

## Preventive Osteopathic Manipulative Treatment and Stress Fracture Incidence Among Collegiate Cross-Country Athletes

Lynn F. Brumm, DO; Carrie Janiski, DO, MS, ATC; Jenifer L. Balawender, DO; and Adam Feinstein, DO

From the Department of Family and Community Medicine (Drs Brumm and Janiski) and the Department of Osteopathic Manipulative Medicine (Dr Feinstein) at the Michigan State University College of Osteopathic Medicine in East Lansing; the Department of Osteopathic Manipulative Medicine at the University of New England College of Osteopathic Medicine in Biddeford, Maine (Dr Janiski); and the Department of Family Medicine at Michigan State University College of Human Medicine in East Lansing (Dr Balawender). At the time of the present study, Dr Janiski was at the Department of Family and Community Medicine at the Western Michigan University School of Medicine in Kalamazoo and the Department of Family Medicine at Michigan State University College of Human Medicine in East Lansing.

Financial Disclosures:  
None reported.

Address correspondence to Carrie Janiski, DO, MS, ATC, University of New England College of Osteopathic Medicine, Department of Osteopathic Manipulative Medicine, Alford Center, 11 Hills Beach Rd, Biddeford, ME 04005-9526.

E-mail: janiskic@msu.edu

Submitted July 15, 2012;  
final revision received  
January 21, 2013; accepted  
January 28, 2013.

**Context:** Stress fractures are common among athletes, particularly distance runners, with many theories regarding the etiologic process of stress fractures and various studies identifying risk factors or suggesting preventive techniques. To our knowledge, no previous studies have discussed the possible causative effects of somatic dysfunction or the preventive capabilities of osteopathic manipulative treatment (OMT).

**Objective:** To apply a preventive OMT protocol for cross-country athletes to reduce the incidence of stress fractures.

**Design:** Cohort study.

**Methods:** Examinations of cross-country athletes at an NCAA (National Collegiate Athletic Association) Division I university were performed by supervising physician-examiners and first- and second-year osteopathic medical students during several consecutive academic years. Athletes re-enrolled in the study each year they continued to be eligible. The intervention included osteopathic structural examination and OMT that focused on somatic dysfunction identified in the pelvis, sacrum, and lower extremities.

**Results:** More than 1800 participant examinations were performed on 124 male and female participants by 3 supervising physician-examiners and 141 osteopathic medical students over the course of 5 consecutive academic years (2004-2005 to 2008-2009). Data from these academic years were compared with data from the previous 8 academic years (1996-1997 to 2003-2004). An average of 20 new participants enrolled yearly. The number of annual stress fractures per team ranged from 0 to 6 for male participants and 1 to 6 for female participants. The cumulative annual incidence of stress fractures for male participants demonstrated a statistically significant decrease from 13.9% (20 of 144) before intervention to 1.0% (1 of 105) after intervention, resulting in a 98.7% relative reduction in stress-fracture diagnosis ( $P=.019$ ). The cumulative annual incidence for female participants showed a minimal decrease from 12.9% (23 of 178) before intervention to 12.0% (17 of 142) after intervention, an 8.5% relative reduction in stress-fracture diagnosis ( $P=.671$ ). The cumulative annual incidence of all participants decreased from 13.4% (43 of 322) before intervention to 7.3% (18 of 247) after intervention, a 45% relative reduction in stress-fracture diagnosis ( $P=.156$ ).

**Conclusion:** There was a statistically significant decrease in the cumulative annual incidence of stress fractures in male, but not female, cross-country athletes after receiving OMT.

*J Am Osteopath Assoc.* 2013;113(12):882-890  
doi:10.7556/jaoa.2013.066

Stress fracture of the lower extremity is a common injury among athletes, particularly distance runners. Track-and-field sports account for up to 50% of all stress fractures in male athletes and 64% in female athletes.<sup>1</sup> Most of the literature in this area is retrospective and comes from studies of cross-country and track-and-field athletes, as well as military recruits. Studies of athletes have reported incidence of stress fracture from 3.9% to 31.3%.<sup>2-5</sup> Similarly, studies of military recruits report the incidence of stress fracture from 1% to 31%.<sup>6-8</sup>

In military studies,<sup>7-10</sup> stress fractures are more often diagnosed in women. In studies of male and female athletes, however, the data have been inconclusive. Goldberg and Pecora<sup>11</sup> and Hickey et al<sup>12</sup> reported a higher incidence of stress fractures in women compared with men, although Bennell et al<sup>13</sup> reported a similar incidence of stress fractures among male and female athletes.

