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Evaluation of functional and structural changes affecting the lumbar spine in professional field hockey players

MAŁGORZATA BARBARA OGURKOWSKA, KRZYSZTOF KAWAŁEK*

Department of Biomechanics, University School of Physical Education, Department of Biomechanics, Poznań, Poland.

Purpose: The aim of this study was to evaluate functional and structural changes in the lumbar spine which occurred as a consequence of playing field hockey. *Methods*: The research group consisted of 20 male professional field hockey players. Computed tomography scans were collected to define the radiological density of the vertebral bodies and to calculate Young's modulus. An electrogoniometer was used to measure the range of movement. Geometric parameters, such as Lumbar Lordosis Angle, Index of Lumbar Lordosis, Whitmann–Ferguson Angle and Anterior Pelvic Tilt, were also measured. *Results*: The values describing lumbar lordosis increased linearly with years of training and were significantly greater than those reported in the literature. Field hockey players displayed a larger range of flexion, side bending and rotation to the right. An analysis of radiological density discovered significantly high values. An analysis of Young's modulus showed that the vertebral bodies become more fragile. *Conclusions*: The results show that overuse changes in the lumbar spine of field hockey players are severe and highly correlated with years of training.

Key words: *overload, sports medicine, biomechanics, bone*

1. Introduction

Field hockey is a team sport in which the aim is to score a goal by hitting a ball with a stick. The short length of the stick forces players to maintain a non-ergonomic position while in possession of the ball, flexing the joints in the lower limbs and bending the trunk forward in the sagittal plane, often coupled with side bending and rotation. According to many authors [4], [10], this is a position that strongly overloads the lumbar spine.

Running on the field with flexed lower limbs causes overuse of the hip and knee muscles, which subsequently become shortened [9]. This shortening of the muscles causes an increase in anterior pelvic tilt and the angle of lumbar lordosis. This angle can also be increased by flexion of the upper limbs, as each forward shift of the center of gravity causes an additional moment of the force of gravity to occur, which must be balanced by the force of the spinal erector muscle. If the stabilizing muscles are inefficient, the angle of lumbar lordosis increases. Field hockey players move on the field holding the stick in their hands, which further increases the moment of the force of gravity. It is also important to note that increased lumbar lordosis causes compression forces to strongly affect the posterior part of the lumbar vertebrae.

Maintaining the lumbar spine in flexion while dribbling the ball and performing dynamic flexion with rotation while passing or shooting strongly affect intervertebral discs [4], [10]. These movements greatly increase the shear component of the resultant force, which pushes the nucleus pulposus into the annulus fibrosus. In consequence, micro-ruptures in the posterior part of the annulus fibrosus arise, and this area is additionally weakened by increased lordosis. Repeated overloading weakens the annulus fibrosus to breaking point and the nucleus pulposus then penetrates the spinal canal.

Some authors have claimed that a player can shoot more strongly and accurately when flexing the trunk in a more forward manner [3], and a special training

* Corresponding author: Krzysztof Kawałek, Akademia Wychowania Fizycznego, Katedra Biomechaniki, ul. Królowej Jadwigi 27/39, 61-871 Poznań, Poland. Tel: +4367761829034, fax. +48618355099, e-mail: krzys.kawalek@gmail.com
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program that forces players to perform maximal flexion of the trunk has been created. It must be emphasized that the long-term repetition of these movements inevitably leads to pathological changes in the lumbar spine.

A study by Ogurkowska and Kawałek [13] showed that professional field hockey players have highly degenerated lumbar intervertebral discs. When the disc is damaged, it loses its shock-absorbing properties [8] and, therefore, compression forces are directly transferred to the vertebral bodies. Overloading such forces during field hockey can lead to acute injuries in the spinal tissues. A stress fracture in the sacral bone of a female player has been reported [18].

An X-ray study [5] found a number of congenital and acquired anomalies in the lumbar spines of field hockey players. However, other methods offer more accurate analysis of spinal structures. The aim of this study was to accurately evaluate functional and structural overloading changes in the lumbar spine in professional field hockey players.

