A Report of Transverse Process Fractures Secondary to the Centrifuge in a Healthy Aviator

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BACKGROUND: Centrifuge training, while an integral component in pilot training, is not without risks. To date there has never been a reported case of isolated transverse process fractures associated with centrifuge training.

CASE REPORT: A 32-yr-old Flight Surgeon underwent centrifuge training as part of an educational course. She had increasing back pain after exposure to the centrifuge. Follow-up studies showed left L2 and bilateral L3 transverse process fractures. No other contributory causes could be identified except for mild vitamin D deficiency.

DISCUSSION: The etiology, incidence, and treatment of transverse process fractures are examined to better prepare the clinician for the management of these cases.

KEYWORDS: vertebral, lumbar, back pain, occupational injury.

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Centrifuge training has been a mainstay of aeronautical training for several decades, arguably being the closest mechanism to simulate the high (>6) $+G_z$ force environment that pilots and crew of high performance aircraft experience. Due to this, centrifuge training has become an integral part in teaching pilots and aircrew how to perform the anti-G straining maneuver (AGSM). AGSM is a key component to maintaining consciousness at high $+G_z$ by contracting the abdominal and lower extremity muscle groups to maintain peripheral venous return. While this training is valuable, it is not without risks.

There have been several reports of injuries related to centrifuge training. Injuries have included cervical and lumbar soft tissue damage,[8] cervical and lumbar herniated discs,[7] thoracic and lumbar compression fractures,[8,9] and pneumomediastinum.[3] There have been at least two known lumbar vertebral fractures, both L5 anterior wedge compression fractures that were associated with osteopenia, one which was reported in 2008[9] and the other occurring at San Antonio, TX, in 2014. There have been no previously reported fractures of the transverse processes related to centrifuge training.

The Brooks City-Base centrifuge in San Antonio, TX, is a single-arm centrifuge that measures 20 ft. It has a maximum level of +30 G_z. The maximum onset is approximately +6 $G_z \cdot s^{-1}$. The seat is identical to the ACES II ejection seat with an adjustable seat angle to match the majority of U.S. Air Force high performance aircraft.

The typical F-16 qualification profile for centrifuge training is a gradual onset of +0.1 $G_z \cdot s^{-1}$ until 100% peripheral or 50% central light loss is reported by the participant, which then becomes the resting G tolerance. After the resting G tolerance is established, the subsequent runs include: +6 G_z for 30 s, +7 G_z for 10 s, or +9 G_z for 15 s in the 'check 6' position, with variable $+G_z$ loads for 90 s as the final run.

CASE REPORT

A 32-yr-old flight surgeon presented to the Outpatient Flight Medicine Clinic with a complaint of worsening back pain 13 d after undergoing centrifuge training in San Antonio, TX. She was in a relatively good state of health prior to undergoing training, recently having an upper respiratory infection and a recent left ankle sprain. She was medically cleared for centrifuge training 3 d prior to centrifuge training. The patient had never been exposed to the centrifuge previously nor had any

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high G force exposure. She had a total of 48.7 flight hours, all in low G performance aircraft. Her centrifuge training proceeded uneventfully and she underwent a standard qualification protocol as above, sitting at a 30° angle (similar to the F16 seat). She was wearing an anti-G suit during the centrifuge run. Her resting G tolerance was 6.0 $+G_z$ and her maximum $+G_z$ was +9 G_z for 15 s. Her AGSM was consistent with someone who was unfamiliar with the high G environment and AGSM. She did not have G-induced loss of consciousness nor complain of any problems while in the gondola. Immediately after her ride, she mentioned some initial lower back pain, which was self-described as mild. She believed it to be normal muscle spasms and exhaustion after being exposed to elevated G force. Her back pain worsened over the next few days and she sought out urgent care at a civilian site close to where she was staying 5 d after training. Plain films of her lumbar spine were done which indicated a potential L3 transverse process fracture. It was recommended she seek out her PCM for a follow-up appointment and was discharged with tramadol for pain and methocarbamol for muscle spasms. At her follow-up appointment at Flight Medicine 2 wk after training, she stated that her back pain was still very painful, but that the methocarbamol was effective in helping her rest.

A review of her past medical history did not reveal a history of any significant chronic illnesses except for seasonal allergies and well controlled gastroesophageal reflux. Her medications included loratidine, fluticasone, montelukast, and omeprazole. There was no immediate family history of cancer, osteopenia/osteoporosis, or degenerative disc disease. She mentioned rare alcohol use (less than monthly) and had quit using tobacco products in 2012. She had maintained a physically active lifestyle, achieving an excellent on her physical fitness assessment in May 2014. She underwent left ankle surgery in August of 2014 for a symptomatic os trigonum; however, wound dehiscence occurred and her wound became infected 2 mo post op. This led to delayed healing and she was not able to resume light jogging until late November 2014. This led to deconditioning prior to her centrifuge experience. She had unfortunately sprained her post op ankle during light jogging; however, 14 d prior to the centrifuge run, her symptoms had resolved before training.

