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Use of Novel Digital X-ray Device Reduces Radiation Exposure, Imaging Costs, and Work Related Injury in the Emergency Department

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ABSTRACT

Background: *Emergency departments (EDs) depend on rapid, reliable radiography. However, conventional mobile X-ray units are often heavy and cumbersome, can contribute to delays in bedside imaging, and are associated with an increased risk of operator musculoskeletal injury. Despite advances in digital radiography, positioning and exposure errors still drive meaningful retake rates, adding avoidable ionizing-radiation exposure and cost; when each exam carries a material per-study cost, repeat imaging accumulates quickly.*

Objective: *To address common ED pain points—unnecessary radiation from retakes, ergonomic burden, and direct imaging costs—by evaluating a handheld, low-output system capable of digital radiography (DR), dynamic digital radiography (DDR), and fluoroscopy.*

Approach: *We describe the implementation of the OXOS MC2 handheld X-ray system in the ED and its design features intended to improve timeliness and safety: compact form factor; low radiation output with small scatter; and alignment safeguards ("no-fire" positioning) to reduce mis-framing and exposure errors. The system can be operated by trained ED personnel under appropriate supervision and local policy, aiming to alleviate technologist bottlenecks during peak demand.*

Significance: *In time-critical settings, every minute from order to first image matters for triage and disposition. By bringing DR/DDR/fluoroscopy directly to the bedside and reducing repeat acquisitions, decreasing cumulative radiation when no truly safe dose threshold has been established, lowering per-episode imaging costs, and mitigating staff injury risk linked to cart transport. The present work discusses ED pitfalls with conventional mobile imaging and outlines how a handheld approach may improve speed and accuracy, reduce wait times, reduce retakes, lower radiation dose, and lower department costs while maintaining diagnostic utility. These findings support broader use of handheld X-ray in emergency care pathways.*

Keywords
Radiation Exposure, Imaging Costs, Digital X-ray, Emergency Department.

Introduction
In recent years, the frequency of diagnostic imaging has increased consistently, with over 3.6 billion exams performed annually. X-ray is by far the most common imaging technique, representing over 50% of all radiography [1]. In emergency departments nationwide, mobile X-ray machines have become an indispensable tool for promoting a timely, accurate patient workup. Timely and accurate interpretation of imaging is particularly vital in critical cases [2], as extensive wait times in the ED have been shown to lead to the worsening of a patient's condition and delays in door-to-imaging

time are associated with increased mortality. Despite advances in the field, up to 15% of digital X-rays are rejected and must be retaken due to poor diagnostic quality [3], most often due to improper positioning, anatomy cut off, and over or under exposure [4]. The consequence of rejected images and subsequent retakes include deleterious health consequences of unnecessary radiation exposure to staff and patient, as well as increased department costs with each image. Additionally, the weight of a standard mobile X-ray machine can reach 1,000 pounds, and, in conjunction with heavy lifting throughout a standard shift, can predispose the technologist to work related injury. The purpose of this article is to address common ED pain points— time to image, unnecessary radiation from retakes, ergonomic burden, and direct imaging costs— by evaluating a handheld, low-output X-ray system with multiple imaging capabilities. The OXOS MC2 is a handheld X-ray device capable of digital radiography (DR), dynamic digital radiography (DDR), and fluoroscopy, equipped with a patented positioning system designed to assist image positioning and reduce retakes. This system is ideal for maneuvering the busy, crowded emergency department, the majority of which operate at or over capacity [5]. In addition, a handheld platform has the potential to shorten care intervals and reduce wait times while mitigating exposure to ionizing radiation. It would stand to reason that by implementing a device that addresses many of the pain points of mobile X-ray in the emergency department, triage would be expedited, patient care would be optimized, staff safety would be improved, and department overhead would be reduced.

