GAIT BIOMECHANICS AND TIBIAL STRESS FRACTURE IN RUNNERS

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Many risk factors for tibial stress fracture in runners have been proposed. This presentation will focus on biomechanical differences which remain when factors such as age, height, weight, sex, footstrike pattern and running mileage were matched in runners with previous tibial stress fracture and healthy control runners without a history of bony injuries. Differences found in running biomechanics included both loading-related and kinematic variables.

KEY WORDS: tibial shock, females, injury, kinematics, ground reaction forces,.

INTRODUCTION: Stress fractures are a common injury in athletes in general, and runners in particular. Stress fractures are a chronic, or overuse, injury resulting from fatigue damage to the bone. They occur when the damage accumulated due to the repeated application of physiological loads exceeds the capacity of the bony tissue to repair itself. The incidence of stress fractures in athletic populations is up to 50% (Brukner et al., 1996). Tibial stress fractures in particular are very common in recreational and competitive runners and military recruits. The tibia is the most common site of stress fracture in distance runners, accounting over 40% of all stress fractures (Brukner et al., 1996). The typical recovery time from a stress fracture is between 6 and 12 weeks. This includes periods of rest and reduced activity, to allow the natural reparative process of bone to take place at a rate exceeding that of damage accumulation. Reduced training capacity for a period of two to three months is a significant amount of time for both runners and military recruits. Therefore, identification of injury mechanisms and the prevention of stress fractures in runners is an important area of study.

RISK FACTORS: Many risk factors for stress fracture have been proposed. Some of these factors are intrinsic to the individual athlete; some are extrinsic and related to environmental factors. Many risk factors can be modified, whereas others can only be accommodated. Proposed extrinsic factors include those related to training, including the volume per session and per week, intensity level, running surface, and recent changes in the program (Bennell & Brukner, 2005). These factors can be modified, although other considerations such as competition scheduling or basic training requirements may influence this. Proposed intrinsic factors include anatomical structure of the lower extremity, muscle strength, flexibility, menstrual status, bone density, diet and nutrition, and running biomechanics (Bennell & Brukner, 2005). In order to investigate contributions to stress fracture risk from biomechanical factors, other risk factors should be standardized as much as possible between comparison groups.

GAIT BIOMECHANICS: A series of investigations into the biomechanics of running in relation to tibial stress fracture have been conducted. The aim of these studies was to determine objectively whether running biomechanics are different in those who have sustained a tibial stress fracture compared to those with no previous lower extremity bony injuries. This may enable identification of those at increased biomechanical risk of tibial stress fracture and of potential strategies to reduce their risk by modification of these factors. In cross-sectional studies the influence of potential confounding factors can be reduced by matching characteristics of the participants across comparison groups. Factors including age, height, weight, sex, footstrike pattern, and monthly running mileage can be matched to reduce the variability between groups due to these potentially confounding factors.

Given that tibial stress fracture is an overuse injury due to fatigue of bone tissue, early work in this area focused on loading characteristics of gait, primarily ground reaction forces.

Studies focusing on peak ground reaction forces were inconclusive, with some indicating greater peak values after tibial stress fracture compared to controls (Grimston et al., 1991) and others finding no difference (Crossley et al., 1999; Bennell et al., 2004). However, greater loading rates were found in runners with a previous tibial stress fracture compared to matched control runners (average vertical loading rate 79.0BW/s vs. 66.3BW/s, $P = 0.041$; instantaneous loading rate 92.6BW/s vs. 79.6BW/s, $P = 0.036$; Milner et al., 2006a). Additionally, a more direct measurement of tibial loading, tibial shock (peak acceleration) measured using an accelerometer, also supported the hypothesis of increased loading of the tibia in those susceptible to tibial stress fracture compared to controls (7.7g vs. 5.8g, $P = 0.014$). However, further analysis indicated that tibial shock explained only 17% of the variance between tibial stress fracture and control groups. This finding supported the hypothesis that the risk of tibial stress fracture is multifactoral, and that other biomechanical factors are likely involved.

FREE MOMENT: During running, the tibia is exposed simultaneously to a combination of shearing, bending and torsional loads, in addition to compression (Ekenman et al., 1998). While vertical ground reaction forces and tibial shock may provide an indication of the compressive load applied to the tibia, they do not indicate torque about the vertical axis. The free moment of ground reaction force indicates this torque at the point of contact of the runner with the ground (Milner et al., 2006b). Thus, it may provide an indirect measure of the torque acting on the tibia. Comparison of the magnitude of peak free moment during the stance phase of running between those with previous tibial stress fracture and matched controls indicated greater values in the stress fracture group (9.3×10^{-3} vs. 5.9×10^{-3}Nm/BW*ht, $P < 0.001$). Further analysis suggested that this variable explained 27% of the variance between the two groups. It's important to note that the majority of runners exhibit an adduction bias in the direction of free moment during the stance phase of running (i.e. resisting toe out torque of the foot on the ground). This torque has been associated with pronation (eversion) in the literature (Holden and Cavanagh, 1991). These loading-related variables that exhibit differences during running between runners with a previous tibial stress fracture and matched controls occur in the earlier part of stance phase. During early stance, body weight is shifted rapidly onto the stance limb. Therefore, studying lower extremity biomechanics during this period of rapidly increasing loading may be critical in understanding differences between runners susceptible to tibial stress fracture and healthy controls.

