

Case Report

Osseous Stress Reaction in a Rower Diagnosed with Positron Emission Tomography (P.E.T.): A Case Report

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Back injury is one of the most frequently encountered injuries in the collegiate rower. The differential diagnosis of back pain in the competitive rower includes muscle strain, ligament/tendon injury, stress reaction, stress fracture, and a tear in the annulus fibrosis.

Endurance sports, such as rowing, have an increased frequency of stress injury. The diagnosis of stress reaction cannot be made with plain radiographs. Many studies have firmly established the efficacy of single photon emission computed tomography (SPECT) bone scans and magnetic

resonance imaging in establishing the diagnosis of a stress reaction.

We present a case of a collegiate rower with mid back pain secondary to a stress reaction of the endplates of the costovertebral articulation at the T8 level diagnosed by a positive positron emission tomogram study in the setting of a negative SPECT scan.

Keywords: Back pain, stress fracture, PET scan, SPECT scan

Back injury is one of the most frequently encountered injuries to the collegiate rower (1). The differential diagnosis of back pain in the competitive rower includes muscle strain, ligament/tendon injury, stress reaction, stress fracture, and a tear in the annulus fibrosis. Endurance sports, such as rowing, have an increased frequency of stress injury (2). In 1985, Holden and Jackson reported a series of rib fractures in elite female rowers (3). Subsequently, during a review of rowing injuries, Josea and Boland reported eight cases of rib-stress injury diagnosed by bone scan (4).

The back produces much of the power required to complete a rowing stroke. Myoelectric and kinematic analysis of the lumbar spine during rowing reveals that the peak stress forces at L4 are approximately 848 Newtons (N) in men and 717 N in women rowers. The average peak compressive loads range from 5000 to 6000 N in women and

men rowers, respectively, approximating seven times the body weight during the drive phase. These high forces put the lumbar spine at risk during vigorous rowing activity, causing the spine to endure repetitive mechanical stress (1). Biomechanical studies suggest that the highest bending stresses occur at the posterolateral section of the rib (5). To transfer the force generated by the legs and trunk into the arms, and subsequently to the oar, the scapulothoracic muscles, especially the serratus anterior, must contract maximally (1). This produces a bellows-type effect on the rib cage, which can result in a stress fracture (1). Repetitive microtrauma to the chest wall and scapulothoracic area can lead to painfully unstable subluxating ribs, scapulothoracic articulation fibrosis, or stress fracture of the ribs, which have all been well documented in rowers (3,6,7).

Stress injuries can be viewed as a spectrum of stress reaction to stress fracture (8). The diagnosis of stress reaction cannot be made with plain radiographs (9). Many studies have firmly established that single photon emission computed tomography (SPECT) bone scans are the diagnostic test of choice in establishing the diagnosis of a stress reaction (10-14). Magnetic resonance imaging (MRI) is a highly sensitive test for the diagnosis of stress injury to bone (15). Magnetic resonance imaging is similar to SPECT in that it allows for depiction of abnormalities several weeks prior to the development of radiographic alter-

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ations. A combination of T1-weighted sequences, which optimizes anatomic detail, and a sequence that depicts bone "edema" are required for the assessment of stress injuries (15). Short-time inversion recovery sequences are the most commonly used edema-sensitive images and typically incorporate fat suppression techniques to further enhance contrast (16).

In 1962, Blau et al introduced the concept of positron emitted [^{18}F] fluoride ion for bone scanning (17). [^{18}F] Fluoride ion is extracted from plasma in proportion to bone perfusion (18-22). The efficiency of any radiotracer extraction is affected by the permeability of the capillary membrane that separates the vascular component from the tissue compartment (23). Fluoride ion can more easily cross the capillary membrane compared to the larger complex molecules of $^{99\text{m}}\text{Tc}$ -labeled phosphate agents (18). The first-pass extraction of fluoride ion in normal bone is nearly 100% (21), and increased uptake may be seen secondary to regional increases in blood flow. For comparison, $^{99\text{m}}\text{Tc}$ diphosphonate compounds have a first-pass extraction efficiency of approximately 60% in the presence of normal bone capillary permeability (18). The biological characteristics of fluoride ion follow a more clearly defined physiologic process, allowing absolute quantitative evaluations of the skeletal system when combined with positron emission tomography technology (24, 25). Another useful feature of the [^{18}F] fluoride ion is excellent bone-to-plasma ratios at the time of imaging, which can usually be initiated 40 to 60 minutes after isotope injection, allowing the entire patient visit to be completed in less than 2 hours (23).

