FOOT & ANKLE Online Journal
OFFICIAL PUBLICATION OF International Foot & Ankle Foundation FOR EDUCATION AND RESEARCH

The vacuum phenomenon in the ankle joint: Air bubbles on CT

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The Foot and Ankle Online Journal 11 (2): 2

Gas or air bubbles in a joint space are most commonly associated with the "vacuum phenomenon," a collection of gas that has precipitated out of solution to take up a gaseous state within a joint. This phenomenon was unbeknown to us upon a patient presentation, seen on computed tomography scan, and so further academic investigation was performed to define this pathology. Because of this lack of awareness, a PubMed® literature review was performed to analyze the rate of incidence in foot and ankle. Additionally, we present a case example of the vacuum phenomenon in the ankle joint of a 50-year old patient presenting with degenerative ankle joint pain symptoms. Further, a review of the condition as well as differentials is discussed in an attempt to raise awareness of this differential diagnosis for gas bubbles within a joint.

Keywords: Air bubbles, ankle, arthritis, CT, computed tomography, foot, gas bubbles, gaseous degeneration, vacuum phenomenon

The presence of gas or air bubbles in a joint was first described by Fick in 1910 when he noticed gas bubbles in hand joints on radiograph (XR) evaluation while under traction [1-3]. Later this radiographic finding was coined the "vacuum phenomenon" (VP) by Magnusson in 1937 [2]. On imaging modalities such as computed tomography (CT) where it is most often visualized, it appears as a dark radiolucent pattern that can be shaped anywhere between a singular, linear bubble to confluence of bubbles within the confines of a joint space [2]. The shape is classically defined as a crescentic lucency paralleling a joint when found articular [3].

Gas bubbles were first thought to be associated with joint traction or trauma, but has since been found in situations of degenerative changes to joints [1,2]. Other associated gas bubble presenting pathologies include fracture-dislocation (e.g. traction injuries, open injuries introducing free air), ligament injury, metastasis, infection (e.g., abscess, osteomyelitis), cancer (e.g., multiple myeloma), intervertebral disc herniation/Schmorl's nodes, abdominal or thoracic free air (e.g., digestive tract perforation, pneumothorax, air embolism), decompression sickness, and iatrogenic causes (e.g., surgical introduction of air, arthroscopy) [2,4].

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Related to degenerative disease, its presence is most often cited to the sacroiliac (SI) joints (i.e., joint, facets, intervertebral discs) but also has been found in the pubic symphysis, lumbosacral space, and the joints of the temporomandibular, wrist, hand, hip, shoulder, knee, ankle (AKJ), subtalar (STJ), and calcaneocuboid (CCJ) [1-4]. Analysis of the gas in the SI location has found it to be predominantly nitrogen (> 90%) based , but oxygen and carbon dioxide among other gases are also present at much lower concentrations [2].

The purpose of this report was twofold: to determine the rate of occurrence of foot and/or ankle VP in the literature through a keyword search and present a case example of the VP to the AKJ in an end-stage degeneration clinical situation.

Methods

A PubMed® advanced keyword search was performed on May 1, 2017, using the term combinations of "air bubble," "bubble," "gaseous degeneration," "vacuum phenomenon," with "foot" or "ankle." The search had no restriction parameter fields applied. (Table 1) The returned abstracts were reviewed to determine their validity whether relevant to the primary search goal of obtaining articles demonstrating the VP from the ankle joint, distally. A table was then created counting the published instances of the VP in the foot and/or ankle.

Case Report

A 50-year old male patient presents to the senior author's office after referral from a previous podiatrist due to his primary complaint of ankle pain. The patient described the pain as a progressive pain upon ambulation. The patient is very active and enjoys running and mountain climbing in particular. He states he can walk up to 8 miles until he can't bare the pain anymore. He states his pain has been progressing in the ankle for 8 years now. Only rest has been able to alleviate his symptoms to this point in time. He has not sought any formal medical treatment prior to presentation.