The etiologic process of stress fracture is widely debated in the literature. Romani et al<sup>13</sup> categorized stress fracture as a chronic overuse injury due to accelerated bone remodeling. Giladi et al<sup>14</sup> and Milgrom et al,<sup>15</sup> however, have questioned this distinction, with diagnosis most prevalent in the first month of activity. There are many competing theories for the development of a stress fracture. In the most prominent theory in the literature, osteoblast activity lags behind osteoclast activity and leaves a bone susceptible to microfractures.<sup>16</sup> Other researchers have theorized different causes for stress fracture, including repetitive stress at the insertion point of a muscle,<sup>16</sup> an initial prolonged focal impaired perfusion of the bone seen in prolonged activity,<sup>17</sup> and smaller cross-sectional area that decreases bone strength.<sup>14,16,18</sup>

Researchers<sup>16</sup> have proposed and studied a variety of risk factors for stress fractures, including previous diagnosis of stress fracture, participation in sports involving running and jumping, rapid increase in a physical training program, poor preparticipation physical condition, running on irregular or angled surfaces, inappropriate footwear,<sup>19</sup> inadequate muscle strength, poor flexibility, and type A personality. An increased incidence of stress fracture was observed in athletes with high lon-

gitudinal arch, excessive forefoot varus, increased hip abduction, and peak rearfoot eversion compared with athletes without these biomechanical traits.<sup>20,21</sup> Edwards et al<sup>22</sup> (using a probabilistic model based on published relationships of bone damage, repair, and adaptation) and Milner et al<sup>23</sup> reported a lower incidence of stress fracture with decreased running speed and average vertical loading rate. In addition, women who developed a stress fracture had a statistically significant difference in the following categories: greater leg length difference, later age of menarche, lower fat intake, higher calcium intake, and decreased calf girth.<sup>24</sup> Other contributing factors to stress fracture development in women have been noted in the literature, including low bone mineral density, nutritional deficiencies, eating disorders, menstrual disturbances, and amenorrhea.<sup>4,16,24</sup>

One complication that arises for any investigator is that stress fracture is not consistently defined in published research. In previous studies, stress fracture was diagnosed after clinical presentation and confirmed by means of radiography or triple-phase bone scintigraphy<sup>24</sup> or by means of clinical presentation and confirmation by triple-phase bone scintigraphy and computed tomography.<sup>19</sup> Only 50% of radiographs, however, reveal a known stress fracture.<sup>16</sup> Magnetic resonance (MR) images convey stress fracture and stress reaction better than bone scans.<sup>25</sup>

Given the multifactorial nature of stress fracture and lack of agreement among authors for given risk factors, prevention of stress fracture is not effectively described in the literature. Suggestions for preventive measures have included adequate stretching during warm-up, gradual increase in exercise intensity, lightweight footwear in good condition, level running surfaces, custom orthotics to address biomechanical concerns, and shock-absorbing insoles.<sup>16</sup>

The objective of the present study was to investigate the relationship between somatic dysfunction and the incidence of stress fracture in collegiate student-athletes. Somatic dysfunction is defined as impaired or altered function of related components of the somatic system including skeletal, arthrodiagonal, and myofascial structures and

related vascular, neural, and lymphatic elements.<sup>26</sup> Specifically, we set out to assess the impact of regular, preventive osteopathic manipulative treatment (OMT) on stress fracture incidence in a group of collegiate student-athletes who had not previously engaged in regular preventive OMT. To the authors' knowledge, there are no studies to date that examine the relationship between somatic dysfunction and stress fracture incidence. We conducted the present study to apply a preventive OMT protocol for cross-country athletes, which we hypothesized would reduce the incidence of stress fractures in this population.

## Methods

### Participants

Participants were recruited from the varsity cross-country teams of an NCAA (National Collegiate Athletic Association) Division I university. All members of these teams were invited to attend an informational meeting hosted by the principal investigators at the beginning of the fall term. At this meeting, the student-athletes were given information about the study and given the option to participate voluntarily. All individuals interested in study participation signed an informed consent form approved by the institutional review board.