Positron emission tomography is an imaging modality that provides regional as well as global information about physiology, chemistry, and metabolism within various body organs (26). The PET scanner itself consists of large positron-sensitive sodium iodide crystal detectors individually analyzed by 180 to 240 photomultiplier tubes. Images are photographed by cameras having a 4.0- to 5.5-millimeter resolution and subsequently constructed by Sun SPARC station computers and array processors. Positron emission tomography scanning utilizes intravenously (IV) injected radioactively labeled glucose [^{18}F -FDG] to identify areas of increased tissue metabolism. Specifically, PET ascertains physiology by demonstrating areas of increased glucose metabolism, oxygen utilization, or neurotransmitter release. When attempting to delineate bone pathology, PET identifies areas of increased osteoblastic and osteoclastic activity, produces tomographic images that have better resolution than SPECT, and is more quantitative

and anatomically precise (27). The reason for this disparity in image quality is the ability of PET to more accurately correct for tissue photon attenuation (27).

This report describes a collegiate rower who complained of mid back pain secondary to a stress reaction of the endplates of the costotransverse articulation at the T8 level diagnosed by a positive PET study in the setting of a negative SPECT scan.

CASE REPORT

A 22-year-old male collegiate rower presented to our spine center stating a chief complaint of mid-back pain. His symptoms were located on the right side, just off midline, below the inferior aspect of the spine of the scapula, and radiated laterally to the right. His pain was initially felt during the drive phase of a rowing stroke beginning 4 months prior to presentation. The intensity of the pain was modest at rest, 50 out of 100 on the visual analogue scale (VAS), but excruciating, 90 out of 100 on the VAS scale, during rowing. His symptoms consisted of a stabbing and aching quality and had been intensifying over the previous 2 weeks prior to presentation. The pain had not affected his sleeping pattern; however, he had to progressively decrease his rowing to the point that he stopped rowing completely approximately 1 week prior to presentation.

Rowing exacerbated the patients' symptoms the most, but sitting for longer than 1 hour also provoked his pain. Advil®, electrical stimulation, and rest provided partial and temporary reduction of symptoms. The patient had initiated a nonspecific physical therapy program just prior to presentation; however, no other treatment had been instituted. The patient had no prior medical or surgical history. His review of systems was noncontributory. There was no significant family medical history. He had no known drug allergies. He was an unmarried university student who consumed one to three alcoholic beverages per week and denied any tobacco or illicit drug use. He was independent, with all activities of daily living and everyday community activities. On physical examination, the patient was a well-developed, young Caucasian man who stood six feet one-inch tall and weighed 190 pounds, with normal vital signs. His skin was without scar, rashes, or ulcers. There was no lymphadenopathy. Gross inspection for deformity was unremarkable. Palpation over the midback inferior to the scapula did not elicit any complaints of pain or tenderness. Girth of the mid-quadrant and mid-calf were symmetrical. Dorsalis pedis pulses were

graded 2+ and strong. Joints in the lower extremities were without effusion and crepitus. Discogenic stress maneuvers were not pain provoking. Sacroiliac stress maneuvers were not pain provoking bilaterally. The patient was able to heel walk, toe walk, and tandem walk without pain or difficulty. Sensation was intact to a pin between T4 and T12 bilaterally. Deep tendon reflexes were graded 2+ and symmetrical at the biceps, brachioradialis, triceps, patella and Achilles bilaterally. Long tract signs were negative bilaterally. Coordination, orientation, mood and affect were normal. Manual muscle testing was graded 5 out of 5 and full in the upper and lower extremities bilaterally. Lumbar flexion was achieved with a long finger to floor distance of 0 cm without discomfort. Lumbar extension was achieved to 50 degrees; however, the patient's usual pain was provoked. Lumbar side bending was achieved to within normal limits without difficulty. Range of motion of the hips, knees, and ankles was within normal limits. An MRI of the thoracic spine, dated approximately 1 month prior to presentation, demonstrated no pathology. There was normal alignment, well-hydrated intervertebral discs, no central or foraminal stenosis, and no disc herniation.

