INFLUENCE OF TURN RADIUS OF RUNNING ON TORSIONAL LOADING OF THE TIBIA

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The purpose of this study was to investigate influence of turn radius of running on the torsional loading of the tibia. Six male subjects ran on a straightway and anti-clockwise corners with different turn radiuses (R=15m and 5m). Data were collected using two high-speed cameras and force platforms. The torsional stresses acting on the inner tibias of runners were compared among each running condition. At beginning, net torsional moments at both ends of the lower leg were calculated. Then, the tibial torsional stresses were estimated, based on equilibrium of those moments. Much larger torsional stress acted on the tibia in later portion of the stance phase of sharper cornering compared to other two running conditions. Mean value of the maximum stress in sharper cornering was also significantly larger ($p<0.05$). These results suggested that the more sharply runners turned the larger torsional loading acted on the inner tibia of runners.

KEY WORDS: tibia, torsional loading, running, turn radius

INTRODUCTION: It has been reported that stress fractures frequently occur within the tibias of long-distance runners. Because repetitive overloading in a certain area of the tibia can cause stress fractures, it is valuable to quantify the tibial loading during running. Carter (1977) calculated the stresses on the tibia during jogging at 2.2m/s, based on the data of the actual strains of the tibia (Lanyon et al., 1975). On the other hand, the tibial stresses in running on a straight way were also estimated non-invasively (Bogert & Nigg, 1991). However to date, the tibial loadings during any cornering have not been investigated. Then, the purpose of this study was to investigate influence of turn radius of running on the torsional loading of the tibia.

METHODS: Six male subjects were asked to run on three types of running tracks at the same velocity, 3.5m/s. The first type of trials was executed on a straightway (straight running); the second and the third types were on anti-clockwise corners with different turn radiuses (R=15m: gentle cornering and R=5m: sharper cornering). Subjects repeated five trials on each running condition.

GRF data were acquired with two force platforms. Then the data were A-D converted and recorded by personal computer at 100Hz. The motions were recorded with two high-speed cameras at 250Hz and digitized.

The loading of the inner tibia of runner was investigated. The subject's left foot and lower leg were modeled as coupled systems of rigid body. In order to describe three-dimensional motions of the segments, Euler angles (θ, ϕ, ψ) were applied.

For estimating the torsional stresses acting on the tibia, net joint moments at both ends of the lower leg ($\boldsymbol{M^a}$ and $\boldsymbol{M^k}$) were calculated using inverse dynamics. In order to calculate the moments about the longitudinal axis of the lower leg (M^a_ζ and M^k_ζ), the direction cosine of the longitudinal (ζ) axis of the lower leg was multiplied to reaction moment of $\boldsymbol{M^a}$ and $\boldsymbol{M^k}$ (Eq.3).

$$M^a_\zeta = -\sin\theta\cos\phi\, M^a_x - \sin\theta\sin\phi\, M^a_y - \cos\theta\, M^a_z \qquad \text{Eq. 3 (a)}$$

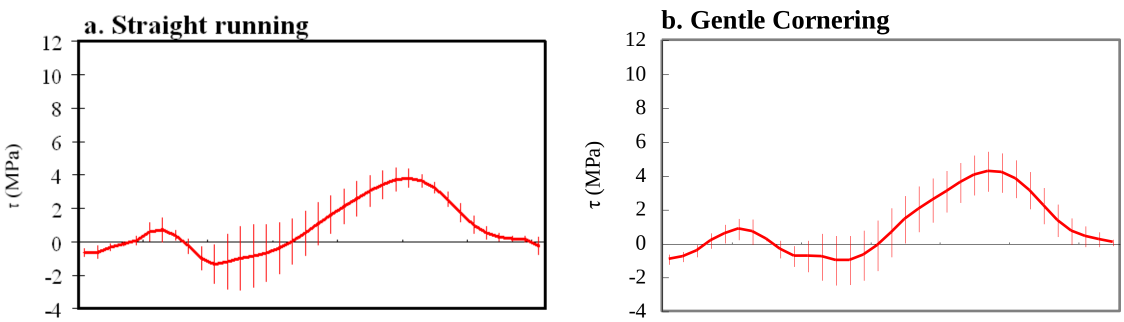
$$M^k_\zeta = \sin\theta\cos\phi\, M^k_x + \sin\theta\sin\phi\, M^k_y + \cos\theta\, M^k_z \qquad \text{Eq. 3 (b)}$$

Those moments were almost kept in equilibrium each other. Then, one of those moments, M^k_ζ was defined as the torsional moment acting on the lower leg (M^{tor}).

The maximum torsional stress at the point of the narrowest tibial width was estimated, based on the assumption that M^{tor} acts only on the tibia. In addition, the cross-sectional geometry of the interested point of the tibia was assumed to be a hollow circle, whose inner and outer diameter was 15mm and 25mm, respectively (Milgrom et al, 1989). Paired Student's T-test was used for statistical analysis.