Inclusion criteria required that each participant be a full-time student at the university and a current member of the men's or women's cross-country team. All participants were required to be aged at least 18 years. History of previous or current stress fracture did not preclude participation in the study. Participants were excluded from the study if they were pregnant or if they began the study and subsequently failed to meet all inclusion criteria.

### Examiners

Osteopathic medical student-examiners were trained and guided by supervising osteopathic physician-examiners. In the inaugural year, the students were trained only by the primary instructor and author of study protocol (L.F.B.) and Steven Dupuis, DO; thereafter, the students were trained by Drs Brumm, Feinstein, and Dupuis, with second-year students serving as teaching assistants and mentors to the first-year students.

Osteopathic medical students from the Michigan State University College of Osteopathic Medicine participated in this study as examiners. The students were trained by experienced osteopathic physician-examiners during their first year of osteopathic medical school for examination and management of somatic dysfunction in the pelvis, sacrum, hips, and lower extremities, per the study protocol (*Table 1*). The study protocol provided a detailed written description of physical examination, assessment, diagnosis, and corresponding treatment. All examiners were taught to conduct examinations in an identical manner as outlined by the study protocol so as to maintain consistency among examiners. Examiners were not allowed to deviate from the study protocol.

To maintain a nontraumatic focus and minimize the risk of harm, the OMT techniques consisted primarily of muscle energy and articular techniques—with the exception of 3 high-velocity, low-amplitude techniques, which were used to treat cuboid, navicular, and superior innominate shear dysfunctions. The training curriculum consisted of six 2-hour general training sessions (*Table 2*), six additional 1-hour practical sessions, 2 hours of research ethics education as prescribed by the institutional review board, Health Insurance Portability and Accountability Act certification (which was integrated into first-year training), and a minimum of 2 hours of observation at participant examinations completed in the fall semester. The training curriculum continued in the spring semester with four 2-hour practical review sessions for a total of 30 hours of training for first-year medical students.

At the end of their formal training, the students were evaluated by means of both a written evaluation and a practical evaluation given by the attending physicians. The students were required to meet both standards to become examiners for the present study. The written evaluation was composed of board-style questions that focused on the detailed knowledge of the research protocol; a minimum 80% score was needed to successfully complete this requirement. For the practical evaluation, the student performed a complete diagnostic examination, making accurate diagnoses based on his or her findings and performing the indicated treatment.

**Table 1.**  
**Body Areas Treated by Osteopathic Medical Student–Examiners**  
**During a Study of 124 Cross-Country Athletes at an NCAA Division I University**

Body Area	Structural Landmarks	Functional or Motion Testing	Diagnoses Managed With OMT
Pelvis	Posterior superior iliac spine Anterior superior iliac spine Pubic tubercle	Standing flexion test Abdominal clock Superior innominate shear Innominate inflare Innominate outflare Superior pubic shear Inferior pubic shear	Anterior innominate rotation Posterior innominate rotation
Sacrum	Sacral base Sacral inferior lateral angle Sacrotuberous ligament	Sacral breathing motion Sphinx test	Sacral unilateral flexion Sacral unilateral extension Flexed sacral torsion Extended sacral torsion
Lower extremity	Fibular head Lateral malleolus Medial malleolus Navicular Cuboid	Anterior hip capsule Posterior hip capsule Hip rotation Hip abduction Hip adduction Hip flexion Thomas test Talocrural joint Tarsal-tarsal joints Metatarsal gliding	Anterior fibular head Posterior fibular head Leg length difference Superior navicular Inferior navicular Superior cuboid Inferior cuboid Hip capsule restriction Hip motion restriction Ankle/foot accessory motion restriction

**Abbreviations:** NCAA, National Collegiate Athletic Association; OMT, osteopathic manipulative treatment.

Successful completion of this requirement was assessed at the discretion of the attending physician.

After the successful completion of the OMT protocol training and evaluation at the end of the fall semester, the first-year osteopathic medical students began their participation in the athletic training room as scribes, recording somatic dysfunction data during participant examinations. At the beginning of the spring semester, the first-year medical students completed a minimum of 2 hours as scribes with second-year medical students. The first-year medical students then completed a minimum of 4 hours as examiners while paired with second-year medical students in the role of scribes. Thereafter, a first-year medical student was, whenever possible, paired with a second-year medical student. Scribe and examiner roles were alternated between partners for each evening examination.

