NEUROMECHANICAL LOAD OF BIOLOGICAL TISSUE AND INJURY IN GYMNASTICS

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Biomechanical and biological factors related to the performance enhancement in gymnastics indicate that the potential of the neuro-musculoskeletal system seems to be close to or even at the ultimate tolerance limits. Acute and chronic severe tissue injuries are frequently reported from male and female gymnasts. In general mechanical loading of the musculoskeletal system is a prerequisite for morphological and functional adaptation of biological material. But if stress and strain increase to a certain level and exceed the mechanical limits of the individual structure, mechanical loading may lead to tissue damage. Young gymnasts have been shown to be particularly prone to overuse injuries, as their musculoskeletal system is still immature. One of the most serious overuse problems for young athletes is the development of abnormal radiological signs in the lumbar spine and the thoracic-lumbar transition. Research on biological load and injury in gymnastics indicated that tissue abnormalities, chronic injuries and acute tissue damage are related to mechanical load, the technical devices and apparatus; as well as, neuromuscular performance, muscular strength and technique.

KEY WORDS: mechanical loading, morphological adaptation, injury

INTRODUCTION: Mechanical load acting on the biological structures of the human musculo-skeletal system during artistic gymnastics is one possible stimulus to maintain and/or increase the strength of biological material. Excessive load may lead to microscopic or macroscopic damage of the anatomical structures. From this perspective mechanical overload is the cause of the damage of one or more biological structures, and an injury can generally be defined as the damage of biological tissue caused by physical loading. Injury can result from a single overload exceeding an individual tissue's maximum tolerance. Such a situation may lead to catastrophic spine injuries. The term catastrophic injury is defined as any injury incurred during participation in sport in which there is a permanent severe functional neurological disability (non fatal) or a transient but not permanent functional neurological (serious) disability. A chronic injury is initiated by microscopic damage of the tissue's structure. Long term repeated loading could worsen the injury eventually becoming macroscopic and/or resulting in tissue degeneration. Based on this definition a relationship between injuries and mechanical energy can be concluded. The principal relationship between mechanical energy and injury gives us reason to examine the causes of muscular-skeletal injury especially in sports where high amounts of mechanical energy and mechanical forces are a prerequisite for successful activity and performance. Gymnastics is a typical sport, which is intuitively combined with high loading of the spinal structures.
Some epidemiological studies suggest that gymnastics (Goldstein et al. 1991) may accelerate the degeneration of spinal structures. Sward et al. (1990) e.g. investigated 142 Swedish top athletes who competed in wrestling, gymnastics, soccer and tennis. All groups of athletes reported previous or present back pain at a higher frequency than found in previous studies of the general population. Radiological abnormalities of the thoracic-lumbar spine occurred in 36-55 % of the athletes. The results may suggest a causative relationship between athletic activities and radiological abnormalities. The radiological findings indicate both direct traumatic changes as well as disturbed vertebral growth. Sward et al. (1990) concluded that both the age at onset of athletic activity and the degree of mechanical load on the skeleton are important factors in the development of these abnormalities.
Only a few recent papers focus on gymnastic related tissue damage; this might be related to a decreased public interest in this sport even if the performance enhancement and the increase of technical difficulty in this dedicated sport exploded in the last two decades. One can speculate that the decreased public interest is related to reduced funding opportunities

for applied research in this area and that this causes the deficit of research and epidemiological papers.

Kujala et al. (1992) found some evidence that as intense physical activity in young athletes (10.3-13.3 years) increases the occurrence of low back pain (LBP). Several papers reported or speculated on a relation between mechanical loading in gymnastics and back injuries (e.g. Petrone and Ricciardelli 1987). The total time of exposure was identified to be the most important cause for increased disc degeneration (Goldstein et al 1991). Some authors warned about overloading the spine by physical activity and sports in the adolescence (Micheli 1985). Other studies found no higher frequency in disc degeneration in young gymnasts than in controls (Terrti et al 1990). Tsai et al. (1993) reported no differences in the frequency of self reported LBP between former gymnasts and controls.

Only few findings of mechanically induced injuries of discs and vertebrae in gymnastics and no data on the loading of the spinal structures during the different gymnastic skills and drills can be identified in the literature. From such a perspective the often-used cause-effect-relation between loading in gymnastics and spinal abnormalities is more intuitive and not well understood. On the one hand there are the positive effects of physical activity and sport in adolescents. On the other hand there are the noteworthy findings regarding the limited load capacity of the developing system. The dual role of mechanical loading as a positive and negative influence on the biological structures and of how beneficial effects of training interact with potential harmful effects of mechanical loading has received relatively little attention. Genetics may also be an important factor in the degeneration process. In a study on monozygotic twins Battié et al. (1995) demonstrated the importance of genetics in relation to a life time of physical activity with regard to disk degeneration. Therefore the individual genetically determined mechanical properties of the biological material should not be underestimated.

