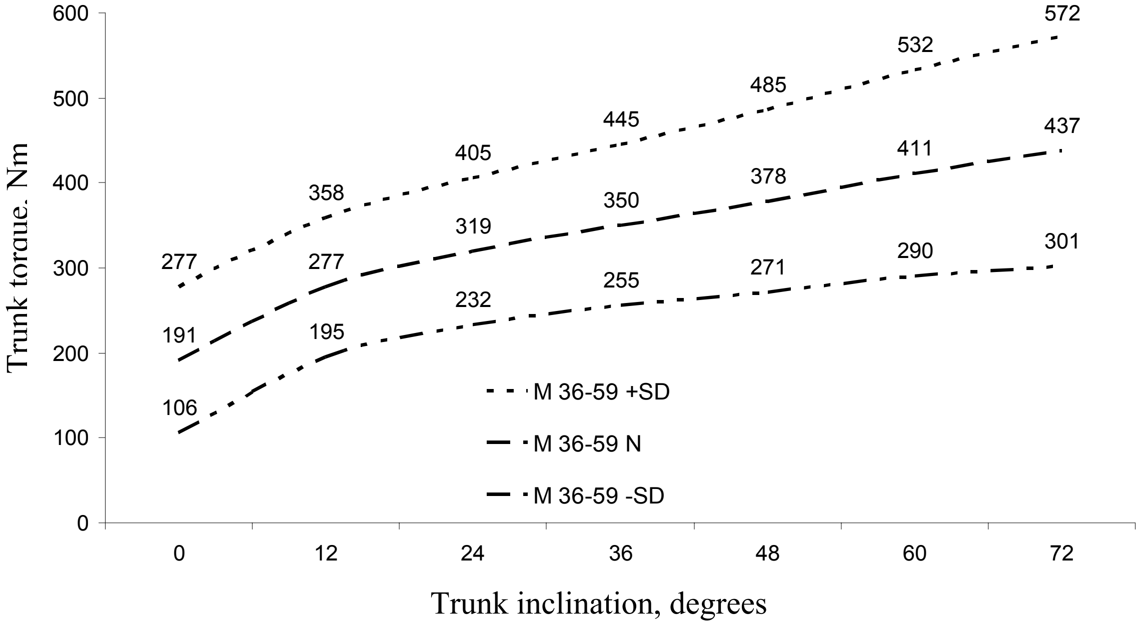

Figure 1. Extension lumbar spine torque

Because of counterbalance, trunk position was just relative to the pelvic and to the erect posture of the spine, so it is possible to apply presented results to wide range of trunk motion and postures. Erect posture of the spine is presented as inclination of 0°.

As shown, lumbar spine extension torque decreases from full flexion to extension because of counterbalance, creating overall view of available trunk torque. In real situation, there is the greatest loss of extension torque in flexion due to trunk mass, also inertia forces if motion occurs.

5. Biomechanical model of lumbar spine forces

In creating biomechanical model that represents forces that act on the spine, few assumptions were made. During specific physical activity trunk position will be changed, most likely in progressive direction, or simply flexed forward by angle α, which will provoke body response in order to stabilize the trunk. That response will induce compressive forces on lumbar spine by contraction of abdominal and back muscles as shown in Figure 2, causing increase of intra-abdominal pressure (IAP) as well as back muscles pressure (BMP) which is created by stiffness of contracted back muscles.

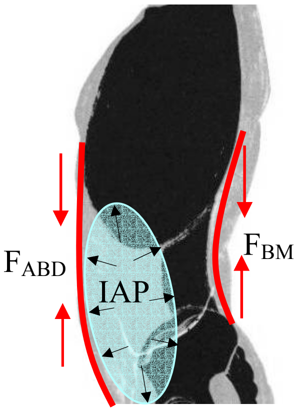

Figure 2. Upper body segment and forces layout for designing of lumbar spine mechanism model. IAP is pressure induced within abdominal cavity, F_{ABD} is force produced by abdominal muscles and F_{BM} is force produced by back muscles. Representation is only schematic.

BMP depends on back muscles contraction level and hypothetically purpose is to provide mechanical support. Both pressure forces are dependent on area size on which they act, they are considered concentrated as resultant forces on center of each lumbar vertebrate area and oriented perpendicular to the spine axis for simplicity of analysis. Also, intra-abdominal cavity is simplified and shown as elliptic, which in real most likely isn't the case.

