ESTIMATING LUMBAR SPINE LOADING DURING VOLLEYBALL SPECIFIC MOVEMENTS USING 3D MODELING

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Volleyball has a high prevalence of back pain resulting from degenerated intervertebral discs in the lumbar spine. Therefore knowledge about volleyball specific spine loading and its direction is very important. In this study a method is introduced to calculate spine forces in volleyball specific situations also accounting for muscle forces. Two players performed volleyball specific movements in a laboratory environment. Kinematic data were captured by an infrared camera system. An inverse dynamic model was used to calculate spine forces in all three movement planes. Results indicate that the spike has the highest loading. However, peak loading was recognized in phases of takeoff and landing. The presented method was found to be adequate and might be used for further research to get a more comprehensive insight into the topic.

KEYWORDS: AnyBody, back pain, force.

INTRODUCTION: Comparing different sports, the prevalence of back pain is highest in volleyball (80%). 69% of the volleyball players have degenerated intervertebral discs in the lumbar spine (Kaneoka, 2013). The maximal compressive force tolerable by a vertebral body is between two and 12 kN and correlates with bone density (Brinckmann, Biggemann & Hilweg, 1989). However, for the purpose of a more comprehensive understanding of injury development the knowledge about spinal loading and its direction in specific situations is very important. Inverse dynamic calculations are based on the equality of forces and moments but usually do not include cumulated muscle forces of agonist and antagonists (De Zee, Hansen, Wong, Rasmussen & Simonsen, 2007). Therefore internal joint forces are likely to be underestimated. The purpose of this study was to introduce a method to account for spinal loading during volleyball specific movements and also factor the muscular force into the total loading.

METHODS: The study took place in an indoor laboratory. Two volleyball players, one female (age: 23, body mass: 77.0 kg, height 1.87 m) of national level and one male player (age: 26, body mass: 81.5 kg, height: 1.88 m) of regional level participated in the study. The participants were asked to perform volleyball specific moves including: spike, overhand front set, overhand jump back set, bump set, deep bump set (dig), ready position. All movements (except ready position) were executed with a ball which was passed by a third person to make movements as natural as possible. However, the ball was neither included in further 3D modeling nor in any calculations. The kinematic data were captured using a 3D infrared camera system (VICON™, Oxford, UK) consisting of 15 cameras (MX F40) operating at 250 Hz. Sixty retro-reflective markers were placed on anatomic reference points (Figure 1) and it was attended to have minimal influence on anticipated movements. Inverse dynamic calculations were executed by means of a modified Gait-Full-Body Model of the AnyBody Modeling System (Version 5.3, AnyBody Technology, Aalborg, Denmark). This model included the lumbar spine model introduced by De Zee et al. (2007). It did not include facet joints or ligaments and used vertebrae dimensions taken from Nissan & Gilad (1986). Muscles were modeled as simple muscles neglecting the force-length-velocity relations as it was done before by Daggfeldt & Thorstensson (2003). The spine model was driven by whole body kinematics estimated from motion capturing and therefore did not need explicit lumbar spine markers. Muscle recruitment during the process of inverse dynamics required balancing the external loads and was based on the principal of minimal energy expenditure. Due to computing time, every second time step was used and only the muscles of the upper body and the neck were included. For each movement one trial was randomly chosen for further calculations. Intervertebral force data for all pairs of vertebral bodies in all three movement planes (proximo-distal, antero-posterior, medio-lateral) were exported. All force curves were then filtered (Butterworth, 4th order, low pass, recursive, 25 Hz Cut Off) and normalized to body mass using MATLAB® (R2013b, The Mathworks, Natick, USA). In this paper the results between L5 and Sacrum are presented.