To approach a better understanding of the relationship between mechanical loading due to gymnastics and the damage or injuries of biological structures the frequency and severity of an injury or a group of injuries should be evaluated. From these figures it could be determined which factors lead to a particular damage or abnormality. Then the relation between these factors and the specific injury or abnormality should be examined to better understand the factors responsible for the tissue response.

METHODS: In a five years prospective study a total number of 135 female gymnasts (10-22 years) were surveyed. From these gymnasts fifty-seven elite female gymnasts were examined over at least three consecutive years. The highest frequency of spinal disorders was found in an age of 12-13years. During the survey 37 of the gymnasts were aged from 12.5 to 15.5 years and therefore in the most vulnerable phase of life. These 37 female athletes were chosen for further analysis. Thirty non-athletic females at the same age were used as controls. The clinical examination was performed twice during the year by the same well-trained medical staff using a precisely defined examination protocol. In cases with a clinical indication or a positive clinical finding radiographs were taken. Once a year, a MRI study of the gymnasts' lumbar spine and the thoracic-lumbar transition was performed.

Muscle strength and anthropometric variables of the subjects under study were measured several times each year. Mechanical loading was estimated from a biomechanical model using kinematic, kinetic and EMG measurements as model input during the most important movements and skills. Using the training protocols the cumulated spinal load for the day, the week and the total year was estimated. The resultant moments and forces at L5/S1 and/or Th12/L1 were calculated using inverse dynamic techniques. For the distribution of the resultant forces and moments to muscles, ligaments, and contact forces at the motion segment an EMG based switch technique was combined with optimization methods.

RESULTS AND DISCUSSION: Forty-nine positive findings in 135 gymnasts in the thoracic-lumbar transition support the weakness of the anterior part of the motion segment. Abnormalities in the posterior part of the ring apophysis are infrequent. From the positive findings in the prospectively surveyed sample (n=37) 59,4% of the signs disappeared or decreased in intensity during the three years control, in 40,6% of the cases the level of severity of the abnormalities increased. Hellström et al. (1990) reported a higher frequency of vertebrae with abnormal configuration (e.g. flattening, wedging and increased sagittal diameter) in young athletes than in non-athletes. They argued that healing of moderate vertebral fractures in children may be disturbed by high intensity loading and can explain the abnormal configuration. Our prospective data indicate some remarkable tissue responses to the induced loading. These responses are an increase of bone mass, an increase in plate area and an increase of normalized disk height and of water content in the intervertebral disks. Sward et al. (1992) found reduced disk MRI signal intensity more than twice as common in male (adult) gymnasts (mean age: 23 years) than in non-athletes. Hellström et al. (1990) reported disk height reduction in wrestlers and gymnasts in comparison with non-athletes. The cause for the different results to other studies (Tertii et al. 1990) may be that the young individuals in Tertti's sample had not passed the growth spurt, a period of time in which the growth plates and apophyses are most sensitive to trauma. The findings of our prospective study support Terttii's results and found no higher frequency of a reduced disc height in the young gymnasts in relation to the controls. Abnormal vertebrae configurations (flattening, wedging, increased sagittal diameter) are of higher frequency in athletes than in non-athletes (Hellström et al. 1990). Our data indicate a peak incidence at a lower level at about the thoracic-lumbar junction. The reported relation to back pain was not supported through our finding. A total of 47.4% of the 135 gymnasts never reported pain during the entire period of the survey. Sward et al. (1990a) concluded that their findings were highly suggestive of a causative relationship between rigorous athletic activities, radiological abnormalities, and back pain. The radiological findings indicate both direct traumatic changes as well as disturbed vertebral growth. Our clinical and radiological examination of former elite gymnasts supported Sward's data in principle and reported the majority of severe and moderate vertebral deformities in the thoracic-lumbar junction. About one third of the examined former female gymnasts (n=37) had severe vertebral deformities, another third showed moderate findings. The most frequent osteochondroses were found in the age groups of 12-15 years of age. These data of the examination of traumatic changes and abnormalities emphasize the vulnerability of the spine especially during the growth period. Both the age of onset of physical activity and the degree of mechanical load on the skeleton should intuitively be discussed as causal factors in the development of the described abnormalities.

The response to mechanical loading in the young gymnasts was shown in a significant ($p<0.05$) increase in vertebral bone mass in comparison to the controls at same age. An increase of BMD during the period of survey was identified in all the cases. In addition an increase of the vertebral endplate areas in the thoracic and the lumbar vertebrae was found. Surprisingly the water content of the disks of the young gymnasts (9 to 13 years) was significantly higher than in the controls. This finding corresponds with a moderately greater disk height of the gymnasts in comparison to the controls. In the older gymnasts (14 to 19 years) a first tissue ageing was identified. It is of interest that age of the material (even in the young gymnasts) of the disk explained 22.4% of the variance of the disk Tw2 signal (water content) whereas only 11.2% was explained through the mechanical loading. 66.4% of the Tw2 variance could not be explained by load or age. This indicates that genetics should not be underestimated when considering biomaterials strength and tissue response to load.

