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Original Research Article

Availability and Functionality of Diagnostic Imaging Equipment for Road Traffic Crash Injury Management in Ghana: Case of Ashanti Region

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ABSTRACT

Background/Objective: Diagnostic imaging technologies have enhanced the understanding and management of road traffic crash (RTC) injuries and are essential for guiding the diagnosis of injuries. Despite their importance, few studies regarding their accessibility to crash-prone areas (blackspots) are available. This study sought to investigate the spatial accessibility, availability, and functionality of four essential imaging modalities (ultrasound, plain X-ray, computed tomography [CT], and magnetic resonance imaging [MRI]) for the management of RTC injuries in the Ashanti region of Ghana. **Methods:** A cross-sectional quantitative study was conducted covering 38 public, private, and mission-based hospitals, and seven diagnostic centers. Data were collected with a structured questionnaire on availability, functionality, and maintenance status of equipment. Spatial distance analyses between RTC blackspots (n = 104) and hospitals with imaging equipment were conducted using ArcGIS, a leading comprehensive geospatial platform, and statistical comparisons were performed using Wilcoxon Signed-rank tests. Descriptive comparative analyses were conducted to determine the functionality and maintenance status of the modalities studied. **Results:** The study discovered 3 MRI, 12 CT, 61 X-ray, and 108 ultrasound machines available in the region, but only 1 MRI in the public sector. While 60% of CTs (n = 12) were found in the private sector, 59% of X-rays (n = 61) and 62% of ultrasounds (n = 108) were in the public sector. The overall estimated mean travel distance from all 104 blackspots to the nearest MRI, CT, and X-ray modality was 35.43 km (± 19.80 km), 26.82 km (± 19.04 km), and 8.68 km (± 5.15 km), respectively. There was no statistically significant impact of non-functional MRI and X-ray modalities; however, travel distance to CT machines increased by 2.8 km (p < 0.001) because of the three hospital-based non-functional CTs in the region. Regarding technical support, in-house hospital-based biomedical engineers were found to possess technical expertise in maintaining X-ray and ultrasound technology, but not CT and MRI. **Conclusion:** This study highlights the disparities in access to diagnostic imaging equipment in the Ashanti region of Ghana. While X-ray and ultrasound modalities were well distributed across the region, access to CT and MRI was limited. Prioritization of the repair and maintenance of the non-functional CT machines in the three health facilities could improve access to this service and prevent delays to emergency care for RTC victims.

Keywords—*Access to care, Diagnostic imaging equipment, Ghana, Road traffic crashes, Accident blackspot, Spatial distribution, Ultrasound, X-ray, CT, MRI.*

INTRODUCTION

Death by road traffic crashes (RTC) is a major public health challenge globally in low- and middle-income countries (LMIC), and especially in Africa.[1–3] In Ghana, the situation is not any better, with the Ashanti region recording the highest number of RTC fatalities.[4,5] Preventing RTC is the gold standard; however, when they occur, minimizing the consequences of severe injuries by providing care to the injured significantly contributes to reducing morbidity and mortality.[6–10] Poor access to emergency medical services, prehospital care, and medical imaging modalities needed for efficient diagnosis in health facilities contributes to preventable deaths that occur in trauma settings, especially in Africa.[11,12]

When injured RTC victims are admitted to the emergency room of a hospital, they are often unconscious, in shock, disoriented, or intubated. Depending only on clinical examination is unreliable for ruling out some traumatic injuries.[13,14] Diagnostic imaging techniques have proven to help in confirming the suspicion of clinicians and helping to guide treatment pathways, resulting in reduced treatment costs and improved outcomes.[15] Improvement in imaging technologies over the last few decades has enhanced the understanding and management of trauma patients and has proven to be essential to guide diagnosis, thereby lessening the risk of mortality and morbidity.[13,14,16]