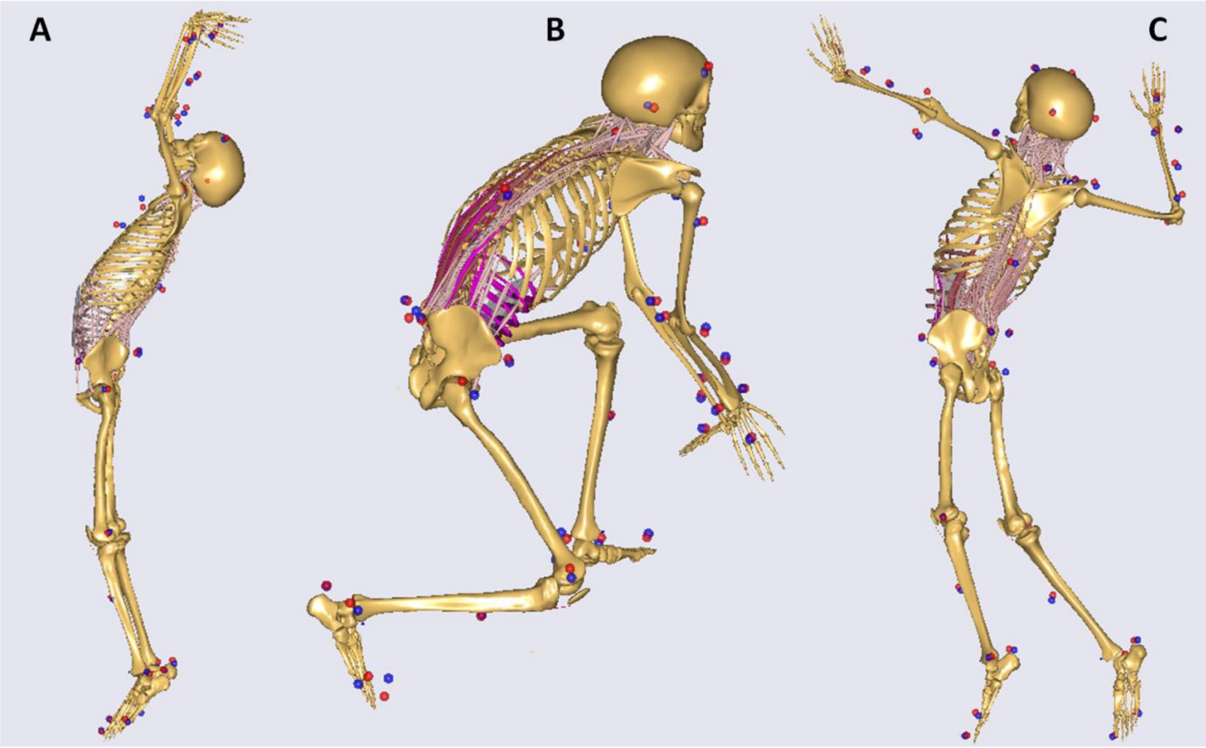

Figure 1: Model view of three selected movements: Overhand jump back set (A), deep bump set (Dig) (B), Spike (C).

RESULTS AND DISCUSSION: Beside the model limitations mentioned above, the assumption of minimal energy expenditure might not be fully applicable for athletes performing with maximal effort. This might lead to an underestimation of muscle activation and consequently to underestimated peak forces.

In accordance to the literature, highest forces were found in the proximo-distal direction for all movements. For both the female and the male player, greatest proximo-distal peak forces were found during bump set, dig and spike. They were between eight and ten times higher than in an upright standing position. Antero-posterior forces were highest for the same movements but three to four times lower as in proximo-distal direction and up to a factor 20 higher than in an upright standing position. (Table 1)

It was reported from an in vivo study, that the compressive load in the spine were smaller by a factor four for upright standing compared to other activities of daily living (including lifting) (Wilke, Neef, Caimi, Hoogland & Claes, 1999). The greater difference in our findings (factor 8 – 10) can be explained by the crucial influence of dynamics and body orientation on the spinal loading, as it was pointed out in previous investigations (Leskinen, StåLhammar, Kuorinka & Troup, 1983). The body's acceleration seems to play a major role for the accumulation of joint loading in the lumbar spine. Accordingly, peak forces for the spike were observed during phases of high acceleration like squatting and landing but not during flight time, when the lumbar spine is flexed the most. With regard to the maximal tolerable forces reported by Brinckmann et al. (1989) the observed forces during the spike were most likely in a tolerable range considering higher bone density for athletes.