Physical exam revealed a well-developed, well-nourished woman with a BMI of 25.4. Her height was 67 in with a weight of 165 lb. There was no appearance of ecchymoses along her back, neck, or abdomen, so other potential injuries or causes were looked for. There was tenderness at the L3-L4 level to light palpation that worsened with vibration. A straight leg test was negative bilaterally. Muscle strength and muscle stretch reflex testing of the lower extremities was benign. Her gait was stiff with reduced truncal swing. Plain films were not available from her earlier visit to a civilian urgent care and thus were reordered. Plain film showed bilateral L3 and left L2 transverse process fractures, with potential bilateral L4 transverse process fractures (see **Fig. 1**). Due to the fact that the patient presented almost 2 wk after her injury and the lack of any other additional symptoms or physical exam findings, a CT was deferred and a lumbar MRI was scheduled within a week. Follow-up MRI did not show any further fractures of the lumbar bodies; however, there was degenerative disc disease noted at L4-L5 and L5-S1. Follow-up radiological studies included a nuclear medicine bone scan, skeletal survey, and DEXA scan. Left L2 and bilateral L3 transverse process fractures were confirmed with the bone scan, but no other injuries were noted. Her DEXA at the L1-L4 vertebral bodies, femoral neck, and proximal femur showed normal bone density for her age group (T-scores in the +1.5 to +1.7 range). Extensive laboratory tests were obtained, including thyroid stimulating hormone, parathyroid stimulating hormone, serum protein electrophoresis, calcium studies, urine studies, and drug and ethanol screens. All tests were negative

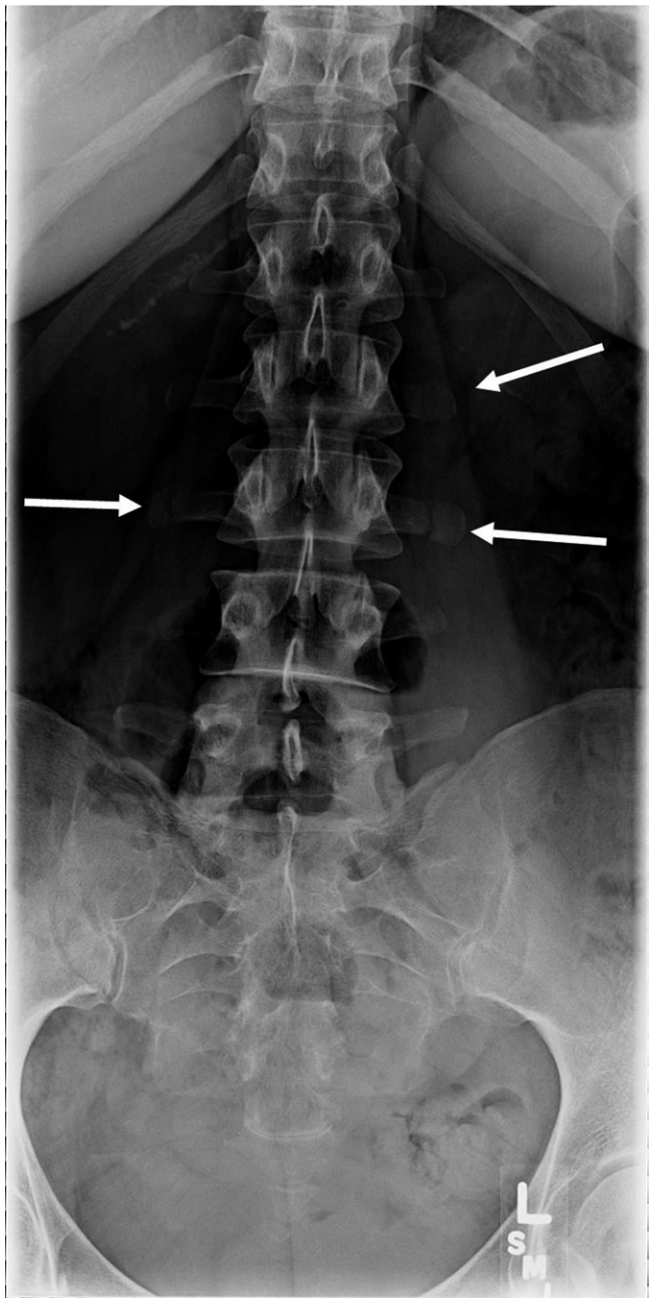

Fig. 1. Plain film that was obtained 2 wk after training showing the fractures.

except for a low vitamin D level (19.7 ng · ml^{-1}, normal range > 30 ng · ml^{-1}) which increased to 25.6 ng · ml^{-1} after oral vitamin D supplementation.