The Advanced Trauma Life Support (ATLS) program of the American College of Surgeons (ACS) has globally influenced the protocols governing the care of severely injured patients. The ATLS is based on the fundamental principle of rapid assessment and resuscitation of patients in the window of opportunity, widely known as "golden hour", to lessen the risk of morbidity and mortality.[17] The ATLS recommends diagnostic imaging for trauma patients during primary surveys for resuscitation, and during secondary surveys for definitive care. The adjuncts to primary survey for trauma patients include anteroposterior (AP) chest conventional radiography (X-ray), pelvic X-ray, and/or lateral cervical spine X-ray to check for fractures and other life-threatening injuries; abdominal sonography (known as Focused Assessment with Sonography in Trauma [FAST]) is performed to quickly detect free intraperitoneal fluid, which may indicate abdominal bleeding. These essential diagnostic examinations offer critical information to clinicians to affirm resuscitative measures.[18] The adjuncts to secondary surveys include specialized diagnostic tests, such as whole/total body computed tomography (CT) scan (using a CT machine) to rule out craniocerebral, cervical, or thoraco-abdominal injuries, or magnetic resonance imaging (MRI) if brain injuries are suspected.[17] These essential diagnostic tools make imaging equipment vital for the initial assessment of RTC victims.

Despite the apparent advantages that diagnostic imaging offers to clinicians in the trauma environment, resource-limited settings have faced significant challenges in improving access to these necessary diagnostic modalities. Some of the barriers relate to the cost of the equipment, lack of infrastructure needed to support their use (water, electricity, Internet, access roads, etc.), poor maintenance regimes because of a lack of trained biomedical engineers, insufficient radiologists, to mention a few.[19–21]

Accessibility can be conceptualized as spatial or aspatial. Spatial accessibility refers to the impedance of travel (typically measured as travel time or distance) between service demand locations and service providers. Availability (an aspatial dimension of access), reflects the volume of services required to meet the population demand.[22] Previous studies in emergency medical care have investigated access to ambulance services[23], hospital emergency departments[24], and surgical services.[25,26] Other studies have explored the availability of diagnostic imaging equipment in resource-limited settings, such as by investigating the number of modalities present within a catchment area. However, to the present authors' knowledge, no study has investigated accessibility to diagnostic imaging equipment from RTC-prone areas (also known as blackspots).

The growing role of medical imaging in the management of trauma victims, along with the development of more sophisticated technologies, supports clinicians in the rapid identification and diagnosis of life-threatening injuries.[14] Although the need for imaging equipment for early and efficient diagnosis of RTC injuries is well documented, there is a paucity of knowledge regarding where they are located with respect to RTC, their functional state, and how accessible they are to crash-prone areas in Ghana.

This study therefore focused on the availability and functionality of diagnostic imaging equipment, whose relevance to RTC injury management is best appreciated with respect to their clinical applications during emergencies. While conventional radiography (X-ray) remains essential for the initial evaluation of bone and skull fractures, pneumothorax, pelvic trauma, and some internal injuries, ultrasound (US), especially FAST, has a critical role in the rapid detection of internal bleeding in the intra-peritoneal area. CT scan is particularly important for rapid assessment of head, spinal, thoracic, and abdominal injuries, and MRI is useful when brain and/or spine injuries are suspected. All these types of injuries are common and potentially life-threatening consequences of RTCs.

The objective of this current study is to investigate the availability and functionality of essential imaging equipment in health facilities for RTC injury management in the Ashanti region. The novelty of this study is that Geospatial Information Systems (GIS) techniques were used to evaluate not only the availability but also the spatiotemporal associations between crash sites and facilities providing diagnostic imaging services. Using GIS methodology can reveal service disparities, enhance

TABLE 1. Summary of essential diagnostic imaging modalities for RTC injury management.