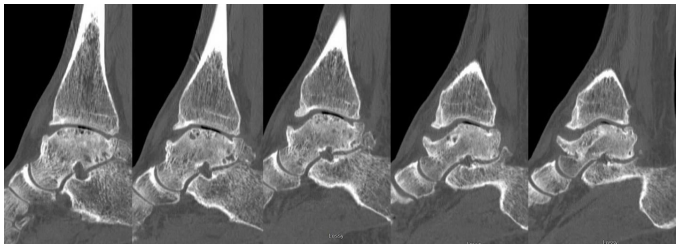

Figure 1 50 year-old male, sagittal CT scan of the ankle. Note the gas formation in the joint as well as presence within the subchondral bone region. Associated talar dome arthritic changes. Images are left to right, lateral to medial.

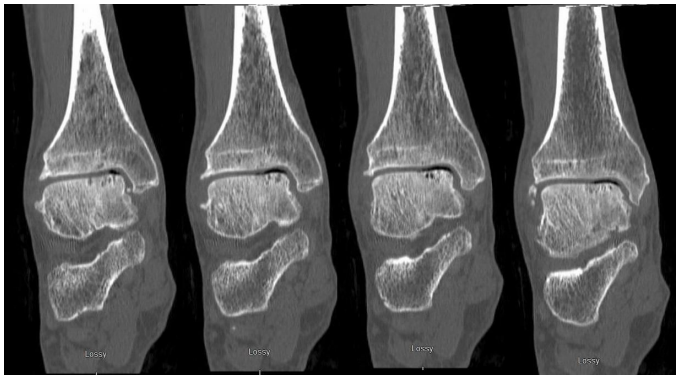

Figure 2 50 year-old male, coronal CT scan of the ankle. Note the gas formation centered around, and within the cystic changes to the medial talar dome. Images are left to right, anterior to posterior.

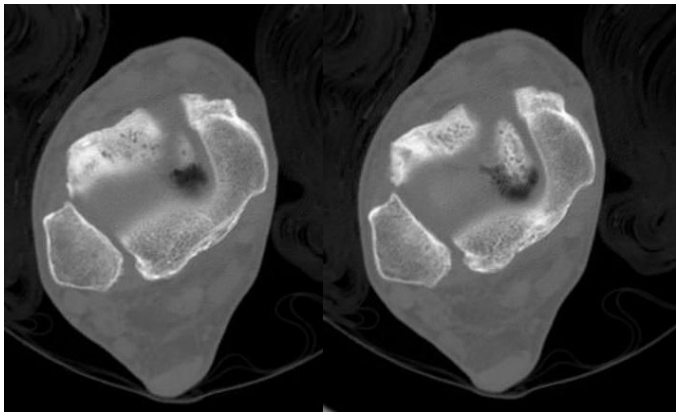

Figure 3 50-year-old male, axial CT scan of the ankle. Note the gas formation is positioned with the lower-lying cartilage defect space. Images are left to right, superior to inferior slices.

Ankle	Foot
● "air bubble" / "ankle"	● "air bubble" / "foot"
● "bubble" / "ankle"	● "bubble" / "foot"
● "gaseous degeneration" / "ankle"	● "gaseous degeneration" / "foot"
● "vacuum phenomenon" / "ankle"	● "vacuum phenomenon" / "foot"

Table 1 Key Word Search Parameters for Study Identification – Vacuum Phenomenon to the Foot and/or Ankle.

Ankle	Foot
● "air bubble" / "ankle" = 0	● "air bubble" / "foot" = 1 o None related to topic
● "bubble" / "ankle" = 3 o None related to topic	● "bubble" / "foot" = 21 o 1 discussing foot drop developed 10 days post-op disc surgery, secondary to nerve root gas bubble (Kloc et al., 1998)(6) o 1 discussing STJ ROM using a bubble inclinometer o 1 discussing diabetic foot bullosis diabeticorum
● "gaseous degeneration" / "ankle" = 0	● "gaseous degeneration" / "foot" = 2 o 1 discussing foot drop developed 10 days post-op disc surgery, secondary to nerve root gas bubble (Kloc et al., 1998)(6)
● "vacuum phenomenon" / "ankle" = 4 o 1 related to dislocated joint/trauma of STJ and CCJ (Ahmad et al., 2007)(5) o 1 related to STJ and AKJ (Lee et al., 1994)(1) o 2 discussing lumbar pathology	● "vacuum phenomenon" / "foot" = 2 o 1 related to STJ and AKJ (Lee et al., 1994)(1) o 1 discussing foot drop developed 10 days post-op disc surgery, secondary to nerve root gas bubble (Kloc et al., 1998)(6)

Table 2 Study Search Resulted Literature – Vacuum Phenomenon to the Foot and/or Ankle.

