Flexibility as risk factor for stress-fracture development in South African male soldiers

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Background: Stress fractures are a common military training injury. Flexibility of muscles and joints may directly influence stress-fracture risk by way of altering the forces applied to bone. Hip external rotation and ankle plantar- and dorsiflexion have been inconsistently reported to pose a risk to stress fracture development in military soldiers. Thus this study aimed to present results that could help define the risk flexibility may pose in the development of stress fractures amongst military male soldiers.
Methods: An experimental one-group pretest–posttest study design assessing the injury incidence, bilateral hip external rotation, ankle plantar- and dorsiflexion of South African male military soldiers ($n = 100$) undergoing 12 weeks of basic military training (BMT) was undertaken. The parametric *t*-test for dependent samples ($\alpha = 0.05$) and effect size (ES) was used to analyse the data.
Results: No stress fractures were diagnosed in the 100 operational military training injuries reported. BMT resulted in significant mean decreases of 10% (L) and 17% (R) in hip external rotation and 18% (L) and 14% (R) in ankle plantar flexion respectively, whilst a significant increase of 37% (L) and 39% (R) dorsiflexion was observed.
Conclusions: Although normal ankle and limited hip external flexibility do not appear to predispose these male soldiers to stress fracture development these variables should not be excluded as possible intrinsic risk factors.

Keywords: ankle dorsiflexion, basic military training, flexibility, hip external rotation, risk factor, stress fracture

Introduction

Flexibility is defined as 'the ability to move a joint through its complete range of motion'.[1] Flexibility of muscles and joints may directly influence stress-fracture risk by way of altering the forces applied to bone. Stress fractures are a common military training injury, with the first reported case being identified by Breithaupt in 1855[2,3] and the incidence of sustained stress fractures in military soldiers reported to be as high as 31%.[4] Both intrinsic and extrinsic risk factors for the development of stress fractures have been investigated, predominantly in European and American soldiers.[2,5–11] Numerous flexibility variables have been assessed as potential risk factors for the development of stress fractures in male soldiers. These have included a range of rear-foot inversion–eversion, ankle plantarflexion–dorsiflexion, knee extension–flexion and hip rotation–extension, together with length of calf muscles, hamstring muscles, quadriceps muscles, hip adductor muscles and hip flexor muscles.[2,5–9,12] From the numerous flexibility variables that have been assessed to determine the association between flexibility and stress fractures only range of hip external rotation[7,9] and of ankle dorsiflexion[12] have been associated, albeit inconsistently, with stress-fracture development. Soldiers with external rotation of the hip > 65° and/or < 10° ankle-joint dorsiflexion have been related to an increased risk of leg stress fractures.[5,7,10,13] This study aimed to present results that could help define the risk flexibility may pose in the development of stress fractures amongst military male soldiers.

Methods and materials
Participants and study design

Ethical approval was obtained from both the South African National Defence Force (SANDF) ethics committee and the research ethics committee of the University of Pretoria to conduct the study. Both committees' ethical guidelines were followed throughout the study. The sample of convenience of

100 male participants (age 20.8 ± 1.14 years; body mass 59.5 ± 8.79 kg; stature 159.57 ± 5.53 cm; mean ± SD) were volunteers from the South African Health and Medical Service intake starting basic military training (BMT). The participants' characteristics are outlined in Table 1.

Of the cohort studied 99% were black whilst one participant was Caucasian. The fact that most of the participants were black Africans is important to note, as Caucasians appear to be at greater risk of developing stress fractures in both athletic and military cohorts than are other race groups.[14–19] An experimental one-group pretest–posttest study design was used.[20] No control group could be used, as all military soldiers who wish to be retained in military service need to successfully complete BMT, including the physical training (PT) component, in the allocated 12-week period. Failure to do so results in dismissal. After attending an information session during which the aim and study methodology were explained, participants were asked to read and sign an informed consent form. All participants had passed a medical entry examination carried out by a medical officer to ensure that they were free of any disorder that would contraindicate their attendance of BMT. A cycle menu, as prescribed by the SANDF,[21] was followed by all participants during BMT, as three meals per day were provided to all soldiers for the BMT period.