Second-year medical students continued to perform participant examinations in the athletic training room in addition to serving as mentors, assisting at the first-year

training sessions and participating in ongoing research education. Each year, approximately 20 first-year medical students committed to 2 years of participation with this project. All diagnoses made and treatments performed by the osteopathic medical students were done under the direct supervision of the attending physicians.

### Procedures

After obtaining informed consent, each participant completed a health history questionnaire and a medical release form to enable access to his or her medical record. Each participant was scheduled for an examination every 2 weeks. Attendance was encouraged, but not required, to continue participating in the study. Participants were allowed additional visits if desired.

The participant examinations were scheduled after the completion of practice activities the same 2 evenings of each week with the exception of holidays and university breaks. The examinations were completed at a university athletic training room familiar to the participants

**Table 2.**  
**Topics Covered in Six 2-Hour General Training Sessions for Osteopathic Medical Student-Examiners During a Study of Cross-Country Athletes at NCAA Division I University**

Session	Topics
1	Subject interview, data collection procedures, osteopathic principles and practice
2	Standing flexion test, innominate and pubic dysfunction
3	Sacral dysfunction
4	Hip and fibular head dysfunction
5	Ankle and foot dysfunction
6	Review, evaluation preparation

**Abbreviation:** NCAA, National Collegiate Athletic Association.

and with use of plinths on site. Each year, the study ran from mid-September to mid-April.

For each session, a participant was randomly paired with a student-examiner. Medical students worked in pairs and alternated duties as scribe and examiner. The scribe was responsible for obtaining and recording the participant's current athletic participation status on the data collection form. The participant was asked to give subjective information about his or her current level of performance and any discomfort he or she was experiencing at that time.

The examiner then assessed 25 structural landmarks and functions of the pelvis, sacrum, and lower extremities in the standing, supine, and prone positions as described in the study protocol (*Table 1*). During the assessments, the examiner and the scribe were blinded to the previous medical record of each participant, to the participants' health history, and to previous structural findings. As dictated by the examiner, the findings from the osteopathic structural examination were recorded by the scribe on the data collection form. All positive findings and diagnosed somatic dysfunctions were then treated on site by the student-examiner or the attending physician-examiner.

In the present study, stress fracture was diagnosed clinically and confirmed by means of plain radiography, triple-phase bone scintigraphy, computed tomography, or MR imaging. Stress fracture was diagnosed clinically by the team physician, taking into account the participant's history and physical examination results, then confirmed by means of the physician's choice of imaging; the type of imaging was not mandated as a part of this study and the study protocol was limited to the OMT.

A retrospective review of the athletes' medical records was also conducted to verify the incidence of stress fractures prior to the initiation of this intervention protocol. A study author (A.F.) conducted the medical record review of the academic years preceding the study (1996-1997 through 2003-2004), which was completed after receiving approval by the institutional review board.

Data were analyzed using the Statistical Package for the Social Sciences, version 20.0 (IBM Corporation). Significance was defined as  $P < .05$  using the Student *t* test.

## Results

The data were gathered by 141 osteopathic medical students under the guidance of 3 supervising osteopathic physicians (L.F.B., Dr Dupuis, and A.F.) who had more than 90 years of combined experience in osteopathic medicine.

A total of 124 athletes were enrolled in the study from the 2004-2005 to 2008-2009 academic years, including 52 men (42%) and 72 women (58%), with athletes re-enrolling in the study each academic year they continued to be eligible. An average of 20 athletes re-enrolled annually. More than 1800 participant examinations were performed over the course of 5 consecutive academic years. The mean (standard deviation) self-reported distance ran per week for athletes enrolled in the study during the academic year was 68.0 (19.9) miles for men and 42.2 (17.5) miles for women. During the course of this research study, no participant withdrew his or her participation, and there were no reported adverse effects. The cumulative annual incidence for the present study population was compared for the 8 academic years before and 5 academic years after the preventive OMT protocol was implemented.