The patient's past medical history consists of hemochromatosis. There is no known past surgical history to the foot or ankle. There is no known family history of foot or ankle pathologies at this time. Medications consist of hydrochlorothiazide and a baby aspirin daily.

The patient's physical exam findings show limited dorsiflexion at the ankle joint and pain upon end range of motion in dorsiflexion at the ankle joint with a hard stop. His neurovascular status was grossly intact. There were no subjective complaints or objective findings of an infectious process based on the history and physical exam. He had no complaints of any other arthritic or painful joints. No other abnormalities were noted to his problem based exam.

A CT scan of the ankle exhibited degenerative joint disease to the talotibial joint along with a large anterior osteophyte of the distal tibia and talar neck at the ankle joint level. The CT scan also exhibited intra-articular gas centrally within the joint (Figures 1-3). Upon discussion with the reading radiologist it was declared that the gas was related to the VP. Further discussion with multiple facility radiologists where the study was performed revealed that the gas is due to nitrous oxide from surrounding synovial tissues, but can also be due to positioning of the ankle joint at the time of the study. From their experience, most VPs noted by these radiologists occur primarily in the lumbar spine and shoulders. None of them have seen such a finding in the ankle until this particular case.

Discussion of treatment options with the patient included less impacting exercises, an anterior ankle joint arthroplasty, and the need for a possible ankle joint replacement in the long term future. The patient was in favor of the anterior ankle arthroplasty procedure but would take time to think about his options moving forward. No treatments have been rendered to date and he has not returned to the senior authors' facility.

Results

From the PubMed® literature search, 33 articles resulted in total. After reviewing titles, abstracts, and database tags, removing irrelevant and duplicate entries, only two articles were relevant to this literature review of identifying examples of the VP in the foot and/or ankle (Table 2). This included a retrospective institutional review of CT imaging over two years evaluating the presence of gas bubbles in the lower extremity joints (i.e., AKJ, STJ, CCJ) and a case example of the VP in the STJ and CCJ after a trauma [1,5]. A third study found discussed a drop foot secondary to epidural gas formation and nerve root compression was not counted due to the distance location of the gas bubbles from the foot [6].

Discussion

The VP is a combination of anatomy and physics, calling into play both Henry's Law and Boyle's Law through hydrodynamic cavitation [2,4]. Simply put, gas precipitates out of solution through a negative intra-articular pressure when a joint is distended (e.g. traction) or collapses. The newly created free space within the joint capsule needs to be filled, and is done so by gas (primarily nitrogen) [2,3]. In this situation it is often by a gaseous element that precipitates out of the local tissue or synovial fluid due to changes in pressure [1,2,4]. Gohil et al (2014) and Yanagawa et al (2016) provide detailed explanations of this phenomenon. Normally, this gas goes back into solution when the joint returns to its normal volume and pressure. However in situations of arthritis, a thickened or fibrotic/scarred joint capsule does not allow the gas to dissolve out. Furthermore, excess joint space due to the presence of cartilage loss and subchondral cysts allows the gas to remain out of solution to fill that "extra" space [1]. In situations of traction or trauma to a joint, the blood gas nitrogen precipitates out of solution to fill the excess free intra-articular space from the joints' distention [5]. In open fractures, the outside air fills the spaces within the extremity, and is not a true VP.

The presence of the VP may be seen as something no more than an academic finding when present on a CT scan of a lower extremity joint. It has been documented in instances related to trauma (i.e. sprain; joint dislocation; rapid joint distention,) degenerative disease, osteochondrosis, osteonecrosis, idiopathic, osteomyelitis / infection, or conditions specific to the joint found in [1,2,5]. Its finding is most often related to degenerative disease to a joint, easily seen on CT due to its greater sensitivity with higher resolution compared to XR or magnetic resonance imaging (MRI) [1,2,4]. Associated pathology such as narrowed space, subchondral cyst, sclerosis, hypertropic degeneration to the joint may be seen along with the gas bubbles in degenerative situations across each imaging modality. In acute trauma, the presence of gas would suggest intact joint capsule and the associated intra-capsular ligaments however reports in the knee have shown otherwise [2].