Measurements

The range of motion (ROM) was assessed bilaterally for the hip and ankle joints, by the same practitioner, using a goniometer at the start and end of the 12-week BMT course. The hip external rotation was measured with participants in a sitting position.[22] The goniometer was centred over the anterior part of the patella with the fixed arm positioned perpendicular to the floor and the moving arm placed over the anterior midline of the lower leg, using the crest of the tibia and a point midway between the

Table 1: Participants characteristics in weeks 1 and 12

	Pretest (mean ± SD)	Posttest (mean ± SD)	Mean difference	95% CI of the difference	Effect size Cohen's D	*p*-value*
Age (yrs)	20.30 ± 1.21	20.62 ± 1.21	−0.32		−0.26	
Mass (kg)	61.78 ± 6.89	63.18 ± 6.61	−1.40	−2.36	−0.21	0.005
Height (m)	171.36 ± 5.86	171.36 ± 5.86	0.07	−0.04	0.01	0.195
BMI†	21.43 ± 2.16	22.42 ± 2.47	−1.00	−1.66	−0.43	0.003

*p-value compares the pretest and posttest in dependent sample *t*-test.
†BMI: body mass index.

malleoli for reference. The participant sat with knees flexed at 90˚, with a rolled towel placed under the femur. The measurement was taken as the amount of rotation, in degrees, completed in external hip rotation with the distal end of the femur acting as the stabiliser. Participants were instructed not to rotate and laterally tilt the pelvis when executing the movement.[23] Ankle ROM was measured with the participant in a sitting position. The goniometer was positioned over the most prominent aspect of the lateral malleolus with the stationary arm being the midline of the fibula, using the head of the fibula as reference. The moving arm was placed parallel to the lateral aspect of the fifth metatarsal, with the tibia and fibula providing the stabilisation. The participant sat on the end of the table with knees flexed and ankles positioned at 90˚. The measurement was taken as the amount of rotation, in degrees, completed in dorsiflexion and in plantar flexion.[23]

Injury incidence

Injury incidence was monitored by the medical officer assigned to the military unit's sickbay for the duration of the training. A stress fracture was defined as 'partial or complete fractures of bone that result from the repeated application of a stress less than that required to fracture bone in a single loading situation'.[24] A stress

Table 2: Time dedicated to each cardiovascular physical training (PT) programme component during the 12-week basic training (BT) course

Cardiovascular PT programme component	Time (minutes) allocated in 12-week BT period
Warm-up	322
Jogging	950
Interval training	213

fracture diagnosis was made when the Maquirriain and Ghisi[25] diagnostic criteria had been met, which included no history of related trauma; pain associated with exercise and relieved by rest;

localised bony tenderness, pain on bone loading or on pain-eliciting manoeuvres; and finally radiographic and magnetic resonance imaging (MRI) confirmation of diagnosis. All soldiers with suspected diagnosis of a stress fracture were evaluated with conventional radiographs and MRI. Stress fracture incidence was confirmed only if all four diagnostic criteria were met.

Basic military training

The participants followed a standardised BMT programme aimed at ensuring a combat-ready soldier at the end of the 12-week period. Standard military activities included drill, compliments and saluting, regimental aspects of procedures, general military aspects of conduct, mine awareness, musketry, shooting, map reading, signal training, field craft, water orientation, buddy aid, parade rehearsal and PT. The BT programme is difficult to quantify as it was made up of a variety of activities; however, the same standardised programme was followed by all the study participants. The cohort acted as its own control. A total of 48 periods of PT, each 40 min in duration, were completed by all participants in the BMT period.[26] A breakdown of time dedicated to the cardiovascular PT programme component during the 12-week BT course is provided in Table 2. The number of exercises completed for each muscle endurance physical training (PT) programme component is outlined in Table 3. Consistency and uniformity in the method of instruction was achieved by providing each PT instructor with the same detailed cyclic-progressive PT programme, together with a PT manual. The PT manual clearly explained all the exercises used in the PT programme.[26] A sample PT programme for the third day of training is outlined in Table 4. The design of the PT programme accommodated the logistical limitations present in the BMT environment where large groups undergo the PT training simultaneously. The exercises had to be clear, completed within a small personal space and be easily corrected by the PT instructor. No individual training weights were available so all muscle endurance and strength exercises were designed based on resistance offered by own body weight and then progressed to the use of solid 20 kg timber wooden poles (2.1 m in length by 25 cm in diameter) for exercises completed in pairs.

Table 3: Number of exercises completed for each muscle endurance physical training (PT) programme component during 12-week basic training (BT) course

Muscle endurance PT programme component	No. of exercises completed in 12-week BT period	Resistance
Upper body muscle endurance exercises	28†	BW*
	64‡	BW* + WP**
Abdominal body muscle endurance exercises	28*	BW*
	64‡	BW* + WP**
Lower body muscle endurance exercises	28*	BW*
	64‡	BW* + WP**

Notes: *BW: body weight.
**WP: 20 kg wooden poles.
†Completed 3 sets of 10–12 repetitions of exercises performed by muscle groups in this body region in week 1 and then completed 2 sets of 10–12 repetitions from week 2 progressing to 3 sets of 10–12 repetitions in weeks 3–4 of exercises performed by muscle groups in this body region.
‡Completed all exercises with 20 kg wooden poles in pairs performed by muscle groups in this body region from week 5 to 12 starting with 2 sets of 10–12 repetitions progressing to 3 sets of 10–15 repetitions.