2. Material and methods

The study design was approved by the Ethics Committee of Poznan University of Medical Sciences, Poznań, Poland. Informed consent was obtained in writing from each participant. The participants were 20 professional field hockey players, members of the Polish national team. They were aged between 24 and 35 years and had been playing field hockey for between 14 and 26 years. Eighteen of the players reported experiencing repeated and acute low back pain, although none of the participants experienced any pain symptoms during the research. The control group consisted of 10 healthy male office workers of similar age who did not practice any sport (Table 1).

Table 1. Characteristics of research participants

	Field hockey players (n = 20)			Control group (n = 10)		
	Mean	Min	Max	Mean	Min	Max
Age [years]	29.6	24	35	28.4	27	30
Training [years]	20.3	14	26	–	–	–
Body height [cm]	178.1	165	187	189	175	196
Body mass [kg]	76.0	58	90	79	69	88
BMI [kg/m^2]	23.9	21.1	27.2	23.1	21.8	24.8

The study consisted of several stages. First, the condition of the lumbar spine was assessed using computed tomography (CT). The participants were in a supine position with a roll inserted under the knee joints. CT scans were evaluated by a specialist radiologist and were then used to calculate the index of lumbar lordosis (ILL) using the formula $ILL = \frac{h}{s} \cdot 100\%$, where h is the maximal length between the chord and lumbar curve and s is the length of a chord, and Whitman–Ferguson's angle, which is the angle between the plane of the base of the sacrum and the horizontal plane.

The angle of anterior pelvic tilt (APT), between the line connecting the posterior superior iliac spine with the upper edge of the pubic symphysis and the horizontal plane, was measured with Wiles calipers. A Penny and Giles electrogoniometer was used to measure the angle of lumbar lordosis between the lower plane of Th12 and the upper plane of S1, as well as the mobility of the lumbar spine in sagittal, frontal and transverse planes.

CT scans were also used to measure parameters describing bone structure: radiological density and elastic modulus (Young's modulus). Radiological density was measured in three parallel layers (1 cm thick) in the lumbar vertebrae L3–L5. Each point of measurement had a surface area of 0.0196 cm^2 and was respectively 0.6 cm, 18.8 cm and 3 cm from the vertebral canal. A total of 540 measurements of radiological density were taken.

The modulus of longitudinal elasticity (Young's modulus) describes the elasticity of bone, i.e., its ability to deform temporarily under a vertical (compression) force and to recover after the force is reduced. Elasticity is different in particular areas of the vertebra due to its heterogeneous structure. It is possible to calculate elasticity using a method described by Ogurkowska [15], who found a correlation between radiological density and the value of Young's modulus. The author presented equations $E(\rho)$ for nine points in each lumbar vertebra (Table 2). In the present study, 540 measurements of Young's modulus were taken. The results show the ability of vertebral bodies to absorb vertical forces arising from body mass above the lumbar spine. The higher the value of Young's modulus, the more fragile the bone.

Table 2. Equations for calculating Young's modulus (E) from the value of radiological density (ρ)

Vertebra number	Point of measurement	Equation
1	1	$E = 0.13358 \cdot e\,(0.0170334 \cdot \rho)$
	2	$E = 0.34539 \cdot e\,(0.0215959 \cdot \rho)$
	3	$E = 3.70143 \cdot e\,(0.0080803 \cdot \rho)$
	4	$E = 1.44122 \cdot e\,(0.0129910 \cdot \rho)$
	5	$E = 1.40624 \cdot e\,(0.0136472 \cdot \rho)$

All variables obtained were analyzed in Statistica 10.0. The mean, median, standard deviation, dispersion, quartiles and standard error were calculated for each variable. The Shapiro–Wilk test was used to establish the distribution of the variables. For those with normal distribution, Student's *t*-test was used to compare both groups, and the Pearson's coefficient of correlation was used to analyze the correlations between the variables. The Mann–Whitney test was used to compare both groups' variables with an abnormal distribution. Spearmen's rank correlation coefficient was used to analyze correlations between variables and years of training.

3. Results

Analysis of the CT scans showed that all players had herniated discs in the lowest lumbar segments: 18 players had hernias in L3/L4, L4/L5 and L5/S1 segments, and 2 players had hernias in L4/L5 and L5/S1 segments.