	MRI	CT[27]	X-ray[13]	Ultrasound
Type of Emission	Magnetic field and radio frequency (RF) waves	X-rays	X-rays	Sound waves
Principle of Operation	Strong magnetic fields align hydrogen nuclei (protons) in the body. Bombarded with RF signals, these protons fall out of alignment. The energy released when the RF signal is turned off is processed into detailed 3D images	Narrow beams of X-ray are transmitted through the body and collected by detectors on the opposite side of the body from multiple angles. Attenuated X-rays are collected and analyzed with complex algorithms into 3D images for viewing	High-voltage electrons from a cathode collide with a metal anode to produce X-rays. Attenuated X-rays are collected on a photographic film based on X-ray absorption capacity of biological organs	High-frequency, inaudible sound waves emitted through a transducer (probe) to the body and received back. Degree of attenuation in the biological material is processed and converted into images[28–30]
Type of Body Part Most Suitable for Use	Soft tissues, especially the brain and spinal cord	Whole body	Skeletal frame and chest	Abdominal (for intra-peritoneal fluid check)
Organs of Interest in RTC Patients	Brain	Brain, spinal cord, chest, and soft tissue organs	Skull, pelvic, chest, and extremities	Kidney, liver, spleen, pancreas, and bladder
Indication for Use	Suspected neurological injury in severely injured patients	Suspected brain or spinal injury	Suspected bone fracture, hemothorax, and pneumothorax	Blunt abdominal injury
Some Advantages	•High resolution •No ionizing radiation •Penetration of bone and air without attenuation	•Non-invasive •Whole body scan in a single exam •Consistent quality •3D imagery •Less dependent on operator •Reproducible •High resolution	•Quick to perform •Readily available	•Non-invasive •Real time •Portable •Cost-effective •Versatile •FAST[a] scans excellent for detecting abdominal fluid in trauma patients[13,31]
Some Disadvantages	•Unsuitable for patients with metallic implants •Expensive •Limited availability •Time consuming	•Ionizing radiation exposure •Allergic reactions to contrast media •Expensive •Limited accessibility in LMICs	•Limited information •2-dimensional •Difficult to discern soft tissue organs accurately	•Limited field of view •Reduced resolution •Operator dependent

Note: CT: computed tomography; [a]: Focused Assessment with Sonography for Trauma; LMIC: low- and middle-income country; MRI: magnetic resonance imaging.

diagnostic imaging resource distribution, and improve the existing health systems.

This study covered four imaging modalities: ultrasonography, X-ray, CT, and MRI. The findings from this study revealed the current situation in the Ashanti region of Ghana, and are expected to help policymakers decide on ways to improve access to these services. In this study, equipment was deemed functional if it was operational, produced reliable and accurate images, was available for use when needed, and was deemed safe to be used by its operator.[32] A summary of these modalities and their usefulness in the management of RTC injuries is presented in Table 1.

MATERIALS AND METHODS

The Ashanti region is Ghana's third largest of the 16 regions covering a land surface of 24,389 km^2. Lying between longitudes 0.15° W and 2.25° W and latitudes 5.50° N and 7.46° N, the region has a population of 5.44 million, making it the most populated region.[33] Ashanti boasts of 658 health facilities, with 53% private, 33% government, 11% quasi-government, and 3% faith-based facilities. The Ghana Health Service and the Ministry of Health have oversight responsibility of all government-owned facilities.[34]