Table 4: Physical training programme (day 3 of week 1)

Serial no.	Exercise description	Exercise no.	No. of sets	Reps
1	Warm-up	Shoulder rolls–forward	2	12
		Shoulder rolls–backwards	2	12
		Jog gently around field	3 min	
		Standing quadriceps stretch	2	20 s
		Standing gastrocnemius stretch	2	20 s
2	Upper body exercise	Shoulder press	2	10–12
3	Leg exercise	Lunges	2	10–12
4	Upper body exercise	Wide-arm push-ups	2	10–12
5	Abdominal exercise	Crunches	2	Max.
6	Back exercise	Back extension on floor (opp. leg with opp. arm)	2	10–12
7	Leg exercise	Abduction straight leg raise	2	10–12
8	Abdominal exercise	Reverse crunches	2	Max.
9	Cardiovascular activity	Walking/ Jogging	45 s walking/15 s jogging 20 = 20 min	
10	Stretching exercise–upper body	Buddy pectoralis stretch	3	20 s
12	Stretching exercise–legs	Sitting hamstring stretch	3	20 s
13	Stretching exercise–legs	Achilles stretch	3	20 s
14	Stretching exercise–back	Lying back stretch	3	20 s

Sufficient periods of recovery from weight-bearing stress during the early weeks of following the PT programme were achieved by including a 10% weekly progression in frequency and intensity in all exercises and building up from walking to jogging.[23,27–33] All PT periods took place on grassed sport fields in military-issued trainers rather than combat boots.[34,35] 'Pole PT' exercises were introduced from the fifth week. This was a cost-effective and viable method of resistance training based on the principle of free-weight training.[23,33] Two isolated resistance exercises for each body region were performed at every PT session. Exercises were also varied so that the same exercises for a muscle group were not repeated on consecutive days and time was given for stretching at the end of each session.[23,32]

Statistical analysis

Data were analysed by means of the Statistical Product and Service Solutions package (SPSS 11.5 for Windows, SPSS Inc., Chicago, IL, USA). Descriptive statistics were calculated for all measurements. The Kolmogorov Smirnov test was used to assess normal distribution of the data. Owing to the normal distribution of the data, the parametric *t*-test for dependent samples was used to evaluate the influence of the BMT, using the conventional 5% level of significance. Effect size (ES) was calculated to assess practical significance with Cohen's[36] criteria classifying effects as small (0.2–0.3), moderate (0.31–0.5) or large (> 0.5). The precision of these estimates was indicated by 95% confidence limits.

Results

The participants' characteristics at the start and end of the BMT period are outlined in Table 1. Significant differences in body mass and BMI were observed. Table 5 outlines the absolute mean differences in flexibility measures that were observed. The cohort had an initial mean hip external rotation and ankle plantar flexion of 25.57° (L)/23.40° (R) and 49.23° ± 8.35 (L)/45.67° ± 7.89 (R) respectively, whilst the initial ankle dorsiflexion was 17.14° ± 3.65 (L)/18.25° ± 4.14 (R) respectively. The *t*-tests for dependent samples showed a significant 37.4% (L)/38.5% (R) increase in dorsiflexion and a significant 17.1% (L)/10.09% (R) and 18.04% (L)/14.43% (R) decrease in hip external rotation and ankle plantar flexion respectively.

Table 5: Absolute mean difference, 95% confidence intervals (CIs) and effect size in flexibility scores (mean ± SD) of the soldiers from the 1st to the 12th week of basic military training

Flexibility measure	Limb	Measurement	Mean ± SD	Mean difference	95%CI	Effect size Cohen D	*p*-value
Hip external rotation	Left	Pre-test	25.57 ± 4.14	4.39	3.41–5.37	0.99	0.0001
		Post-test	21.18 ± 4.71				
	Right	Pre-test	23.40 ± 3.72	2.36	1.33–3.39	0.54	0.0001
		Post-test	21.04 ± 4.91*				
Ankle dorsiflexion	Left	Pre-test	17.14 ± 3.65	−7.44	−10.61–4.27	−0.65	0.0001
		Post-test	24.58 ± 15.72				
	Right	Pre-test	18.25 ± 4.14	−7.03	−10.03–4.03	−0.65	0.0001
		Post-test	25.28 ± 14.84*				
Ankle plantarflexion	Left	Pre-test	49.23 ± 8.35	8.88	5.24–12.61	0.68	0.0001
		Post-test	40.35 ± 16.38				
	Right	Pre-test	45.67 ± 7.89	6.59	3.05–10.13	0.55	0.0001
		Post-test	39.08 ± 15.15				

Table 6: Type and number of operational military training injuries reported during the 12 weeks of BMT

Type of operational training injury	Number of different types of operational training injuries (*n* = 100)
Arthropathies	50
Dorsopathies	8
Soft-tissue disorders	27
Signs and symptoms involving the neuromuscular and musculoskeletal systems	4
Injuries to the elbow and forearm	1
Injuries to the hip and thigh	1
Injuries to the knee and lower leg	3
Injuries to the ankle and foot	2
Injuries to unspecified parts of trunk, limbs or body	4

A total of 337 diagnoses were made at the clinic during BMT. Of these, 100 (29.67%) were classified as operational military training injuries. Operational injuries are represented in Table 6. Among these injuries no stress fracture incidents were reported during the 12 weeks of military training.