INITIAL LOADING: Higher vertical ground reaction force loading rates and higher tibial shock have been found in runners with previous tibial stress fracture compared to matched controls. The effect of external loading on the body can be modulated by body's the response to it. A good example is jumping off a wall onto the ground: landing in a stiff posture with knees maintained in extension results in higher loads transmitted through the body than landing with a large range of flexion motion at the lower extremity joints. In this respect, the knee is often considered to be of primary importance as a damper during landing. During running, each stance phase can be considered a single-legged landing, since the runner moves from a flight phase to single limb support. Thus, the initial loading part of the stance phase, from foot contact to the impact peak of vertical ground reaction force, may be important in terms of factors relating to tibial stress fracture. Vertical loading rate, which is calculated over the initial loading period, is greater in runners with a previous tibial stress fracture compared to controls (Milner et al., 2006a). Therefore, the body's response, in particular at the knee, to the high rate of loading during early stance may be an important consideration in injury risk. Knee joint stiffness was indeed found to be greater in runners with previous tibial stress fracture compared to controls (0.044Nm/(mass*ht) vs. 0.030 Nm/(mass*ht), $P = 0.015$; Milner et al., 2007). It was also positively correlated with tibial shock. However, there was only a moderate relationship in the stress fracture group between knee stiffness and tibial shock ($r = 0.406$). In the control group, the relationship was weak ($r = 0.161$). Thus, the body's response to loading during the early part of stance phase may also be important in understanding the complex relationship between loading and the occurrence of tibial stress fracture.

PROXIMAL AND DISTAL FACTORS: While several studies have focused on ground reaction forces and tibial shock measures in relation to tibial stress fracture, it should be remembered that the lower extremity is a linked chain with several joints and segments. The position of each lower extremity joint is important in determining the position of each segment. While static alignment factors in general have not shown strong association with tibial stress fracture, there is some evidence that extremes of foot type (very high or very low arches) may increase the risk of tibial stress injuries (Barnes et al., 2008). It has been suggested that dynamic alignment during the stance phase of running may be important in relation to stress fracture (Bennell & Brukner, 2005). Abnormal joint kinematics within the lower extremity chain may contribute to abnormal distribution of musculoskeletal loads, including within the tibia. Both proximal and distal joint kinematics may contribute to the combination of factors predisposing some runners to tibial stress fracture, even in the presence of normal loads. Altered frontal and transverse plane joint positions may change the axial, bending and torsional loads in the tibia. Several important differences were found in a comparison of frontal and transverse plane kinematics at the hip, knee, and ankle in female runners (Milner et al., in review). In particular, peak rearfoot eversion (11.7° vs. 9.0°, $P = 0.015$) and peak hip adduction (11.6° vs. 8.1°, $P = 0.004$) were both several degrees greater in runners with previous tibial stress fracture compared to controls with no previous bony injuries.This ties in with other work that found peak hip adduction, peak rearfoot eversion and the absolute free moment were the most important predictors of previous tibial stress fracture in distance runners (Pohl et al., 2008). Currently, it cannot be determined whether the differences in the frontal plane at the hip are a proximal compensation for the distal differences in the frontal plane at the rearfoot or vice versa.

DISCUSSION: While many factors, both internal and external to the runner, likely play a role in the development of tibial stress fractures, several biomechanical variables have been associated with this injury. It should be noted that the studies reported were retrospective and cross-sectional in design. Therefore, it cannot be determined whether the biomechanics of runners with a previous stress fracture measured after recovery from the injury are the same as prior to the stress fracture. While this is a limitation in relation to predisposing factors for tibial stress fracture, a large proportion of runners suffer multiple stress fractures after the initial occurrence. Thus, the information obtained in these studies is directly applicable to the case of recurring stress fractures. Future prospective studies may be able to confirm whether the high risk biomechanical features of running were also present in runners with tibial stress fracture prior to their injury. Primarily, several loading-related variables and joint angles have been identified and found to be greater in runners with a previous tibial stress fracture compared to runners with no previous bony injury. In terms of loading, the literature is somewhat inconclusive with regard to ground reaction force variables. While it seems intuitive that bony injury and fatigue fracture (i.e. stress fracture) are associated with damaging loads that exceed the body's ability to repair itself, tibial loading is only indirectly linked to ground reaction force variables. However, it appears that vertical loading rates (Milner et al., 2006a) and the absolute free moment (Milner et al., 2006b) may be increased in runners with previous tibial stress fracture. These variables may be providing an indication of the magnitude of compression and torsional loads that the tibia is subjected to during the stance phase of running. Given the lower magnitudes of these variables in healthy runners compared to those with a previous stress fracture, these aspects of running biomechanics may be modifiable. Decreasing their magnitude may decrease the risk of injury in susceptible runners. Similarly, the kinematic differences observed and abnormal peak angles reported at the hip and rearfoot in runners with previous tibial stress fracture (Milner et al., in review) may also be modifiable. Although a detailed consideration of interventions to modify running biomechanics is beyond the scope of this paper, several options may be considered. These may be mechanical or functional interventions. Potential mechanical interventions include orthotics or specialized footwear, or changing the running surface. Possible functional interventions include various types of instruction to retrain gait.

CONCLUSION: While acknowledging the limitations of retrospective cross-sectional studies, several biomechanical variables have been identified as having greater magnitude during running in those with previous tibial stress fracture compared to controls. Loading-related variables include vertical ground reaction force loading rates, the magnitude of peak free moment, and peak tibial shock. Kinematic variables include peak knee flexion stiffness during initial loading, peak rearfoot eversion and peak hip adduction.

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