When found, one important point is to correlate the finding to the presenting pathology through the patient history and physical exam so to not over or under diagnose the true pathology at hand [2,3]. This is most important when wanting to rule out any potential infectious processes such as septic joint, open fracture-dislocation, or penetrating joint trauma. Joint gas and spinal infection has been associated with bacteria such as obligate anaerobes or facultative organisms such as clostridia, *Peptococcus*, and *E. coli* [1,7]. Patterns of gas formation have been cited with different pathology from a linear formation in more benign pathology while bubble-like multi-lobulated patterns suggest infection [2]. In closed injuries, the presence may suggest a recent joint dislocation that otherwise may not be visible on imaging [5].

Specific to the lower extremity, Lee et al. (1994) performed an institutional retrospective review of CT scans over a two year period to determine the incidence of gas within the STJ and/or AKJ [1]. It

was documented in 12 cases (n = 495, 2.4%) on CT, none of which were related to infection. Of these, 11 were in situations of arthritis (post-traumatic, 10; non-traumatic, 1), 10 cases in the STJ, and although the XR did not show gas or air in the joints, degenerative changes were present and visible on both XR and CT. In the only other example, Ahmad et al. (2007) demonstrated the VP in a single case of an acute, closed STJ and CCJ fracture-dislocation [5]. One final unrelated but interesting case included epidural gas collection secondary to vertebral disc degeneration causing nerve root compression and a drop foot [6]. Ultimately, surgical decompression resulted in resolution of the drop foot.

The VP is very under-reported in the literature and in radiology reports [2]. In the SI joint where the finding is most common, one study found only a 16% reported rate [2]. For the case presented here, the finding was not mentioned in the radiologists report. Only in calling the radiologist who performed the evaluation did we get an explanation of the gas finding seen on CT. The condition may be unfamiliar to physicians other than radiologist, as was in this instance, where more awareness would be important for the ordering physician to add the VP to their differential diagnosis of gas in a joint without jumping directly to infection [2,7].

The authors surmised the VP finding in the lower extremity may not be seen in high percentages due to two more reasons. These are based on the physics of the VP and some speculation [2]. The first is that the VP is most sensitive on CT imaging. In instances of acute trauma to the lower extremity such as traction injuries (i.e. sprains) that are often evaluated, diagnoses, and treated in the outpatient setting, an MRI is often the modality used if advanced imaging is required. In these traumatized joints, by the time imaging is performed, the gas has possibly gone back into solution and fluid fills any remaining excess intra-articular space. In acute injury settings such as joint dislocations, it has been suggests that gas bubbles may be routinely seen within 4 hours of dislocation while occasionally seen after 48 hours on CT scan [8]. Another multi-joint study found, after inducing a transient traction-VP, the gas bubbles to disappear within 10 minutes [3]. If acute fracture-dislocations present in the emergent setting and the more sensitive CT is ordered, the VP finding may often be overlooked due to the more pressing osseous trauma that requires urgent treatment or be attributed to a concomitant open injury and free air. Second relates to the duration of gas presence in a joint, other than the aforementioned points. In situations of chronic degenerative disease, over time the gas within the joint achieves a new solubility equilibrium and will dissolve back into solution and not be visible. The time to reach equilibrium was not found in any report.

Conclusion

The VP is a finding consisting of gas or air bubbles on CT within a joint space. Its finding is under represented in the lower extremity joints with only two citations to date (not including this report). The presence should not be alarming when seen in a non-infectious presentation. Although its finding to date is not correlated with a more advanced joint degeneration to the lower extremity, the finding can be another example of degeneration in addition to visible cartilage loss, subchondral cysts, and scarred joint capsules. This example adds to the literature base of VP to the lower extremity and provides another mode of bringing awareness to physicians who treat the lower extremity.

Financial Disclosures / Funding Declaration

None

Conflict of Interest

None

Acknowledgements

None

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