The hockey players had higher indices of geometric parameters in comparison to the control group (Fig. 1). The differences between the groups were statistically significant (p <0.005) for all measures apart from Whitman–Ferguson's angle (p = 0.1636).

In further analysis, changes in geometric parameters in relation to years of training were observed. The results showed that all parameters increased with years of training (Fig. 2). The correlation is best described by a polynomial regression curve of 2nd or 3rd degree and the coefficient of determination R^2 was from 71% to 42%.

Figure 3 shows the range of motion in the participants' lumbar spine. The field hockey players presented significantly higher values of forward flexion and rotation to the right and significantly lower value of extension than the control group.

Changes in the cancellous part of the vertebral body were also studied. Evaluations of radiological density in the players' vertebrae showed that they had much higher values than those reported in the literature [15]. The most significant increases were observed at L3-1 (45%), L5-9 (41%), L5-1 (31%) and L4-1 (20%). Only point number 2 in the evaluated lumbar vertebrae had similar values to the reference data (Fig. 4).

The analysis of maximum values of radiological density vertebrae showed even greater differences between players and reference data. The highest value was observed at points L5-9 and L5-8, where one player exceeded the norm by 96% and 85% respectively. It is important to note that this player had been undergoing field hockey training for only 15 years.

Changes in bone density in relation to years of training were also evaluated. The correlations for L5-1 and L5-3 are statistically significant (p = 0.0066 and p = 0.0041, respectively) but insignificant for L5-2