CONCLUSION: The mechanical load of the spine in gymnastics may reach or be close to the limits of tissue tolerances. The injury or the tissue damage will occur when these limits are exceeded in one traumatic failure or in repeated micro-failures. Apparatus, gymnastic technique and training determine the mechanical load of the biological structures. In order to prevent spinal injuries these factors have to be discussed to reduce the risk that loads exceed the physiological limits. The proper technique can contribute to the reduction and control of mechanical load of the spine. This is especially valid for the posterior column of the lumbar spine, the lumbo-sacral junction, and the anterior column of the thoracic-lumbar spine. Forward bending or inclining the trunk when high external forces are applied to the

body lead to an increase of peak pressure on the anterior area of the vertebrae at the thoracic-lumbar junction. This mechanism loads the apophysical ring when landing from a jump or a dismount with forward lean and bent trunk position. The landing technique and the technique of the skills prior to landing have a major influence on the pelvis and spine posture and therefore on peak pressure and pressure distribution at the motion segment. In bending with lumbar spine flexion up to 45° to horizontal the trunk is counterbalanced by the erector spinae muscles. If the flexion increases to about 60° the passive posterior ligaments become taut. In continuing the forward movement the pelvis rotates forward until the pelvis rotation is passively restricted by the gluteus and hamstring muscles. In this deep forward lean position no muscular activity of the back muscle can be registered. The inertial force and the weight of the trunk is counterbalanced by passive forces of ligaments, fasciae and muscles. Therefore landings with an extreme forward lean contribute to the load of the passive posterior structures. The landings with a more or less upright trunk position are controlled by the erector spinae muscles, which must clearly be activated prior to landing. In order to minimize the total muscle force and the resulting compression force of the motion segment well prepared athletes do not co-activate the abdominal muscle in landing.
The physical preparation of the athlete is a major concern in the prevention of spine injuries. This is true for expected loading and falls. The development of a muscular corset for the thoraco-lumbar spine seems to be the most effective strategy to ensure a controlled mechanical loading. The strengthened back muscles are able to control and counterbalance the trunk's weight and inertial force during impact loading.

REFERENCES:

Battié, M.C., Videman, T., Gibbons, L.E. Fisher, L.D., Manninen, H., Gill, K. (1995) Determinants of lumbar disc degeneration: A study relating lifetime exposures and magnetic resonance imaging findings in identical twins. Spine 20, 2601-2612.
Goldstein, J.D., Berger, P.E., Windler, G.E., Jackson, D.W. (1991) Spine injuries in gymnasts and swimmers. An epidemiological investigation. Amer. J. of Sports Med., 19 (5), 463-468.
Hellström, M., Jacobbson, B., Swärd, L., Peterson, L.(1990) Radiologic abnormalities of the thoraco-lumbar spine in athletes. Acta Radiol. 31, 127-132.
Kujala, U. M., Salminen, J. J., Taimela, S., Oksanen A., Jaakkola L. (1992) Subject characteristics and low back pain in young athletes and nonathletes. Med. Sci. Sports Exercise 24, 627-632.
Micheli, L.J. (1985) Back injuries in gymnastics. Clin. In Sports Med, 4 (1), 85-93.
Pettrone, F.A., Ricciardelli, E. (1987) Gymnastic injuries: The Virginia experience 1982-1983. Amer. J. of Sports Med., 15, 59-62.
Sward, L., Hellström, M., Jacobsson, B., Peterson, L. (1989b) Spondylolysis and the sacro-horizontal angle in athletes. Acta Radiologica 30; 359-364.
Sward, L., Hellström, M., Jacobsson, B., Nyman, R., Peterson, L., (1990) Acute injury of the vertebral ring apophysis and intervertebral disc in adolescent gymnasts. Spine 15: 144-148
Sward, L., Hellstrom, M., Jacobsson, B., Peterson, L. (1990a) Back pain and radiologic changes in the thoraco-lumbar spine of athletes. Spine 15(2), 124-129.
Sward, L. (1992) The thoracolumbar spine in young elite athletes: Current concepts on the effects of physical training. Sports Medicine 13(5), 357-364.
Sward, L., Hellström, M., Jacobsson, B., Karlsson, L. (1993) Vertebral ring apophysis injury in athletes: Is the etiology different in the thoracic and lumbar spine ? The American Journal of Sports Medicine 21(6), 841-845.
Tertti, M., Paajanen, H., Kujala U.M., Alanen, A., Salmi, T. et al. (1990) Disc degeneration in young gymnasts. Am. J. Sports Med. 18, 206-208 .
Tsai, L., Wredemark, T. (1993) Spinal posture, sgittal morbility, and subjective rating of back problems in former elite gymnasts. Spine 18, 872-875.