**Table 3.**  
**Annual Incidence of Stress Fracture in 124 Men and Women at an NCAA Division I University Before and After an Osteopathic Manipulative Treatment (OMT) Protocol, No. (%)**

Year	Men		Women		Total	
	n	Stress Fractures	n	Stress Fractures	N	Stress Fractures
<b>Before OMT Protocol</b>						
1996-1997	19	1 (5.3)	25	3 (12.0)	44	4 (9.1)
1997-1998	16	1 (6.3)	22	4 (18.2)	38	5 (13.2)
1998-1999	15	2 (13.3)	20	3 (15.0)	35	5 (14.3)
1999-2000	19	1 (5.3)	25	2 (8.0)	44	3 (6.8)
2000-2001	19	6 (31.6)	15	3 (20.0)	34	9 (26.5)
2001-2002	20	1 (5.0)	22	1 (4.6)	42	2 (4.8)
2002-2003	18	3 (16.7)	25	2 (8.0)	43	5 (11.6)
2003-2004	18	5 (27.8)	24	5 (20.8)	42	10 (23.8)
<b>After OMT Protocol</b>						
2004-2005	14	0	29	3 (10.3)	43	3 (7.0)
2005-2006	20	1 (5.0)	22	3 (13.6)	42	4 (9.5)
2006-2007	24	0	27	6 (22.2)	51	6 (11.8)
2007-2008	23	0	31	3 (9.7)	54	3 (5.6)
2008-2009	24	0	33	2 (6.1)	57	2 (3.5)

**Abbreviation:** NCAA, National Collegiate Athletic Association.

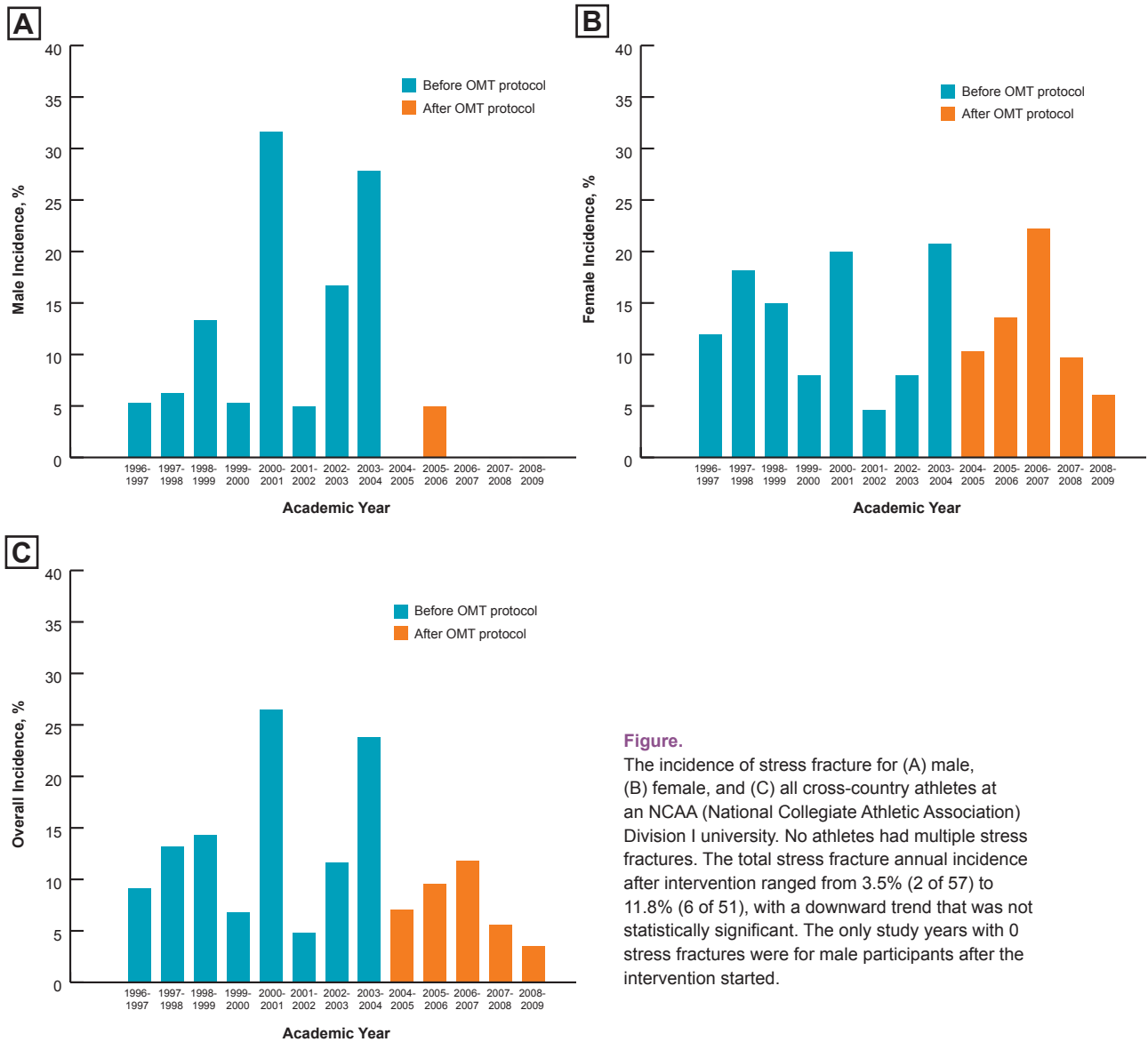
The female participants experienced a higher incidence of stress fractures compared with the male participants in 11 of the 13 years of study (Table 3). The percentage of annual stress fractures per team ranged from 0% to 31.6% (6 of 19) for male participants and 4.6% (1 of 22) to 22.2% (6 of 27) for female participants. No athletes had multiple stress fractures. The highest percentage incidence per year for male participants was 31.6% (6 of 19) before intervention and 5.0% (1 of 20) after intervention (Figure 1A). The highest incidence per year for female participants was 20.8% (5 of 24) before intervention and 22.2% (6 of 27) after intervention (Figure 1B). The overall annual incidence of stress fractures for all participants before intervention ranged from 4.8% (2 of 42) to 26.5% (9 of 34) (Figure 1C). The total stress fracture annual incidence after intervention ranged from 3.5% (2 of 57) to 11.8% (6 of 51), with a downward trend that was not statistically significant. The only study years with 0 stress fractures were for male partici-

