BENEFICIAL KINETIC ADAPTATIONS AFTER ENDURANCE TRAINING

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Endurance training produces adaptations in running kinetics, although it does not produce changes in kinematics. We performed a prospective study of 23 runners who joined established marathon training teams. Each was tested in their first month of training and again two weeks prior to their marathon. The approximate time between tests was three months. Four peak ground reaction forces were reduced significantly after the training: lateral (15.4%), acceleration (7.10%), vertical (2.1%) and the normalized resultant (2.1%). Kinetic variables associated with iliotibial band injuries and anterior knee pain also had significant reductions. Peak hip adduction moments were reduced by 6.0%, peak patellofemoral contact force was reduced by 7.6%.

KEY WORDS: running adaptation, endurance training, iliotibial band, patellofemoral contact force

INTRODUCTION: Very few biomechanical studies have been done on kinematic and kinetic adaptations by uninjured athletes. Normally the benefits from endurance training are considered in physiological terms. Changes in resting heart rate, VO_2max and other physiologic variables have become established tests for validation of one's training. Improving performance on these tests correlates with improved competitive results.
Although studies have not been done to show that kinetic variables also change, we feel that these values can also favorably improve.
Quite often biomechanical research is concerned with mechanisms associated with established injuries. Some research has related kinetics to the risk of injury. Peak hip adduction moments correlate with the risk for injuries involving the iliotibial band (ITB), while peak patellofemoral (PF) contact forces are associated with risk of anterior knee pain (Scott & Winter, 1990).
From previous work, the peak hip adduction moment was 33% higher during running for those who did not suffer that injury (MacMahon, et al., 2000). In walking, *in vivo* forces in the ITB have been measured as high as 700N (Huggler & Jacob, 1983). Using a generalized anatomical model, this generates a normalized adduction moment of 8(%BWHT).

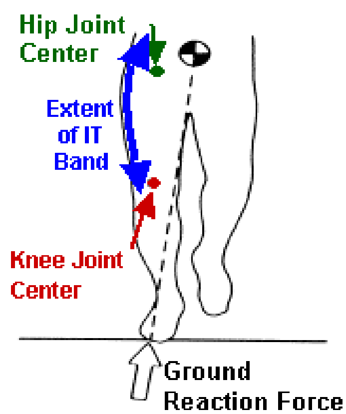

Figure 1 - Illustration of the mechanism that produces adduction moments during running. The ground reaction force vector acts medially to the joint centers, creating moments that adduct the thigh and shank. The IT band along with the hip abductors counteracts these adduction moments. (Adapted from Andriacchi & Mikosz, 1997)

This study searched for adaptations that may result in reducing the risk of injury. Specifically we tested whether or not runners going through endurance training adapt their kinetics to achieve a beneficial reduction in loading.

METHODS: Twenty-four volunteers from two organized marathon training seasons participated in the study. All subjects met the following criteria.

Table I Inclusion Criteria for the Study

Question	Criteria
Experience	No more than 3 marathons completed
Weekly Mileage	less than 20 miles/week prior to joining the team
Lower limb injury / surgery	No major injuries or surgeries to either lower limb

All subjects were tested before the end of the second month of training and less than two weeks before they ran their marathon. The protocol consisted of a one-mile warm-up jog, followed by walking and running trials. Gait tests were performed using a previously described six-marker retro-reflective system developed by CFTC using 120Hz Qualisys cameras and a Bertec force plate (Andriacchi & Mikosz., 1997). The kinematics and joint kinetics were calculated for the hip, knee and ankle.

Since injuries are not bilateral in nature each leg was included in the study. For each leg of each subject a pre-training running trial, and a speed-matched post-training trial, (2.69m/s to 2.65m/s, P>0.05) were chosen for comparison. For all of the statistical analyses two-tailed pair-wise t-tests were used.

Three kinetic measures associated with injuries were analyzed, peak hip adduction moment, peak patellofemoral contact force and peak ground reaction forces.

To estimate the PF contact force, a model similar to that described by Scott & Winter (1990) was used (Fig. 2). Using anatomical cadaver data from the literature we estimated origins and insertions of the various muscles and tendons (White et al., 1989), as well as the orientation of the patellar tendon and the ratio of quadriceps force to patellar tendon force (van Eijden, 1985). The inputs to the model were the external knee flexion moment, knee flexion angle, ankle flexion angle, and external ankle flexion moment.