Table 1: Peak spine forces between L5-S1 in proximo-distal, antero-posterior and medio-lateral direction for a female and a male athlete in seven volleyball specific movements

	Force [N/kg]						
	Upright standing	**Ready position**	**Overhand front set**	**Overhand jump back set**	**Bump set**	**Dig**	**Spike**
Proximo-Distal							
male	6.85	34.69	23.97	39.89	67.33	64.75	68.22
female	6.93	36.28	19.54	43.22	53.79	48.17	62.74
Antero-Posterior							
male	0.91	8.10	5.48	10.02	19.98	19.23	18.32
female	0.66	9.15	2.73	5.94	13.70	15.10	14.34
Medio-Lateral							
male	0.05	0.14	0.40	0.86	1.74	1.45	1.59
female	<0.01	0.19	0.10	0.31	0.94	2.24	2.05

Even though the bump set and the dig are less dynamic movements than the spike, the peak forces in all three movement planes appear to be on the same level. This might be due to the fact that the athletes lean forward, creating a greater lever arm between the center of gravity and the intervertebral joint, which has to be counteracted by higher muscle forces resulting in greater joint loadings. The same observation might explain the fact that the calculated compressive forces for the ready position are five times higher than in the upright standing position even though both are static conditions.
Brinckmann, Biggemann & Hilweg (1988) pointed out that not only high peak forces can create problems in the lumbar spine but also repetitive small forces potentially lead to fatigue fractures of the bone. This has to be accounted for in volleyball specific back pain research, due to the sports demand of numerous repetitions of vertical jumps.

CONCLUSION: The results of this study suggest that the observed peak forces during volleyball specific movements are not crucial for the incidence of back pain in volleyball. Furthermore, the presented results allow estimating the total volume of spinal loading during a training session and therefore imply valuable information for coaches. It might be concluded that training protocols including a high volume of vertical jumps or deep bump sets without adequate recovery between single executions, should be dosed carefully. Three dimensional modeling using the AnyBody Modeling System was found to be a suitable scientific tool to estimate lumbar spine loading during volleyball specific movements.

REFERENCES:

Brinckmann, P., Biggemann, M., & Hilweg, D. (1988). Fatigue fracture of human lumbar vertebrae. *Clinical Biomechanics (Bristol, Avon)*, *3 Suppl 1*, i-ii,S1–S23. doi:10.1016/S0268-0033(88)80001-9

Brinckmann, P., Biggemann, M., & Hilweg, D. (1989). Prediction of the compressive strength of human lumbar vertebrae. *Spine*, *14*(6), 606–610. doi:10.1016/0268-0033(89)90071-5

Daggfeldt, K., & Thorstensson, A. (2003). The mechanics of back-extensor torque production about the lumbar spine. *Journal of Biomechanics*, 36(6), 815–825. doi:10.1016/S0021-9290(03)00015-0

De Zee, M., Hansen, L., Wong, C., Rasmussen, J., & Simonsen, E. B. (2007). A generic detailed rigid-body lumbar spine model. *Journal of Biomechanics*, *40*(6), 1219–1227. doi:10.1016/j.jbiomech.2006.05.030

Nissan, M., & Gilad, I. (1986). Dimensions of human vertebrae in the sagittal plane. *Journal of Biomechanics*, 19(9), 753–758. doi:10.1016/0021-9290(86)90198-3

Kaneoka, K. (2013). Low back disorders among athletes and its prevention. *The Journal of Physical Fitness and Sports Medicine*, *2*(2), 185–190. doi:10.7600/jpfsm.2.185

Leskinen, T. P. J., StåLhammar, H. R., Kuorinka, I. A. A., & Troup, J. D. G. (1983). A dynamic analysis of spinal compression with different lifting techniques. *Ergonomics*, *26*(6), 595–604. doi:10.1080/00140138308963378

Wilke, H. J., Neef, P., Caimi, M., Hoogland, T., & Claes, L. E. (1999). New in vivo measurements of pressures in the intervertebral disc in daily life. *Spine*, *24*(8), 755–762.

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