pants after the intervention started.

The cumulative annual incidence for male participants showed a significant decrease from 13.9% (20 of 144) before intervention to less than 1% (1 of 105) after intervention, a 93% reduction in stress fractures ( $P=.019$ ). The cumulative annual incidence for female participants showed a minimal decrease from 12.9% (23 of 178) before intervention to 12.0% (17 of 142) after intervention, a 7.0% decrease in stress fractures ( $P=.671$ ). The cumulative annual incidence of all participants decreased from 13.4% (43 of 322) before intervention to 7.3% (18 of 247) after intervention, a 46% reduction in stress fractures ( $P=.156$ ).

## Comment

In the present study, a preventive OMT protocol for cross-country athletes resulted in a statistically significant decrease in the cumulative annual incidence of



**Figure.** The incidence of stress fracture for (A) male, (B) female, and (C) all cross-country athletes at an NCAA (National Collegiate Athletic Association) Division I university. No athletes had multiple stress fractures. The total stress fracture annual incidence after intervention ranged from 3.5% (2 of 57) to 11.8% (6 of 51), with a downward trend that was not statistically significant. The only study years with 0 stress fractures were for male participants after the intervention started.

stress fractures for men. No statistically significant decrease was observed in the incidence of stress fractures for women. Somatic dysfunction may be less of a contributing factor to the etiologic process of stress fracture in females compared with males, and therefore treatment of somatic dysfunction may reach statistical significance only with a larger sample size.

Previous research has not consistently identified a difference among male and female risk factors for devel-

opment of a stress fracture. However, stress fracture is likely a multifactorial injury with a broad array of contributing causes. The present study focused on the musculoskeletal system, which is just 1 aspect in the development of stress injury to bone. The etiologic process of stress fracture in female athletes may be complicated by the “female athlete triad” of menstrual disorders, low bone mineral density, and reduced energy intake. As such, the contribution of the musculoskeletal system in the devel-

opment of stress fracture may be proportionally more substantial for male athletes, which may account for the statistically significant decrease in diagnoses of stress fracture we observed in the men but not the women.

To our knowledge, the present study is the first to investigate the role of OMT in the prevention of stress fractures in athletes. By its nature, OMT is difficult to study because of the high level of clinical expertise required of the examiner. Consistency in both diagnosis and treatment among examiners and the focus on examiner training in this study ensured that the clinical process was properly standardized. This athlete cohort also provided a participant population with similar training and competition schedules and who were exposed to the same coaching staff, training atmosphere, and medical staff. Finally, this project has created a remarkable opportunity for osteopathic medical students to be involved in research, stimulate interest in sports medicine, and promote training in OMT.