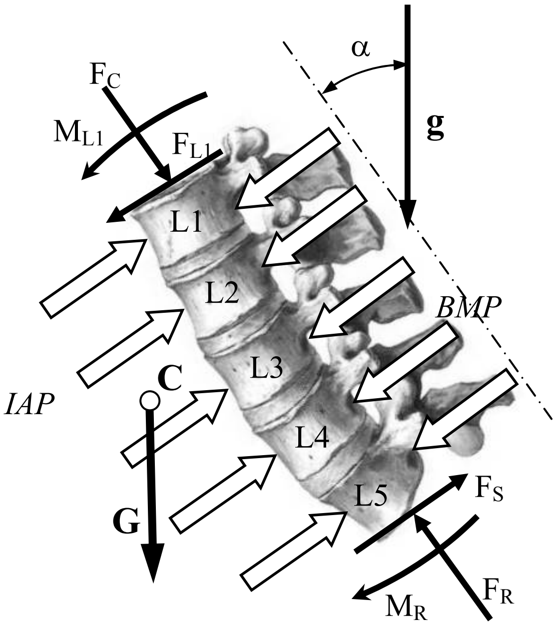

Figure 3. Lumbar spine forces model designed for analysis, with active and reactive forces applied on the lumbar spine during physical activity.

Lumbar trunk segment shown on Figure 3 is simplified, with included forces that are induced during physical experiment. External forces are relevant in the meaning of resulting forces that can act on lumbar spine and in magnitude of stress they produce, but in purpose of universal use of this model their magnitude and direction isn't of primary importance. They are included in cross-sectional forces beside upper and lower body mass forces (relative to cross-sectional areas). Figure 3 represents the lumbar spine segment forces model and is isolated from other body.

F_R, F_S and M_R are reactive forces on the lower cross-section of lumbar spine, F_C, F_{L1} and M_{L1} are active forces on upper cross-section of lumbar spine, and G is mass force of lumbar trunk volume. IAP and BMP are presenting resultant forces for each vertebrate induced by them. Gravity vector is marked with **g**. If the lower section is fixed as assumed, then F_C, F_{L1} and M_{L1} consist from all external and muscle forces induced at that area. Dynamic forces are assumed to be zero because the system should firstly overcome static equilibrium. Also, lower body is assumed to be fixed.

Range of motion of lumbar spine is 72 degrees, when pelvic fixed. During everyday activities it is impossible to fix pelvic, but this isn't the scope of this analysis.

Static equilibrium equations for our model in axial and perpendicular direction yield two significant equations:

$$F_C = F_R - G \cdot \cos\alpha \tag{1}$$

$$F_{L1} = F_S + \Sigma F_{IAP} - G \cdot \sin\alpha - \Sigma F_{BMP} \tag{2}$$

6. Discussion

Activation of abdominal wall and back muscles induce *IAP* and *BMP* increase that provide lumbar spine stiffness and stability. It is noticed earlier that they rise by increase of trunk inclination. They also affect magnitude of compressive force F_C, which is dependent on trunk position; it should increase by level of trunk inclination, as shown by equation (1). This fact proves connection between F_C, *IAP* and *BMP*. If external vertical load is applied on upright positioned trunk, compressive force F_C will raise without co activation of abdominal and back muscles, so buckling effect can occur. Still, compressive force may trigger *IAP* and *BMP* increase to provide trunk stability.

Increase of trunk inclination provokes back muscles activation and correlated *BMP* increase, which tends to decrease shear force F_{L1} by inducing forces F_{BMP}. Mass force G tends to support such action. If induced forces F_{BMP} can cancel out or at least offset forces F_{IAP}, than equation (2) is even easier to understand. Furthermore, it seems if F_{BMP} can overcome F_{IAP}, then shear force would be even more decreased, which is even better.

What would happen if there is no *IAP* induced? Since back muscles would be activated, compressive force will raise, and nothing can prevent buckling to occur. Frontal stability of lumbar vertebrates as well as other benefits is missing.

This analysis confirms conclusion that IAP role is to assure lumbar spine stability and stiffness. Therefore, for handling loads it is needed for lumbar spine mechanism to produce sufficient *IAP*.

If back muscles produce force that is insufficient for completing physically assigned task, then the lack of back muscles torque and mechanical support for lumbar spine may occur. *IAP* will increase with abdominal muscles activation in order to stabilize the spine, which increases force F_C, so flexion of the lumbar spine is much more possible, which can lead to injury.

Considering achieved results, trunk torque is greatest in flexed position, which means that lumbar spine system can produce greatest forces, needed for executing of designed tasks. Considering dynamic task, in which acceleration should be produced, is possible. Also, in flexion back muscles contraction produce greatest force, which means that lumbar spine stability is most jeopardize. Compressive force would be present by that cause as greatest, which means that *IAP* should be also high.

7. Conclusion

As assumed, lumbar spine system is self regulative, providing most efficient way to protect its functionality and health. Evidence for such a statement is in fact that every subsystem of lumbar spine system has its role, described as follows:

1. *IAP* should help in providing mechanical stability and stiffness of the spine;
2. back muscles, besides inducing *BMP*, should produce force to overcome applied load and complete designed task;
3. *BMP* should offer support for the spine as well as contribution to mechanical stability and stiffness of the spine;
4. abdominal wall muscles are intended to create *IAP*, but also indirectly to stiffen the spine.

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