Timely Imaging: An Emergency Department (ED) Bottleneck

Imaging plays a key role in emergency medicine, and is a tool that can be used to establish a diagnosis when the clinical picture may not be clear based on symptoms alone. Timely and accurate interpretation of imaging is particularly vital in critical cases [2]. O'Connell and Patlas state that emergency radiology is highly time-sensitive, as extensive wait times in the ED may lead to the worsening of a patient's condition and compounding wait times for other patients waiting to be seen [6]. Furthermore, studies have shown that patient mortality is associated with door-to-imaging time, which can be delayed by emergency department crowding [7]. The use of mobile imaging devices has proved to be helpful in the emergency department, which often function at or beyond capacity due to high patient volumes. Portable X-ray systems can be implemented directly at the point of care, are able to quickly obtain diagnostic imaging, and permit accelerated diagnosis, treatment, and discharge of patients. The advent of portable X-ray systems has helped streamline operations in the often chaotic and high-stress environment of the ED. The effect of this increased efficiency is reduced ED overcrowding, expedited diagnostics, and lower wait times [8]. Despite these improvements, current portable X-ray systems may be challenging to maneuver, predisposing ED staff to work-related musculoskeletal injury and burnout. In addition to higher than optimal retake rates associated with current portable X-ray systems, implementation of devices that protect ED staff while also delivering uncompromising patient care at a fast pace is of best interest to the department.

Retake Rate

When a radiograph is considered unacceptable due to inadequate diagnostic value or poor quality, it is rejected and must be retaken. Hasaneen and colleagues found that most technicians evaluate over 30 patients per shift and repeat up to 5 images [9]. On average, 10% to 15% of film-based X-rays are rejected, most often due to extremes of exposure rendering the image uninterpretable. Film-based X-rays, however, have largely been replaced by digital X-ray systems, an advantageous alternative that allows for faster image capture, improved quality, and interpretation of larger caseloads. Determining an exact retake rate (RR) for digital X-ray is difficult. Fintelmann and colleagues state this is because when an image is deemed unsatisfactory by the technologist, digital systems allow for immediate deletion on the acquisition station and are most likely never transferred to the Picture Archiving and Communication System (PACS) for storage [10]. Although likely an underestimation, studies have shown that 8%-13% of digital X-rays still require retake due to inadequate patient positioning, cutoff of anatomy, under or over exposure, patient motion, or artifact [10,11]. The skillset and ability of the technician also plays a role [12]. As the average X-ray in the United States costs $125 but can reach $500 in some regions [13], the financial burden of hasty image capturing as well as a low threshold for discard and retake can accumulate quickly and cannot be ignored.

Work Related Injury in X-Ray Technicians

The U.S. Bureau of Labor and Statistics states that overexertion has been the primary cause of workplace related injury for the past 25 years and costs $13.7 billion annually [14]. In healthcare settings specifically, over 40% of work related injuries are related to lifting or moving patients equipment [14]. For an X-ray technician or technologist (RT), moving equipment and patients is a central component of the job, as the transition from film to digital radiography has given rise to mobile X-ray stations that often weight up to 1,000 pounds. (Figure 1) [15,16]. Although this has improved diagnostic radiology and has permitted interpretation of a larger caseload, the contemporary radiology workstation has been widely associated with work related musculoskeletal disorders and injury [17], with up to 83% of X-ray technicians enduring pain or discomfort while performing work-related tasks [18]. Literature shows that ergonomic, occupational risks for injury include lifting, holding, or transporting heavy materials and equipment; working with the upper limbs above the head or away from the body (Figure 2) [19]; moving patients in bed; transferring patients; and moving patients with inappropriate equipment or with a number of professionals below what is considered adequate [20]. The X-ray technician may be presented with all of the aforementioned risk factors in a single shift, and risk of injury is increased further with night shift work. Maneuvering a portable X-ray system may be particularly difficult in a crowded, busy emergency department. Kling and West found that systems requiring extensive reorganization of hospital furniture or patient lifting and repositioning for image capture increase physical demands during a shift and therefore increase the likelihood of fatigue, burnout, and injury in RTs. This is often observed in fixedbase imaging systems that are incompatible with portable patient lifts [21]. Pew and colleagues found that an injured RT can cost an employer over a half million dollars each year through various means, such as; $32,000 in workers' compensation per injury per year, $52,000 in loss of revenue per injured technologist, $60,000–$80,000 per year in replacement staffing, and $20,000 per year in medical bills, which does not include surgical treatment [22]. Conservative approaches, such as recommending physical therapy regimens for injury prophylaxis, have been suggested in literature [17] and applied in some settings; however, addressing the root of the problem and equipping RTs with an ergonomic, handheld X-ray station would likely prevent burnout, eliminate the majority of work related injuries, and mitigate injury associated costs in the emergency department setting.