The rate of diagnosis may have varied naturally during the study as a result of differing and evolving clinical practice of team physicians, who advised athletes on level of suspicion of injury and on optimal timing for removal from participation. Of note, the present study was conducted by osteopathic physicians and osteopathic medical students, all of whom were performing a service that was adjunctive to an athlete's regular care by the sports medicine team (ie, an athlete's primary physician who remained unchanged, and an array of sports medicine fellows, who changed each year).

The advancement of imaging technology has led to a 4-stage MR imaging grading system that may prompt increased use of MR imaging-aided diagnosis and more aggressive management for stress reactions, with a resultant decrease in overall time lost and overall number of stress-fracture diagnoses. Future research may look at the role of MR imaging-aided diagnosis and earlier removal from participation in cross-country or study participation as it contributes to time lost and recovery.

Many other factors may have contributed to stress fracture incidence, such as supplementation, diet, distance, or equipment. A notable outlying data point may have occurred in the 2006-2007 academic year, at which

time we observed a large increase in the incidence of stress fractures in the women. The coaches and staff were the same as the previous year, but athletes' shoe type was not. In 2006, the athletes were all given the same style of shoe to wear, whereas in previous and subsequent years, each athlete wore the shoe of his or her choice. We posit that the change in footwear requirement may have made a contribution to the spike in stress-fracture diagnoses that year, although we are unsure as to why the men were unaffected. The contributions of shoes and orthotics have been discussed previously in the literature,<sup>19-21</sup> but the varying results necessitate additional research, particularly in combination with other possible risk factors or preventive measures, such as OMT.

The limitations of this study include the study design. The present study was principally a clinical and educational program, and thus it did not allow for random assignment to treatment and control groups. A comparison was instead made of previous years' athletes to those enrolled in the present study, which we recognize introduces many confounding variables. Precise training of student-examiners was emphasized, but standardization among examiners can only be inferred and some variability should be expected. Nonetheless, the level of variability may reflect the variability that would occur among osteopathic physicians in a clinical setting. Finally, our results are of limited generalizability because of the present study's relatively small sample size.

## Conclusion

Osteopathic evaluation and treatment of lower extremity somatic dysfunction was associated with a statistically significant decrease in the incidence of stress fracture in male cross-country athletes. In the clinical setting, osteopathic structural examination and OMT for somatic dysfunction can easily and efficiently be worked into a routine athlete examination. Future studies could examine the relationship between stress fracture development and specific somatic dysfunction diagnoses, with the additional consideration of running distance, previous or concurrent injuries, and frequency of preventive OMT sessions.



## Acknowledgments

We thank Steven Dupuis, DO, who was instrumental in the first years of the project in recruiting osteopathic medical students and developing the study. We thank Justin McCormick, DO, and Carol Monson, DO, for their administrative and financial support. We thank Noshir Amaria, DO, for his long-term commitment to the organization of this program. Finally, we must acknowledge the enthusiasm, dedication, and performance of the 142 osteopathic medical students who contributed to this project, particularly Brooke Lemmen, DO, ATC; Brian Moody, DO; Kim Pfothenhauer, DO; Robin Page-Echols, DO; Catherine Asselin, DO; Rob Beers, DO; John Breck, DO; Mayo Mitsuya, DO; Bill Clark, DO; Jesse Guasco, DO; and Jason Muir, DO.