Due to the unusual mechanism of injury, Orthopedics was consulted for further input. A thoracolumbar sacral orthosis brace was ordered for patient comfort. Her pain medication was increased to oxycodone and dermal lidocaine patches. Other pain modalities that were considered included osteopathic manipulative treatment and auricular acupuncture; however, due to time constraints and availability of providers these were not performed. She remained on light duty and started to make progress until she reinjured her back after a fall approximately 1.5 mo later, after which she was hospitalized for 2 d. After her discharge, her pain remained resistant to tapering and was referred to Pain Management for better control of her symptoms. She was placed on oxycodone/acetaminophen 7.5/325 mg extended release and celecoxib 100 mg BID and continued on tramadol and methocarbamol. She began intensive physical therapy approximately 3 mo after her centrifuge training. She was no longer on oxycodone 10 mo after her injury, but continued on the tramadol, celecoxib, and methocarbamol. Due to ongoing rehabilitation and medication use, a fitness for duty board was convened, a process which is still ongoing.

Table I. Associated Injuries with Isolated Lumbar Transverse Process Fractures (Adapted from Xia et al.[11]).

SITE (% CHANCE THAT IT OCCURS IN CONJUNCTION WITH AN ISOLATED LTPF) AND INJURY
Head (18.7%)
Intracranial hemorrhage
Traumatic brain injury
Eye injuries
Skull and maxillofacial fractures
Thorax (30.1%)
Rib/sternum fractures
Hematopneumothorax
Mediastinal emphysema
Mediastinal injuries
Lung or heart contusions
Diaphragm injuries
Intrathoracic vascular injuries
Abdomen (13.1%)
Intra-abdominal substantial or hollow viscera injuries
Renal injuries
Adrenal injuries
Mesenteric injuries
Intra-abdominal vascular injuries
Pelvis (19.2%)
Pelvic fractures
Limbs (24.5%)
Limb fractures

DISCUSSION

This is the first reported case of lumbar transverse process fractures (LTPF) that has occurred secondary to exposure to high G force. While this is the first reported case in the centrifuge, transverse process fractures are the most common fracture site in the lumbar spine, with L2 and L3 transverse processes most frequently fractured.[11] LTPF are typically associated with high energy direct trauma. These fractures can be seen in high speed motor vehicle collisions, but also as a result of falls and sports injuries. Reported cases have included LTPF injures in the setting of a 10-ft fall[1] and a football (soccer) player who fell while performing an overhead kick and landed on his back.[5] Studies of vertebral fractures in skiers and snowboarders found that isolated LTPF accounted for 29 to 37% of reviewed fractures.[4,12]

The L2 and L3 transverse processes are the most common LTPF, mostly due to their long, thin shape compared to the other transverse processes. The most likely mechanism for the cause of these lumbar fractures are avulsion injuries when the spine is struck, causing intense muscle spasms of the psoas major and quadratus lumborum.[4,11] In addition, the lumbodorsal fascia also attaches to the lumbar processes, which can also provide additional forces that can pull on the transverse processes.

There are a surprisingly high number of associated injuries that can occur in conjunction with LTPF. These associated injuries can include a perforated colon, rib and sternal fractures, and intracranial injuries (see **Table I**). The rates can be as high as 55.7% in cases of isolated LTPF and 64.5% in cases of vertebral fractures with an associated LTPF.[11] Fractures of the transverse processes at L5 are the greatest predictor of additional injuries, especially pelvic fractures, because the sacroiliac ligament attaches to the L5 transverse process.[11] Neurological deficits, especially spinal cord and peripheral nervous system injuries, are quite rare; however, traumatic brain injuries can appear in up to 8% of vertebral fractures with an associated LTPF.[2]

When assessing a patient for LTPF, physical exam clues can include pinpoint tenderness along the lumbar vertebrae, palpable muscle spasms, and mild scoliosis. This presentation is extremely common with other back injuries, with the only factor being trauma to lead a clinician to order radiological studies. While plain films are still considered an acceptable method of detection, the rate of detection of fractures is only 75.3% overall[11] and only 39% in the emergency department setting.[10] Confirmation with a CT should be sought in acute cases due to the insensitivity of plain films and the increased chance of intrathoracic and intra-abdominal additional injuries.