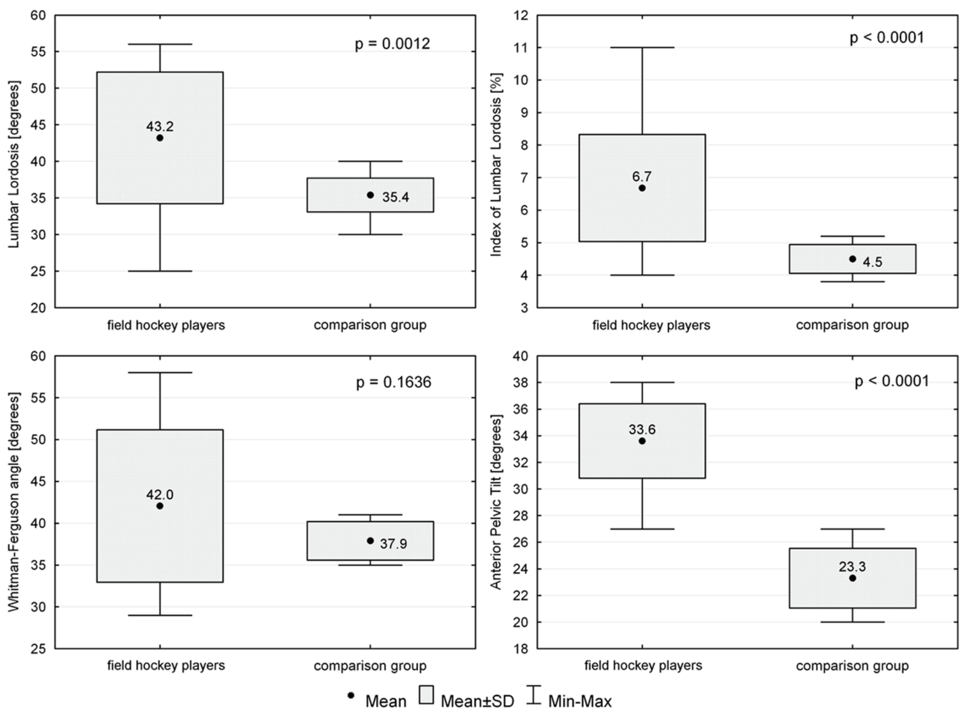

Fig. 1. Geometric parameters of the lumbar spine

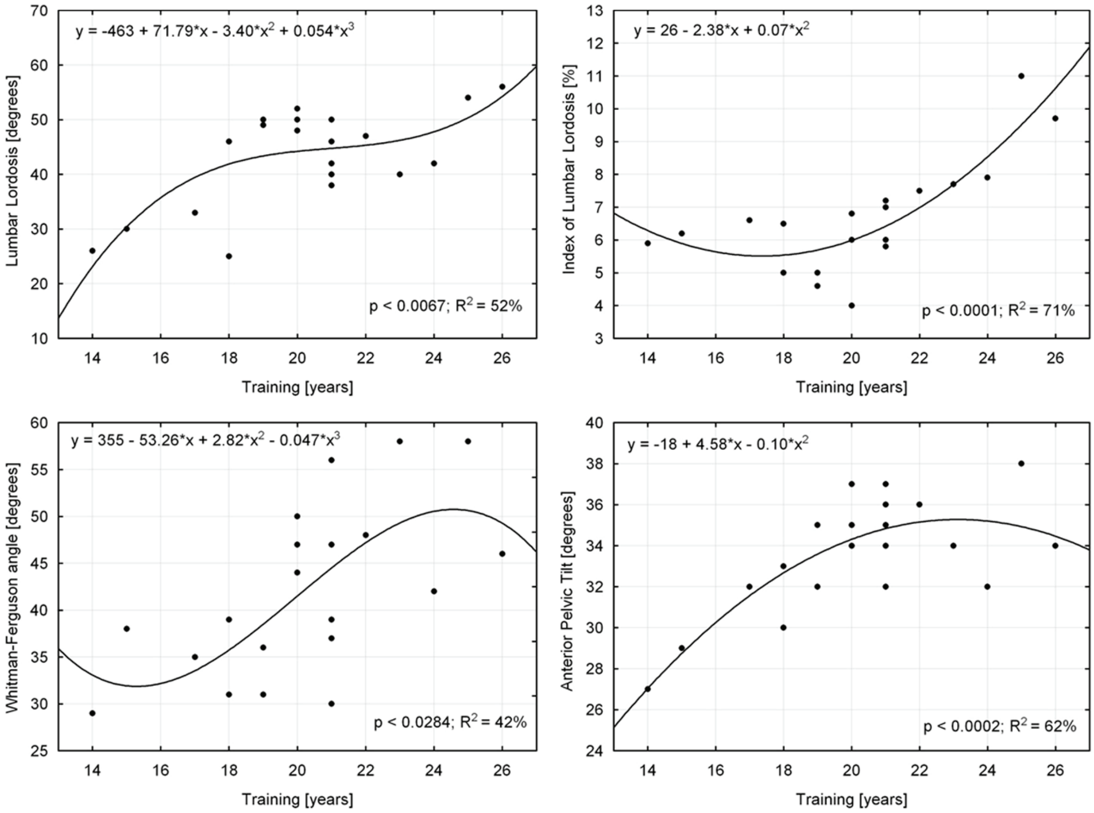

Fig. 2. Geometric parameters in relation to years of training

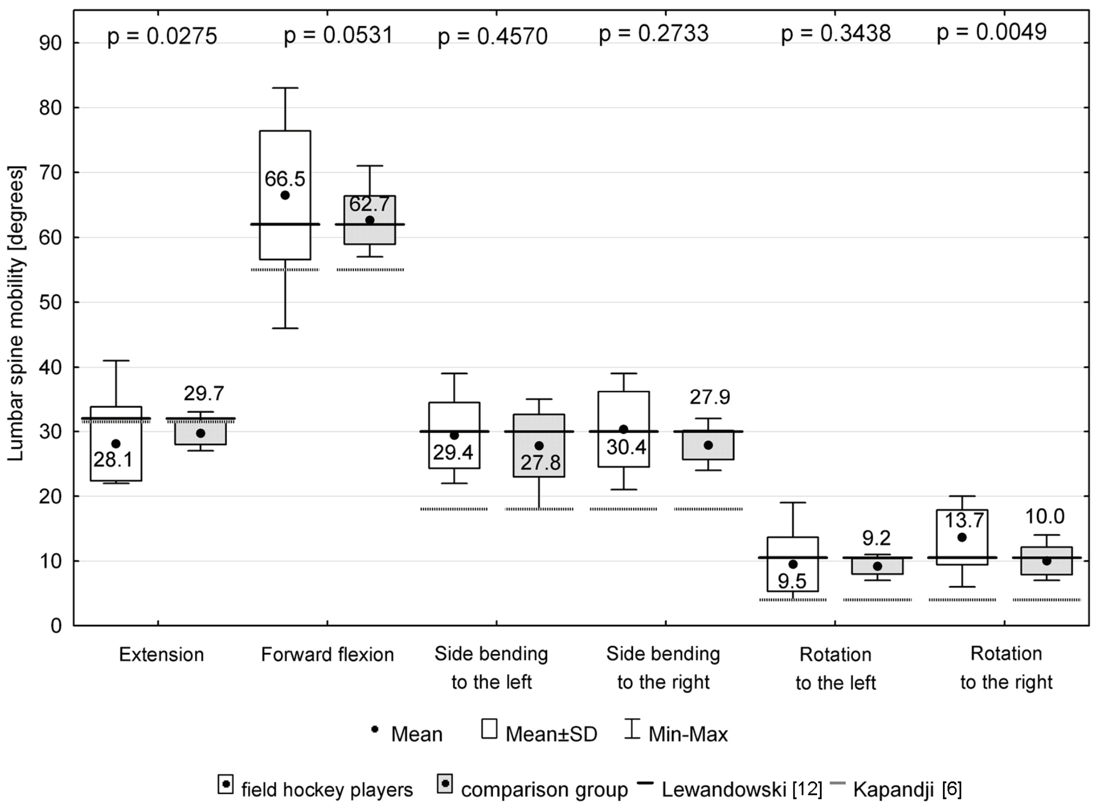

Fig. 3. Range of motion in the lumbar spine

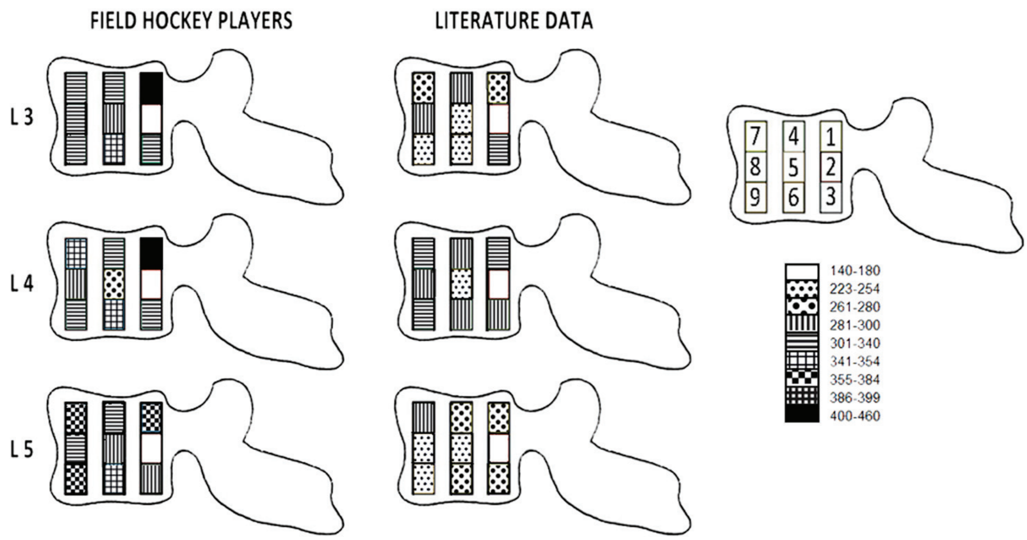

Fig. 4. Distribution of radiological density in the vertebral bodies L3-L5

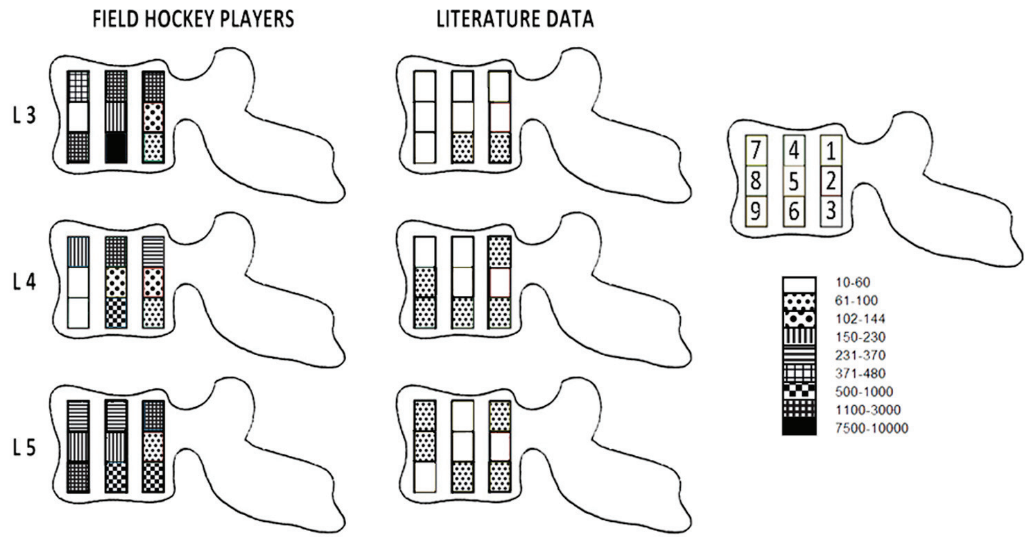

Fig. 5. Distribution of Young's modulus values in the vertebral bodies L3-L5

(p = 0.1790). For all evaluated vertebrae, players had the highest value of bone density after 14 years of professional training. All measured points were negatively correlated with years of training, except for L3-2, L4-2, L5-2, L4-5 and L5-5. The correlation is best described by a simple regression.

Pathological changes observed in the intervertebral discs, along with the increase in bone density, suggested that the elasticity of vertebral bodies should be evaluated. A comparison of the elastic properties of the players' vertebral bodies with published data revealed much greater differences than those found for radiological density. The range of Young's modulus for the lumbar vertebrae presented in the literature is very vast. Tyndyk et al. [19] has reported the value of 344 MPa and