Our initial clinical suspicion was that symptoms were caused by a stress reaction of the posterior elements of the thoracic spine. Bone SPECT scan was acquired 3 hours after IV injection of 750 MBq ^{99m}Tc -MDP using a dual-

headed gamma camera (Picker Prism® 2000). This scan failed to demonstrate abnormal bone metabolism. Subsequently, a PET scan was performed using a dedicated PET scanner (C-PET®, ADAC UGM). Approximately 110 minutes after IV injection of 142 MBq ^{18}F -sodium fluoride (1.64 MBq/kg BW), three emission scans of 6 minutes each, covering 51.2 cm axial FOV, were acquired. Interleaved postinjection singles transmission scans of 1-minute duration were acquired using a ^{137}Cs point source. Image reconstruction employed an iterative algorithm (RAMLA), including corrections for scatter and decay. The transverse image of the thoracic spine (Fig. 1a) reveals several foci of moderate-to-high tracer uptake, predominantly at the costotransverse articulations of T7 to T10 bilaterally, consistent with a stress-induced alteration in the bone metabolism. Fig. 1b displays the transverse image of the patient's scan at the level of T9. The normal tracer distribution of ^{18}F -sodium fluoride, using a comparable PET acquisition in a healthy 19 year-old man without symptoms, is shown in Figs. 2a and 2b.

DISCUSSION

Stress fractures occur as a result of bones being exposed to repeated cyclic loading that eventually exceeds its elastic resistance (28, 29). There are two types of stress fractures. Fatigue fractures, such as tibial stress fractures in long-distance runners, occur when abnormal stress is ap-

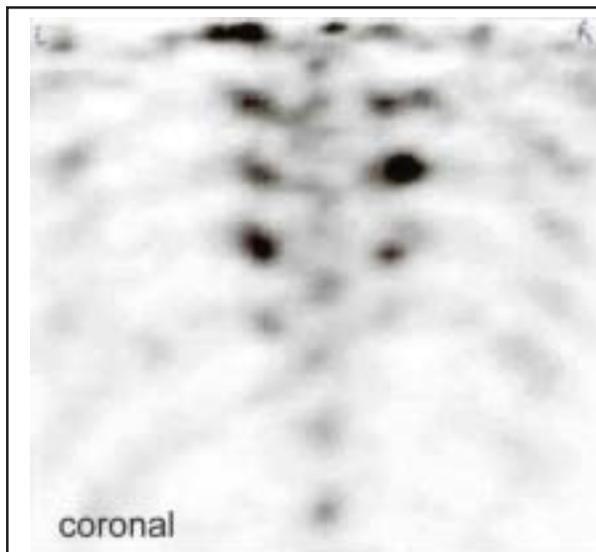


Fig. 1a. Transverse view at the T9 level demonstrating high uptake on the right costo-transverse articulation.

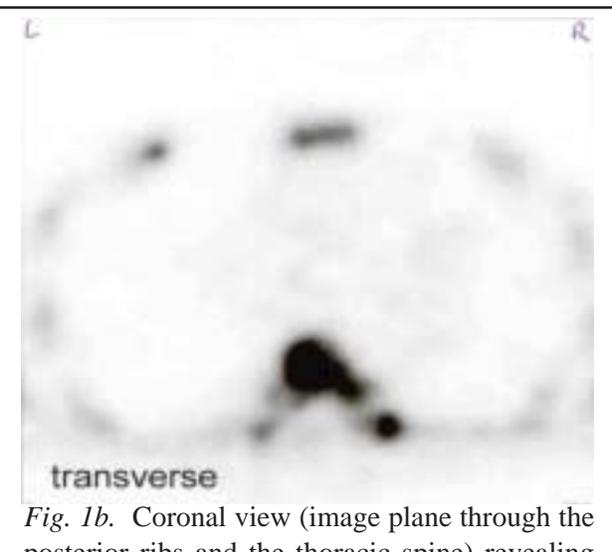


Fig. 1b. Coronal view (image plane through the posterior ribs and the thoracic spine) revealing several foci of moderate-to-high tracer uptake, predominantly at the costotransverse articulations of T7-to-T10 bilaterally, consistent with a stress-induced alteration in the bone metabolism.