Discussion

Normal ankle and limited hip external flexibility does not seem to predispose male South African soldiers to develop stress fractures during BMT. This cohort's mean hip external rotation of 25.57° (L)/23.40° (R) was below the recommended 45°–50° average ROM value for healthy adults.[23] Soldiers with external rotation of the hip greater than 65° experienced an incidence of stress fracture 1.8 times higher than that of soldiers with lower degrees of rotation (95% CI 1.3, 2.5).[5,7] Milgrom et al.[37] failed to relate this measurement to stress-fracture risk. The difficulty involved in assessing the role of muscle and joint flexibility in stress fractures may be related to a number of factors, including the relatively imprecise measurement methods (limited by having the same tester perform all measurements), the heterogeneity of these variables and the fact that both increased and decreased flexibility may contribute.[2] The BMT resulted in a significantly large decrease in both left (17.17%) and right (10.09%) hip external rotation.

Hughes[13] showed that restricted ankle-joint dorsiflexion (ROM < 10°) was related to an increased risk of metatarsal stress fractures. The soldiers who had a reduced range were 4.6 times more likely to develop a metatarsal stress fracture. The average ankle dorsiflexion ROM value for healthy adults is 20°.[23] This cohort's dorsiflexion flexibility (17.14° ± 3.65 (L)/18.25° ± 4.14 (R)), although slightly lower than the norm advocated by Heyward,[23] does not appear to be a risk factor. Kaufman et al.[8] reported that their 407 male Navy SEAL trainees had a mean ankle dorsiflexion of 20.5° ± 5.5, which was higher than the dorsiflexion results measured in the male participants of this study (17.14 ± 3.65 (L)/18.25 ± 4.14(R)). Kaufman et al.[8] classified > 18.5° dorsiflexion as tight and 18.5°–23.0° dorsiflexion, with the knee bent at 90°, as a normal range. These authors did not suggest either range to be associated with a greater risk for the development of stress fractures.[8]

The methodology used to assess the ankle dorsiflexion with knee at 90° flexion meant that the gastrocnemius muscle was relaxed. DiGiovanni et al.[38] showed that isolated gastrocnemius contracture, as measured by dorsiflexion and with the knee at 0° flexion, assisted in the development of forefoot and/or midfoot

pathology in otherwise healthy people. These findings are, however, not supported by Kaufmann et al.[8] As this cohort did not have limited dorsiflexion this study cannot exclude limited ankle dorsiflexion as a possible risk factor in the development of stress fractures. BMT did, however, result in a significantly large increase in the soldiers' dorsiflexion (43.40% (L)/38.52% (R)) over the 12 weeks (Cohen's D > 0.5), possibly offering some form of protection from injury. In the South African context, further study that would entail measuring ankle dorsiflexion with the knee at 0° flexion is recommended.

The increase in dorsiflexion was counteracted by a significantly large decrease in the soldiers' plantar flexion (18.04% (L)/14.43% (R)). Although studies have reported prospective flexibility measures of toe-touching ability to have increased during BMT, there appears to be no clinical relevance.[30,31,39,40] Studies have shown that lower extremity stretching before training does not offer a protective effect from stress fractures or reactions.[40,41] Additionally, studies involving stretching have concluded that pre-exercise stretching did not reduce the incidence of muscle soreness or lower extremity injuries, including stress fractures, in young active adults involved in running and marching.[42,43]

The PT programme followed by this cohort as outlined in Tables 2–4 does not favour a higher probability of stress fractures as it appears to have allowed sufficient periods for recovery and gradual progression of exercise intensity and duration. The PT programme also allowed for stretching at the end of each session. Regardless of the reasons, the results of this study raise questions concerning the efficacy and the necessity of pre- and post-exercise stretching for the prevention of lower extremity injuries, including stress fractures.

Conclusion

The initial flexibility of this cohort did not appear to place it at risk for the development of stress fractures; however, this study cannot exclude limited hip and ankle ROM as an intrinsic risk factor in the development of stress fractures. This study supports others that have failed to find an association between hip and ankle flexibility as a risk factor for stress-fracture development.[8,37] Further studies utilising larger cohorts should be undertaken. This study highlights the need to realign the PT programme used during military training to ensure that external hip ROM and plantar flexion are at least maintained during military training, thereby possibly preventing associated injuries.

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