RESULTS: Typical mean curves and standard deviations of the tibial torsional stresses in three types of running are shown in Figure.1. With respect to sharper cornering, much larger torsional stress acted on the tibia in the later portion of the stance phase, compared to the other two running conditions.

Mean values and standard deviations of the maximum torsional stresses are shown in Table 1. Those values were 3.5 MPa and 4.2 MPa in straight running and gentle cornering, respectively. Mean value of the maximum torsional stress in sharper cornering was 10.1MPa. This value was significantly ($p<0.05$) larger than mean values in other two running conditions.



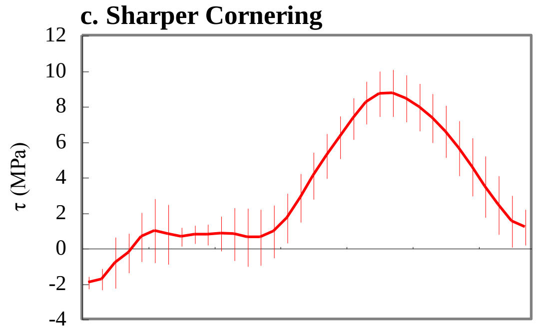


Figure 1 - Tibial torsional stress during three types of running: (a) straight running, (b) gentle cornering and (c) sharper cornering.

Table 1 The Maximum Torsional Stresses in Running on a Straightway and on Corners with Different Turn Radiuses

	Sub. 1	Sub. 2	Sub. 3	Sub. 4	Sub. 5	Sub. 6	Average	S.D.
Straight Running	7.3	3.7	-2.1	6.8	3.0	2.8	3.6	3.4
Gentle Cornering (R = 15m)	8.2	4.0	-1.4	8.0	4.5	2.3	4.2	3.6
Sharper Cornering (R = 5m)	8.1	8.6	13.8	11.0	13.4	5.8	10.1	3.2

Significance brackets: Straight Running vs. Sharper Cornering *; Gentle Cornering vs. Sharper Cornering *

*: $p<0.05$

DISCUSSION: Three types of loadings act along the tibia during running, namely the longitudinal, transverse and torsional stresses. In this study, the tibial torsional stresses were investigated, because the torsional loading is considered a serious factor leading to tibial fractures. This torsional loading is probably exacerbated by foot overpronation in the stance phase of cornering, that is torsional loading of the left tibia, the inner leg in anti-clockwise cornering.

In order to estimate the torsional stresses of the tibia, net longitudinal rotational moments at both ends of the lower leg were calculated. Those moments seemed to depend on joint structures (e.g. ligaments and joint surfaces), because there were no large muscle groups, which contributed to the longitudinal rotation of the tibia. Therefore, it was valid to apply the link-segment models for estimating the longitudinal rotational moments on the tibia rather than a particular musculoskeletal model.

Net longitudinal rotational moments at both ends of the lower leg (i.e. M^a_ζ and M^k_ζ) were almost kept in equilibrium with each other. This equilibrium seemed to depend on the following two reasons: Firstly, the narrow range of rotational motion of the lower leg and second, negligible moment of inertia about the longitudinal axis of the lower leg. Consequently, it was valid to estimate the tibial torsional loading in running likewise static.

Mean value of the maximum torsional stress in straight running was 3.5MPa. This value was relatively larger than the stress calculated from in vivo strain gauge measurements on the tibia (Carter, 1978). This discrepancy could be due to several reasons. First, running velocity (3.5m/s) in this study was faster than that (2.2m/s) in Carter's study. Second, moments at both ends of the lower leg segment were assumed to act only on the tibia. Finally, the cross-sectional geometry of the tibia was assumed to be a simplified hollow circle, based on previous study (Milgrom et.al, 1989). The torsional stresses might be overestimated due to these two assumptions. Still, the stresses estimated in this study seemed valid, taken into account that the stress was reported to be 3MPa in both walking (Carter, 1978) and running (Bogert & Nigg, 1991).

Although the tibial torsional stress in the stance phase of gentle cornering was a little larger than that in straight running, (Figure1a and 1b), mean values of those maximum stresses were not significantly different each other (Table 1). These results suggested that when runners turned gently (corresponding to R=15m), the tibial torsional loading was not largely influenced. On the other hand, large torsional stress acted on the tibia in the later portion of the stance phase of sharper cornering (Figure1c). In addition, mean value of the maximum stress in sharper cornering was significantly larger ($p<0.05$), compared to other running conditions (Table1). These results suggested that the more sharply (corresponding to R=5m) runners turned, the larger torsional loading acted on the inner tibia.

CONCLUSION: The torsional loading of the inner tibia was compared in running on a straightway and corners with different turn radiuses. The results suggested that the more sharply runners turned, the larger torsional loading acted on the inner tibia of runners. This work provides significant information for persons concerned with tibial stress fractures in athletes.

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