Management of isolated LTPF can be very straightforward, typically without needing the intervention of Orthopedics or Neurosurgery. This is due to the fact that there is rarely a neurological deficit and that isolated LTPF are stable fractures. There are other additional points of attachments for the various paraspinal muscles and ligaments that continue to provide spinal support.[2] Rarely does bracing therapy, such as a thoracolumbar sacral orthosis brace or stabilization surgery benefit the patient. Lumbar corsets have been recommended for patient comfort, which can also help remind patients to practice safe body mechanics. When there are other associated vertebral fractures

(such as vertebral body fractures), more intensive treatments may be required as the incidence of destabilization is higher.

Therapy for isolated LTPF should be focused on appropriate pain management and physical therapy to provide early mobilization.[6] Awaiting consults for spine specialists can serve to delay treatment. Recovery time can vary depending on the presence of other additional injuries. Reported recovery times average 1-2 mo for return to normal activities. Studies in professional football players can have a return to play within a month after an isolated LTPF.[5]

This was the first reported case of isolated transverse process fractures related to centrifuge training. This is most likely due to the fact that many isolated LTPF are not identified as they follow a similar natural history as soft tissue injuries of the back and the relatively insensitive nature of early plain films. Early identification of high energy trauma should prompt the clinician to assess the patient with a CT to not only evaluate for the presence of fractures, but also due to the high incidence of additional injuries occurring. Appropriate pain management and early mobilization are fundamental to recovery.

In conclusion, while this is the first reported case of isolated LPTF to occur in the centrifuge, it is most likely not the first case. As the symptoms can be mild, these fractures can be misdiagnosed as simple muscle spasms. Even if the clinician ordered lumbar radiographs, there is an increased chance that these fractures may not be visualized. It is imperative for clinicians to pay close attention and obtain advanced imaging sooner rather than later. While there were no pathological processes that were identified in this case report, the combination of deconditioning and unfamiliarity with the AGSM most likely led to improper body positioning and poor recruitment of stabilizing muscles. This is what most likely contributed to the patient's fracture development. While the patient had sought out urgent care, she should have been referred either to an emergency room or sent for immediate CT given the high frequency of associated internal injuries. As to the patient's recovery, access to a comprehensive pain management program that incorporated multiple modalities such as biofeedback, acupuncture, manipulation, and medical management could have benefited the patient as well. This case study should prompt flight surgeons to carefully assess individuals who complain of pain or other symptoms after completing centrifuge training.

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REFERENCES

1. Agrawal A, Srivastava S, Kakani A. Isolated transverse process fracture of the lumbar vertebrae. J Emerg Trauma Shock. 2009; 2(3):217–218.
2. Bradley LH, Paullus WC, Howe J, Litofsky NS. Isolated transverse process fractures: spine service management not needed. J Trauma. 2008; 65(4): 832–836.
3. Gan WH, Lam PM, Chong CH, Tan BCB, Fong KL, Tan HYR. Pneumomediastinum diagnosed by chest radiograph after centrifuge training. Aviat Space Environ Med. 2008; 79(4):424–428.
4. Gertzbein SD, Khoury D, Bullington A, St. John TA, Larson AI. Thoracic and lumbar fractures associated with skiing and snowboarding injuries according to the AO Comprehensive Classification. Am J Sports Med. 2012; 40(8):1750–1754.
5. Gray M, Catterson P. Multilevel lumbar transverse process fractures in a professional association football player: a case report. Oxf Med Case Reports. 2015; 2015(5):288–291.
6. Homnick A, Lavery R, Nicastro O, Livingston DH, Hauser CJ. Isolated thoracolumbar transverse process fractures: call physical therapy not spine. J Trauma. 2007; 63(6):1292–1295.
7. Kang K-W, Shin YH, Kang S. Acute spinal injury after centrifuge training in asymptomatic fighter pilots. Aerosp Med Hum Perform. 2015; 86(4): 386–391.
8. Lange B, Nielsen RT, Skej ØPB, Toft P. Centrifuge-induced neck and back pain in F-16 pilots: a report of four cases. Aviat Space Environ Med. 2013; 84(7):734–738.
9. Low R, Teo T, Loh A, Ooi A. Vertebral fracture in a pilot during centrifuge training: finding of osteopenia. Aviat Space Environ Med. 2008; 79:1067–1070.
10. Patten RM, Gunberg SR, Brandenburger DK. Frequency and importance of transverse process fractures in the lumbar vertebrae at helical abdominal CT in patients with trauma. Radiology. 2000; 215(3):831–834.
11. Xia T, Tian JW, Dong SH, Wang L, Zhao QH. Non-spinal-associated injuries with lumbar transverse process fractures: influence of segments, amount, and concomitant vertebral fractures. J Trauma Acute Care Surg. 2013; 74(4):1108–1111.
12. Yamakawa H, Murase S, Sakai H, Iwama T, Katada M, et al. Spinal injuries in snowboarders: risk of jumping as an integral part of snowboarding. J Trauma. 2001; 50(6):1101–1105.