## References

- Bennell KL, Brukner PD. Epidemiology and site specificity of stress fractures. *Clin Sports Med*. 1997;16:179-196.
- Arendt E, Agel J, Heikes C, Griffiths H. Stress injuries to bone in college athletes: a retrospective review of experience at a single institution. *Am J Sports Med*. 2003;31(6):959-968.
- Bennell KL, Malcolm SA, Thomas SA, Wark JD, Brukner PD. The incidence and distribution of stress fractures in competitive track and field athletes: a twelve-month prospective study. *Am J Sports Med*. 1996;24(2):211-217.
- Nattiv A. Stress fractures and bone health in track and field athletes. *J Sci Med Sport*. 2000;3(3):268-279.
- Snyder RA, Koester MC, Dunn WR. Epidemiology of stress fractures. *Clin Sports Med*. 2006;25(1):37-52.
- Major NM. Role of MRI in prevention of metatarsal stress fractures in collegiate basketball players. *Am J Roentgenol*. 2006;186(1):255-258. doi:10.2214/AJR.04.1275.
- Protzman RR, Griffis CJ. Stress fractures in men and women undergoing military training. *J Bone Joint Surg Am*. 1977;59(6):825.
- Protzman RR, Griffis CC. Comparative stress fracture incidence in males and females in an equal training environment. *Athl Train*. 1977;12:126-130.
- Brudvig TJ, Gudger TD, Obermeyer L. Stress fractures in 95 trainees: a one-year study of incidence as related to age, sex, and race. *Mil Med*. 1983;148(8):666-667.
- Jones BH, Bovee MW, Harris JM III, Cowan DN. Intrinsic risk factors for exercise-related injuries among male and female army trainees. *Am J Sports Med*. 1993;21(5):705-710.
- Goldberg B, Pecora C. Stress fractures: a risk of increased training in freshman. *Phys Sports Med*. 1994;22(3):68-78.
- Hickey GJ, Fricker PA, McDonald WA. Injuries to elite rowers over a 10-yr period. *Med Sci Sports Exerc*. 1997;29(12):1567-1572.
- Romani WA, Gieck JH, Perrin DH, Saliba EN, Kahler DM. Mechanisms and management of stress fractures in physically active persons. *J Athl Train*. 2002;37(3):306-314. <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC164361/>. Accessed on April 29, 2013.
- Giladi M, Milgrom C, Simkin A, et al. Stress fractures and tibial bone width: a risk factor. *J Bone Joint Surg Br*. 1987;69(2):326-329.
- Milgrom C, Giladi M, Stein M, et al. Stress fractures in military recruits: a prospective study showing an unusually high incidence. *J Bone Joint Surg Br*. 1985;67(5):732-735.
- Sanderlin BW, Raspa RF. Common stress fractures. *Am Fam Physician*. 2003;68(8):1527-1532. <http://www.aafp.org/aafp/2003/1015/p1527.html>. Accessed November 13, 2013.
- Otter MW, Qin YX, Rubin CT, McLeod KJ. Does bone perfusion/reperfusion initiate bone remodeling and stress fracture syndrome? *Med Hypotheses*. 1999;53(5):363-368.
- Popp KL, Hughes JM, Smock AJ, et al. Bone geometry, strength, and muscle size in runners with a history of stress fracture. *Med Sci Sports Exerc*. 2009;41(12):2145-2150. doi:10.1249/MSS.0b013e3181a9e772.
- Shaffer SW, Uhl TL. Preventing and treating lower extremity stress reactions and fractures in adults. *J Athl Train*. 2006;41(4):466-469. <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1748425/>. Accessed April 23, 2013.
- Korpelainen R, Orava S, Karpakka J, Siira P, Hulkko A. Risk factors for recurrent stress fractures in athletes. *Am J Sports Med*. 2001;29(3):304-310.
- Pohl MB, Mullineau DR, Milner CE, Hamill J, Davis IS. Biomechanical predictors of retrospective tibial stress fractures in runners [published online April 2, 2008]. *J Biomech*. 2008;41(6):1160-1165. doi:10.1016/j.jbiomech.2008.02.001.
- Edwards WB, Taylor D, Rudolphi TJ, Gillette JC, Derrick TR. Effects of running speed on a probabilistic stress fracture model [published online January 22, 2010]. *Clin Biomech (Bristol, Avon)*. 2010;25(4):372-377. doi:10.1016/j.clinbiomech.2010.01.001.
- Milner CE, Ferber R, Pollard CD, Hamill J, Davis IS. Biomechanical factors associated with tibial stress fracture in female runners. *Med Sci Sports Exerc*. 2006;38(2):323-328.
- Bennell KL, Malcolm SA, Thomas SA, et al. Risk factors for stress fractures in track and field athletes: a twelve-month prospective study. *Am J Sports Med*. 1996;24(6):810-818.
- Fredericson M, Bergman AG, Hoffman KL, Dillingham MS. Tibial stress reaction in runners: correlation of clinical symptoms and scintigraphy with a new magnetic resonance imaging grading system. *Am J Sports Med*. 1995;23(4):472-481.
- Ward RC, executive ed. *Foundations for Osteopathic Medicine*. 2nd ed. Philadelphia, PA: Lippincott, Williams & Wilkins; 2002.

© 2013 American Osteopathic Association