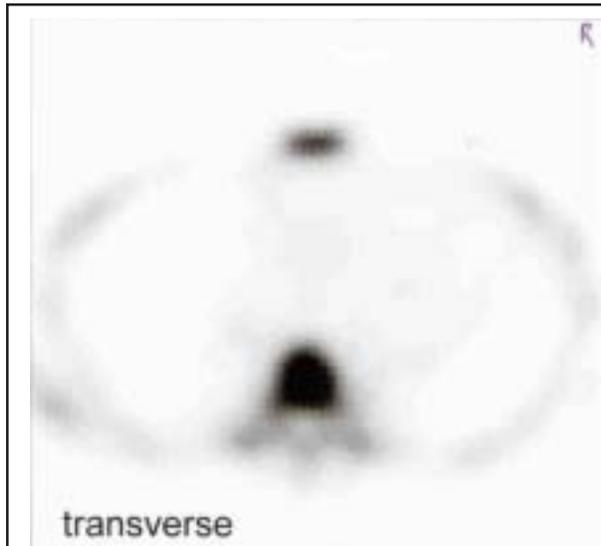


Fig. 2a. The normal tracer distribution of [18F]-sodium fluoride, using a comparable PET acquisition, in a healthy 19-year-old man without symptoms (transverse view at the T-9 level).

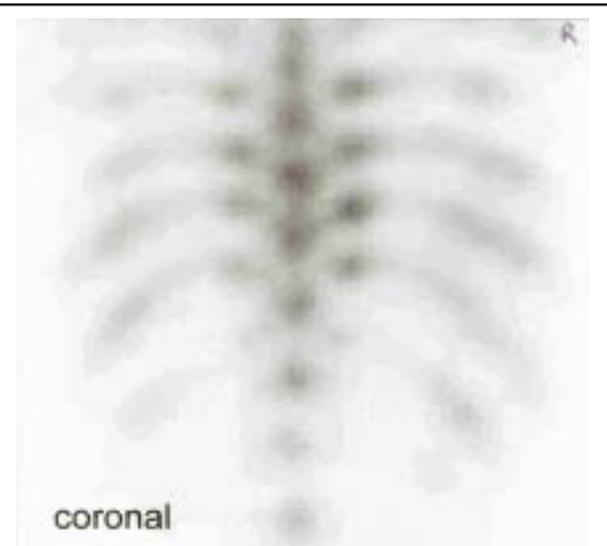


Fig. 2b. The normal tracer distribution of [18F]-sodium fluoride, using a comparable PET acquisition, in a healthy 19-year-old man without symptoms (coronal view of the same patient).

plied to normal bone (28, 29). Insufficiency fractures occur when normal forces are applied to abnormal or weakened bone, such as vertebral compression fractures in osteoporotic patients (28, 29).

In 1855, Breithaupt, a Prussian military surgeon, originally described stress injury to bone in military soldiers (30). This entity was initially visualized via roentgenography approximately four decades later (31). As comprehension of the pathophysiology of overuse injury has emerged, and progress in radionuclide imaging has occurred, a model of stress injury to bone has been proposed. This paradigm suggests that stress injury to bone occurs on a continuum, ranging from normal bone remodeling/repair to stress reaction to frank cortical fractures (32). Currently, terms such as *bone strain* (33) and *stress reaction* (34) are used to reflect the early pathological response of bone to repetitive mechanical loading. If the inciting external stress continues, the stress response may progress to trabecular or cortical disruption and become a stress fracture.

It is universally accepted that bone is a dynamic tissue that undergoes continuous remodeling in response to the demands placed upon it. Under normal conditions the rate of bone formation equals that of bone resorption. When cyclic mechanical forces (stress) are applied to bone, this homeostatic equation may be altered, leading to a stress injury (35). Following the application of a sudden pulse

of increased stress upon bone, there is an initial osteoclastic response that may weaken bone. Osteoblastic activity subsequently increases in an attempt to balance bone loss and, thereby, strengthen the bone. If the repetitive musculoskeletal demands persist without sufficient time to allow for restitution of a homeostatic osseous balance, the rate of healing may be overwhelmed, leading to a stress reaction or fracture.