This study was a cross-sectional work with a quantitative approach. Preliminary data on possible locations of the modalities in question were sourced from the Ashanti Regional Health Directorate of the Ghana Health Service and consolidated with work done by Bour et al.[35] Essential imaging modalities of interest were ultrasound, X-ray, CT, and MRI because they have been recommended by the ATLS for the initial evaluation of trauma patients involved in high-energy vehicular crashes.[17] A structured questionnaire adapted from the World Health Organization's (WHO) Harmonized Health Facility Assessment (HHFA) tool[36] was used to collect data on the availability, functionality, and maintenance status of these modalities in the health facilities. The study questionnaire was administered by Akofa Bart- Plange (ABP) and research assistants, to appropriate personnel (administrators, radiologists, and/or biomedical engineers) at all 48 public, private and Christian Health Association of Ghana (CHAG)-owned facilities (hospitals and diagnostic centers) known to have at least one of the modalities of interest. Written consent was obtained from each participant at the facility. Information collected included details of the facilities, and the presence and functional status of the equipment. GIS data of all imaging equipment identified during the study were collected for mapping. The presence of ultrasound machines alone did not qualify a facility to be part of this study as most of such facilities were maternity or family clinics without emergency departments, hence unsuitable as destination hospitals for RTC victims. The primary data were collected between March and April 2024. Secondary GIS data of all blackspots in Ashanti region were sourced from Mesic et al.[37] The type of facility at which the equipment was located was classified as either "health facility" (hospital) or "diagnostic center" (a location where diagnostic tests are performed but other care is not provided).

All the imaging modalities were mapped geospatially using ArcGIS Pro software (version 3.3.2, Environmental Systems Research Institute [ESRI], Redlands, CA, USA, 2024) after which geolocations of all the blackspots were superimposed on the data set. A proximity tool (Near Analysis) was used to determine the travel distance between all blackspots and each of the modalities available, assuming 100% functionality, and repeated exclusively with actual functional units. The output of the solver was exported into a Microsoft Excel spreadsheet version 16.92 (Microsoft Corporation, Redmond, WA, USA) for analysis and visualization.

A second tool, the Closest-Facility Solver, was used to find the number of blackspots closest to health facilities with CT-installed base, assuming 100% functionality; the same analysis was conducted with only actual functional units and differences in access were examined. The descriptive analysis was based on imaging modality type, ownership, age from the year of installation, type of maintenance cover, and functional status. Comparative analysis of ownership/functionality and maintenance cover type/modality was performed.

This study was approved by the Ghana Health Service Ethics Review Committee (GHS-ERC:024/10/23), the Komfo Anokye Teaching Hospital Institutional Review Board (KATH.IRB/AP/014/24), and the Ethical Committee for Basic and Applied Science of the College of Basic and Applied Science, University of Ghana (ECBAS 006/23-24).

RESULTS

Spatial Analysis and Characteristics of MRI, CT, X-Ray, and Ultrasound Equipment

Figure 1 shows the geographical spread of the imaging modalities with respect to injury blackspots in the Ashanti region of Ghana. All three MRI machines found were concentrated in the center of the region. Two (16.67%) CT machines were geographically located outside the central part of the region, one of which was non-functional (NF). X-ray machines were sufficiently spread around most of the blackspots in the region.

Table 2 presents the characteristics of all the four imaging modalities covered by the study. In all, 48 facilities were visited and a response rate of 93.8% was achieved; 84.4% (*n* = 38) were health facilities and 15.6% (*n* = 7) were diagnostic centers.

Table 2 shows that two of the three MRIs in the region were in health facilities: one in a public hospital and the other in a private hospital. At the time of data collection, all three MRIs were functional and in use with an average usage age of almost 10 years. No faith-based facility owned an MRI machine.

The CTs found in this study were primarily in health facilities (60%) and in the private sector. Majority (66.7%) were discovered to be functional and in use with an average usage age of 6.5 years.

Almost 60% of X-ray machines were found in the public sector, with CHAG and private facilities constituting 11.5% and 29.5% ownership, respectively. The majority (82%)