Figure 1: Examples of Mobile X-ray Systems [16].

Figure 2: Mobile X-ray System in Use [19].

Figure 3a: OXOS MC2 Portable System.

Figure 3b: OXOS MC2 Handheld X-ray Device.

OXOS MC2

The OXOS MC2 is a wireless, portable X-ray device with low radiation output, small scatter area, and a patented positioning system for image capture. OXOS MC2 features four distinct imaging modes; digital radiography (static imaging), dynamic digital radiography (live diagnostic imaging), fluoroscopy (live interventional imaging), and photography mode. OXOS MC2 is able to ensure adequate patient positioning prior to image capture with an integrated viewfinder that quantifies the angle and distance of the X-ray source to the detector, properly aligning the X-ray beam to the patient anatomy. The system is also "no fire" and prevents users from capturing an image prior to achieving the correct alignment required for diagnostic integrity. Accurate first-time image capture reduces retake rate and unnecessary IR exposure to staff and patient from subsequent takes. Furthermore, the low radiation output X-ray system emits less than 80% of the effective dose of a standard digital X-ray system, able to evaluate each patient's anatomy and size and deliver the minimum X-ray dosage required for high quality image capture. The unit's lightweight design, weighing 8 pounds, allows for easy mounting on a rolling cart (Figure 3a) and removal for image capture (Figure 3b), thereby easing the maneuverability challenges posed by standard systems. A recent study from The Ohio State University Medical Center evaluated and compared the use of OXOS MC2, a C-arm (GE OEC FPD Ergo-C), and a handheld portable X-ray system (MinXray TR90BH) in battlefield medicine. Proper evaluation of fracture in the field requires X-ray evaluation; however, the cumbersome nature of current X-ray systems and equipment is a major obstacle impeding diagnosis on the battlefield. The authors concluded the briefcase sized footprint of the MC2 is ideal for frontline integration into battlefield medicine, making it more than ideal for implementation into a hectic ED. Most importantly, the study found that OXOS emitted significantly less radiation than the C-arm and MiniXray, stating an OXOS operator would need to capture 102 hours of fluoroscopic images or more than 220,000 radiologic images to equal the average annual dose of background radiation on earth [23]. The findings of this study and the features of the OXOS MC2 provide a solution to the common pitfalls associated with X-ray imaging, such as IR exposure, image retake, and poor maneuverability.

Dynamic Digital Radiography (DDR)

Dynamic Digital Radiography (DDR) is a low-dose, high-frame-rate sequence of discrete radiographs that preserves full diagnostic quality for every frame, allowing replay and frame-by-frame analysis of anatomy in motion. Unlike fluoroscopic cine, which uses continuous exposure and integrates information across frames, DDR produces independent exposures without frame averaging or motion-compensation blur, enabling precise measurement of transient findings. In the emergency department, the Focused Assessment with Sonography in Trauma (FAST) exam is an ultrasound protocol developed to assess pericardium and three potential spaces within the peritoneal cavity for pathologic fluid [24]. If hemopericardium or hemoperitoneum has been identified and the patient remains hemodynamically stable, a computed tomography (CT) scan will be performed for further evaluation of the location and extent of the bleeding source. Patient throughput at the CT scanner is necessary to prevent bottlenecks and increased wait times; however, this is contingent upon many variables, such as timely image orders, lab orders and results, team communication, patient transport, and image interpretation. Evaluation of trauma patients often disrupts this flow even further [25]. High volumes of CT scans can often exacerbate ED wait times and are a primary contributor to delays in disposition and treatment. A noncontrast scan takes approximately 15.7 minutes, Stetson and colleagues found that a maximum of 3.2 scans can be performed per hour to prevent delays and maintain patient flow in the ED [25]. Furthermore, in an eight month period during which 10,063 CT scans were ordered in a New York ED, Perotte and colleagues found the average time from a CT order to the availability of the radiologist's final report was 5.9 hours [26]. Despite contributing to considerable wait times and costs, literature has shown that 25-33% of CT scans ordered in the ED are medically unnecessary [27,28]. In recent years, DDR has been most frequently implemented in chest imaging, as dynamic acquisitions not only convey information involving the movement of the diaphragm, thoracic wall, lungs, and mediastinal structures [29], but can even detect blood flow defects associated with thrombosis without the need for contrast agents [30,31]. In addition, DDR is able to measure pulmonary ventilation and perfusion, as well as assess airway narrowing. Use of a tool that is able to evaluate many of the same conditions as CT in a fraction of the time would be valuable for promoting CT throughput of critical patients, ultimately mitigating department wait times.