The cyclic mechanical forces that regulate bone remodeling exist mainly in two forms: compressive and tensile. The compressive forces are resisted by the mineral component of bone, whereas the tensile forces are resisted by the collagen component. This complex interaction of transmitted forces upon the organic/mineral matrix of bone and the resultant adaptive remodeling is expressed in Wolff's law. The bony adaptation is a function of the number of loading cycles, cycle frequency, amount of strain, strain rate, and strain duration per cycle (36). Bone responds to excess strain by osteonal remodeling (ie resorption of circumferential lamellar bone and replacement by dense osteonal bone). Whether adaptation results in strengthening or weakening of the tissue is dependent on a multitude of factors: metabolic state, present level of fitness, biomechanical changes, menstrual patterns, age, sex, and ethnicity (36).

In 1963, Johnson et al (37) described the histogenesis of

stress reactions. During the first week there was active osteoclastic resorption of the cortex; but decalcification, microfracture, microcallus, and osteocyte death were not apparent. During the second week, endosteal (and occasional periosteal) callus formation was present. Johnson found that, if the inciting activity was discontinued at this time, no actual fracture occurred. On the other hand, if the inciting activity was continued, a thin crack appeared in the cortex. Resorption was complete at the end of 3 weeks, and callus was maximal at 6 weeks. When bone is stressed, there is a gradual and progressive resorption of circumferential lamellar bone and its subsequent replacement by dense osteonal bone. This period of remodeling is characterized by local hyperemia, edema, and osteoclastic activity. As a consequence of this process, a vulnerable period exists following a stressful occurrence in which the cortical bone is less capable of withstanding further stress and in which foci of osseous resorption may be transformed into sites of microfracture. Stress events in bone are more likely to occur when there has been an increase in the strength of the acting muscle over a relatively short time as the concomitant increase in strength of bone lags behind that of muscle. The stress fracture begins as a small cortical crack that can progress as the stress continues (1,4,5). This progression is characterized by the appearance of subcortical infarction in front of the main crack in the bone. If the stress is eliminated, the sequence is interrupted or slowed so that new bone formation can "catch up" with the increased demand, and a state of increased bone strength is achieved. Rest interrupts the process for osteoblastic activity to outpace osteoclastic activity, thereby allowing for periosteal or endosteal healing (38).

A variety of theories have been proposed to explain the biomechanics and pathophysiology of the stress response. The classical and perhaps oversimplified explanation is that a change in the volume or intensity of mechanical stress applied to bone overwhelms the bones' remodeling process, described as Wolff's law (39-41). Another theory is that physical exercise leads to muscle fatigue, thereby altering movement patterns and distributions of stress, with resultant excessive concentration of force being transmitted to focal sites in the underlying bone (42, 43). A third proposal is that repetitive mechanical loading results in increased muscle activity, with secondary concentration of excess force at the sites of origin or insertion of the muscle on the bone (44). Carter and Caler (45) suggest that bone remodeling occurs as a result of the piezoelectric phenomena. This suggests that tension forces create an electropositivity that results in bone resorption by initiating osteoclastic activity. Weakened bone is therefore

created, and is susceptible to injury or fracture. Alternatively, compression forces develop an electronegative field that induces bone deposition by osteoblastic activity and strengthens bone. Carter has shown that most cortical stressors are tension or torsion in nature, and tend to result in microfractures along a cement line (43). Histologically, small cracks can be seen at the cement lines of the haversian canals (46). Frost (47) proposed a new theory of bone biology to help understand the skeletal adaptations that occur with mechanical usage. This paradigm is based on a "mechanostat theory" to explain the structural and density changes of bone that ensue when bone is repeatedly stressed by its mechanical environment (47,48). The mechanostat theory is based on two main premises. First, there exists a minimum strain threshold for modeling (MESm) and another minimum strain threshold for remodeling (MESr). These two thresholds are viewed as "set points," between which most normal activity occurs (within the physiologic loading zone). Second is that a "controller" of bone biology (the mechanostat) senses bone strain induced by mechanical usage and compares it to the MESm and MESr thresholds and activates an adaptive cellular response. The mechanostat theory, therefore, helps to bridge the gap between bone adaptations to mechanical stress (exercise) and environmental factors.

CONCLUSION

This is the report of a case in which PET scan diagnosed a stress reaction when other radiological studies were inconclusive. Positron emission tomography scan may be more sensitive than either SPECT or MRI in diagnosing an early stress reaction in bone; however, further study is required comparing these diagnostic studies directly before any definitive statement can be made.

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