Borkowski et al. [2] has reported 400 MPa. However values presented by Ogurkowska [15] are more accurate, since she has measured them at many points in a single vertebra. The values reported as norms range from 60 to 100 MPa. This data is considered as the reference data in the following research. The mean values recorded for the field hockey players in this research for L3-6, L5-9, L3-4 and L5-1 were respectively 11,000 MPa, 4500 MPa, 2500 MPa and 2400 MPa; values lower than the data in the literature were observed in L4-3, L4-8, L4-9, L3-3 and L3-8 (Fig. 5).

Changes in Young's modulus in relation to years of training were also evaluated. All obtained correlations were statistically significant, e.g., L5-1, p = 0.0094; L5-2, p = 0.0489; L5-2, p = 0.0026. Similar to radiological density, the value of Young's modulus in the lumbar vertebrae decreased with years of training, except for points L3-2, L4-2, L5-2, L4-5 and L5-5. Young's modulus was highest after 14 years of training.

4. Discussion

The results of the spondylometric analysis indicate that the index of lumbar lordosis, the angle of lumbar lordosis and the Whitman–Ferguson's angle increase with years of training. The available literature reports a significant spread in the values for the angle of lumbar lordosis, with the difference between various authors ranging between 20° and 60° [1], [7], [12], [16], [17]. These differences are caused by different methods of measurement and different measured segments. The difference between Th12-L5 and Th12-S1 lordosis can be up to 30%. The value of Whitman –Ferguson's angle should be highest in the standing position, lower while sitting and lowest in the supine position. The players were examined in the supine position with a roll under their knees but despite this, the mean value of the Whitman–Ferguson's angle was 42.05°. In some individuals, the value was extremely high (up to 58°). A Whitman–Ferguson's angle greater than 40° strongly overloads the lumbar-sacral junction.

The curvature of lordosis depends mainly on the balance of muscles attached to the pelvic region. Increased lordosis is caused by shortened hip joint flexors and lumbar spine erectors [11]. During a game of field hockey players must, due to the shortness of the hockey stick and the playing technique, bend their lower limb joints, which sets the hip flexors in a shortened position. Further, moving on the field with flexed hips eliminates the extension that could naturally stretch these muscles. Previous research has shown that the iliopsoas muscles were shortened in 100% of cases, and the rectus femoris muscles in 63% [9].