In the evaluation of musculoskeletal conditions, those of which comprise 20% of all ED visits [32], DDR supports rapid functional stress testing of injured extremities at the point of care, making occult instability visible when static radiographs are normal. For the hand and wrist, DDR can reveal scapholunate diastasis or abnormal carpal kinematics during clenched-fist or radial/ulnar deviation maneuvers, document dynamic subluxation after perilunate injury, and demonstrate valgus laxity of the thumb MCP suggestive of ulnar collateral ligament insufficiency ("skier's thumb") under motion. For the foot and ankle, DDR can unmask lateral ankle instability (ATFL/CFL) by quantifying talar tilt and anterior translation during varus, plantarflexion, and anterior-drawer sequences; reveal syndesmotic injury via dynamic widening of the tibiofibular and medial clear spaces with external-rotation/eversion stress; and expose Lisfranc/midfoot instability under forefoot abduction/pronation or weightbearing stress. It also depicts anterior/posterior impingement during dorsiflexion/plantarflexion cycles and documents first-MTP ("turf toe") and lesser MTP plantar-plate injuries with dorsiflexion stress showing dorsal subluxation and sesamoid malalignment, using the contralateral side as an internal control. DDR complements standard radiography and ultrasound for initial assessment, while fluoroscopy remains preferred for continuous real-time guidance during reductions or percutaneous procedures. By exposing dynamic pathology quickly at the bedside, DDR helps triage patients more accurately and expedites definitive management. Inclusion of an excessively portable X-ray system that is capable of DDR provides immense utility in an ED setting.

The Effects of Ionizing Radiation

Over 50% of manmade ionizing radiation exposure is from X-rays alone [33]. Siama and colleagues presented a study that concluded chronic exposure to a low level of IR is a non-avoidable occupational hazard for health care workers, therefore increasing the risk of health deterioration. This risk is dose-dependent; directly dependent upon the time spent with X-rays, the amount of radiation received, and the number of patients handled daily [34]. Exposure to IR is the strongest established environmental causative factor for breast cancer in men and women [35]. Furthermore, multiple studies [36,37] have found a higher incidence of breast cancer in nurses compared to the general population. In fact, a 35 year longitudinal study including over 830,000 women found that female healthcare workers in general had a significantly higher risk of breast cancer compared to nonhealthcare professionals [38], further pointing to the potential consequences of long term, low dose exposures to medical radiation. The dose-related consequences of IR exposure extend beyond carcinogenesis alone, and have even been associated with the development of circulatory and metabolic disease [39]. In addition, Chen and colleagues explored associations between thyroid disease in 28,649 physicians and 57,298 members of the general population to discover that physicians had a significantly higher risk of thyroid disease, including thyroid cancer, hypothyroidism, and thyroiditis. The authors concluded that exposure to medical radiation, which is higher and more frequent in physicians than in the general population, is a possible explanation for this finding [40]. Healthcare workers were found to have an increased risk of hypothyroidism in another study; and interestingly, IR exposure of the study group was within ICRP threshold for allotted annual exposure [41]. The results of these studies point to the importance of mitigating radiation exposure by choosing systems designed with low emission, low retake rate and high accuracy in mind, as no safe dose has truly been identified.