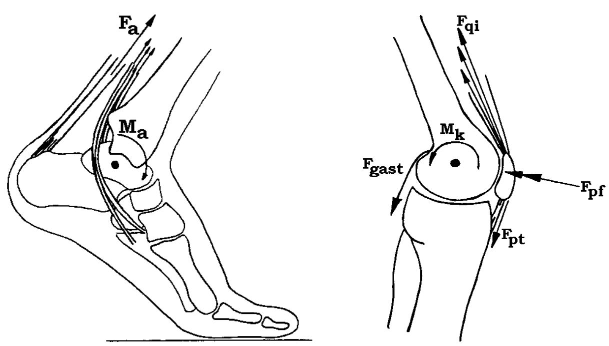

Figure 2 - Model of foot/ankle complex and knee used to calculate patellofemoral force (Scott & Winter, 1990).

Because all of the loading on the body initiates from the ground, the peaks in ground reaction force were also examined for sings of adaptation.

RESULTS: We present the results from the ground up. Four of six of the peaks in ground reaction force, normalized to bodyweight, were significantly reduced at the end of the training. The peak lateral force had the largest percentage reduction (15%). The peak normalized F_Z and peak normalized resultant force both had the largest absolute reduction of 4.7(%BW).

Table 2 Changes in Peak Ground Reaction Forces due to Training

Peak Normalized Force (%BW)	LATERAL *	MEDIAL	BRAKE	ACCEL. **	Fz MAX *	NFRMAX *
Start of Season	5.9	8.8	24.8	26.3	220.7	221.1
End of Season	5.0	8.2	24.9	24.4	216.0	216.4
% Change	-15.4	-6.9	0.4	-7.1	-2.1	-2.1

* P<0.05 **P<0.001

This reduction was achieved without associated changes in the overall kinematics of the subjects. The range of sagittal plane motion of all joints remained unchanged through the training season (Table 3).

Table 3 Changes in Peak Ground Reaction Forces due to Training

Joint Ranges of Motion (°)	ANKLE	KNEE	HIP
Start of Season	32.4	6.0	46.5
End of Season	30.9	5.5	45.7
% Change	-4.7	-7.6	-1.9

No changes were significant.

The peak normalized patellofemoral force during running decreased significantly between pre- and post- training trials (Table 4). At the beginning of training this population's average PF force was 5.95 BW and after training it was 5.30 BW. This change equates to a 10.9% decrease in PF.

Table 4 Peak Normalized Patellofemoral Forces During Running at the Start and End of the Season

Normalized Contact Force (BW)	PEAK PATELLOFEMORAL *
Start of Season	5.95
End of Season	5.30
% Change	-10.9%

* P<0.05

The peak normalized hip adduction moment was significantly reduced after training, from 6.8(%BWHT) to 6.4(%BWHT) (Table 5).

Table 5 Changes in Peak Normalized External Hip Adduction Moment due to Training

Peak Normalized Force (%BWHT)	PEAK ADDUCTION MOMENT *
Start of Season	6.8
End of Season	6.4
% Change	-6.0%

* P<0.05

DISCUSSION: Runners in endurance training adapt their biomechanics in a manner that reduces the risk of injury. High ground reaction forces, contact forces and moments are all favorably reduced due to training. These findings are consistent with the observation that training can reduce the frequency of knee stiffness and pain (Satterthwaite et al., 1999). The adaptations were not affected by direct coaching of running style. The coaching staff did advise the runners to stretch before and after runs and they also recommended the runners do some strength workouts on their own once a week.

We theorize that a combination of the factors plays a role in producing these favorable results:

1. Proprioceptive feedback
2. Physical conditioning
3. neural responses, below the pain threshold

There is now a research opportunity to test these factors individually to ascertain their individual levels of contribution in reducing loading. Specific training may be designed to accelerate these favorable biomechanical adaptations. Although, through the course of training the subjects almost certainly had increases in their muscular and cardiovascular endurance, these variables alone would not produce the present results.

CONCLUSION: This study suggests neuromuscular adaptations take place during training that produce favorable reductions in loading for the distance runner.

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