Increased lumbar lordosis suggests that the lumbar spine erectors are shortened and, therefore, the range of trunk forward flexion is limited. The present study found the opposite: the players had a greater range of forward flexion than the comparison group and the literature data (from 7% to 21%) and rotation to the right (from 30% to 241%). Rotation to the right was 10% lower than Lewandowski's data [12] and, at the same time, 138% higher than Kapandji's data [8].

Previous research has found advanced degeneration of the intervertebral discs in this group of sportsmen confirmed by a radiologist [13]. It is known that muscles and ligaments, which naturally limit the range of motion, must be overloaded and lengthened before chronic overuse causes disc degeneration. Multiple instances of forward bending (often in maximal range) lead to pathological and irreversible changes in the stabilizing system of the lumbar spine.

The decreased range of extension observed in the players is caused by increased lumbar lordosis, which sets the spine in extension. Therefore, the range of extension from a player's natural position to the physiological limit will be lower.

Increased rotation to the right in the players under study is caused by their playing technique, in which the grip on the hockey stick leads to a preference for forehand shots. To perform a forehand shot, the player must rotate his trunk to the right, and numerous repetitions of this action lead to an increase in the range of movement. Dribbling also forces the trunk to be set in forward flexion, with a side bend and rotation to the right. Rotation to the right is an often-repeated movement in field hockey.

Once damaged, the intervertebral disc loses its shock-absorbing characteristics. Consequently, compression forces arising in the spine are directly transferred to the vertebral bodies. Cancellous bone can adapt to these forces; in the area where compression is higher, the density is increased to enhance its durability. The density of cancellous bone is lower than compact bone and the presence of both can be evaluated from CT scans.

The cancellous bone of the players under study increased in density, as shown by the radiological density of the vertebral bodies, which was similar to that of compact bone. The maximum values for bone density were found in players aged 21, who had been training in field hockey for 14 years. The highest density was observed at point number 1, the superio-posterior area of the vertebral body. This is caused, firstly, by its position (directly under the damaged intervertebral disc) and, secondly, by lumbar hyperlordosis, which increases the pressure on the posterior area of the vertebra.

Measurement points in the anterior areas of the vertebral bodies (7, 8, and 9) also had higher densities, e.g., the density value for point 9 was 30% higher than the literature data. This means that the anterior areas of the vertebral bodies are also exposed to increased pressure. An analysis of field hockey playing technique leads to the observation that, due to the short stick, athletes have to bend forward when in possession of the ball, which moves their center of gravity forward and increases the moment of the force of gravity affecting the anterior areas of the discs and the vertebral bodies. Griskevicius et al. [6] have found that among cyclists these force can reach up to 530 N.

It is worth noting that point number 2 in all evaluated vertebrae had density values equal to the literature data, and all points of measurement in the middle layer of the vertebral bodies (2, 5, and 8) had relatively lower densities than the upper and lower layers. This is caused by the nutrition canal, where blood vessels enter the bone, which runs at this level. Normal bone density in this area protects the vertebrae from decreased blood supply. However, the radiological density values in the medium layer were found to increase with years of training. This means that players who practice field hockey for an extended period are vulnerable to developing limited blood supply into the vertebral bodies.

The analysis of Young's modulus found similar results to those for bone density: areas lying directly under damaged intervertebral discs had much higher modulus values. This means that the bone becomes much more stiff and fragile, and is no longer able to absorb forces. In extreme cases, this can lead to compression fractures, and in fact, the first scientific report of a sacral stress fracture in a female field hockey player is now available [18]. Similar changes have been observed in rowers [14].

The lowest values of Young's modulus were observed, as for radiological density, at points 2, 5 and 8. Again, this is due to the protection of the nutrition canal, which in cases of advanced structural changes may lead to decreased blood supply to the bone.

5. Conclusion

In summary, biomechanical analysis of CT scans of field hockey players showed a number of functional and structural pathological changes in the lumbar spine that strongly correlate with years of training. Exaggerated lumbar lordosis and differences in lumbar spine mobility suggest that the stabilizing system of the spine is affected and overused. This can be proved by structural changes; significant increases in radiological density and Young's modulus values were observed. Such changes mean that the intervertebral discs do not function properly and vertical forces are directly transferred onto the vertebral bodies. Further training can lead to the destruction of bone structure or the formation of osteophytes. Presentations of overuse changes are expected in other sport disciplines with similar biomechanics.

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