Discussion

Over 1 billion X-rays are performed worldwide each year and will continue to escalate, with bedside X-rays showing a 30% increase annually from 2010 to 2020 [42]. The advent of digital

X-ray systems maneuvered by an RT have been an indispensable component in emergency medicine in recent years; however, improving speed and accuracy, reducing retake associated cost, improving machine configuration, and mitigating IR exposure would benefit staff and patient. Emergency radiology is highly time-sensitive, as extensive wait times in the ED may lead to the worsening of a patient's condition and compounding wait times for other patients waiting to be seen. As door-to-imaging time directly corresponds to patient mortality, systems that foster fast and accurate image capture are essential considerations to optimize patient care. Diagnostic accuracy is vital for reducing retake rate, which increases IR exposure to patients and staff. Multiple studies have associated IR exposure with the development of cancer, circulatory, and metabolic disease, with healthcare workers being at higher risk than the general population for several radiation-dependent conditions. The literature shows adverse health events can occur at levels of IR exposure within margins deemed safe by the ICRP; therefore, it is in the best interest of medical staff and patients alike to choose interventions that mitigate IR exposure as much as possible. Reducing IR exposure can be accomplished by minimizing the amount and frequency of X-ray image retake captures. Studies have shown 58% of X-ray retakes are due to inadequate patient positioning and 18.3% are due to anatomy cut off [11], ensuring the patient and anatomy is in place before imaging is an effective intervention that not only limits IR exposure, but also confers a cost saving benefit to the department as each X-ray costs approximately $125 [13].

Additional cost saving can be procured with the use of devices that do not require a technician with specialized training for operation and can be used accurately and effectively by any member of the care team. According to the Bureau of Labor Statistics, the median annual wage of a RT is $77,660 and the field is projected to increase by 6% by 2033 [43]. Furthermore, when considering up to 83% of X-ray technicians endure pain or discomfort while performing work-related tasks [18], likely due to the weight and poor maneuverability of the contemporary portable X-ray, a single injured RT has the potential to cost an employer over a half million dollars annually [22]. The OXOS MC2 is a wireless, handheld system that addresses each disparity described above. With radiation emission between 9-59% of standard clinical X-ray machines. In addition, operator dosage was reduced, as an OXOS operator not wearing lead would need to capture between 75-225 hours of fluoroscopic images or between 67,500-165,000 radiologic images to equal the average annual whole body radiation approved by the NRC (5,000 mREM per year) [23,44]. When compared to allowable annual NRC dosage for the extremities (50,000 mRem per year), an OXOS Operator wearing lead, increased the allowable exposures to 750-2250 hours or 670,000-1,065,000 images for fluoroscopic and radiologic images, respectively [23]. These dosage calculations were based on radiographic set-ups using 40-70kvp, 0.16-0.25 mAs, and SID 45-80 cm, which varied based on configuration for hand, shoulder, knee, or ankle image capture. Similarly, fluoroscopy dosage was assessed based on 5 pps, 50-64 kvp, 0.08 mAs, and SID 45-80 cms for the same anatomy as listed above. The system is able to evaluate each patient's anatomy and size, delivering the minimum X-ray dosage required for high quality image capture, mitigating X-ray scatter and IR dose. This technology also features a "no fire" positioning system which greatly reduces the need for retakes, as the system will not allow the operator to capture an image with an improperly positioned patient or if the anatomy is not visualized in its entirety. Therefore, any member of the care team can take high-quality X-rays, accelerating the time and ease of imaging and eliminating the need for trained RTs entirely. Most notably, OXOS MC2 is lightweight, portable, and easy to maneuver, with one study stating its briefcase-sized ergonomic design is effective for frontline use in battlefield medicine. A compact, lightweight X-ray system would be ideal for use in a crowded, busy emergency department, particularly because the operator can position the device over the patient directly, foregoing the need to physically move patients and hospital furniture for image capture. After elaborating on the benefits of each component of OXOS MC2 individually, it would stand to reason that use of a portable X-ray device with these combined features in the emergency department will mitigate radiation exposure to both staff and patient, expedite triage, improve diagnostic speed and accuracy, reduce wait times, and lower department costs.

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