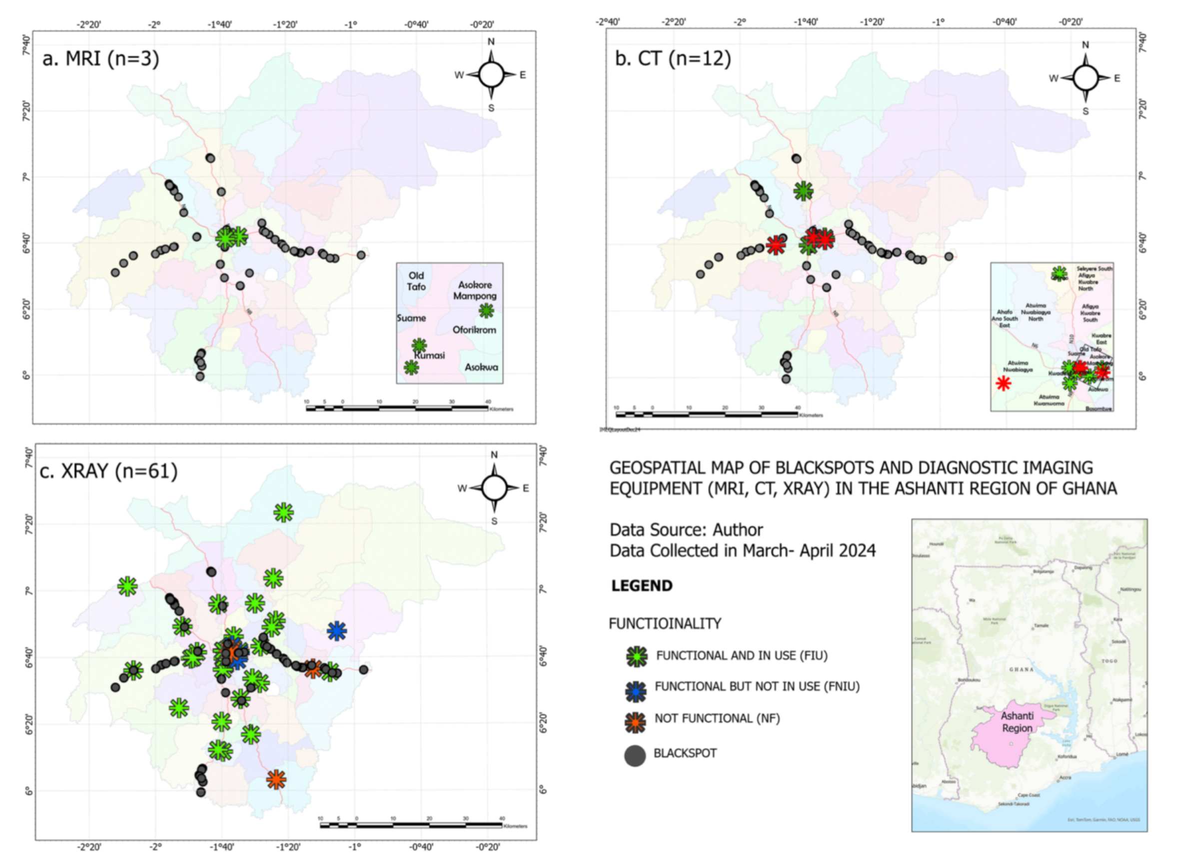

FIGURE 1. Distribution of MRI, CT, X-ray, and RTC blackspots in the Ashanti region of Ghana. The mapping of ultrasound machines was left out, as it is a replica of X-ray machines; all X-ray locations had an ultrasound machine. Moreover, locations with only ultrasound machines were also not included in the study, as they were likely to be maternity clinics, gynaecological scanning diagnostic centers, or private hospitals without emergency departments for RTC victim management.

of X-ray units were discovered to be functional and in use with an average age of 7.8 years (Table 2).

TABLE 2. Characteristics of diagnostic imaging equipment in Ashanti region.

	MRI (*n* = 3)	CT (*n* = 12)	X-ray (*n* = 61)	Ultrasound (*n* = 108)
Availability				
Health facility	2 (67.0)	8 (60.0)	54 (88.5)	97 (89.8)
Diagnostic center	1 (33.0)	4 (40.0)	7 (11.5)	11 (10.2)
Ownership				
CHAG	-	2 (20.0)	7 (11.5)	15 (13.9)
Private	2 (67.0)	6 (60.0)	18 (29.5)	26 (24.1)
Public	1 (33.0)	2 (20.0)	36 (59.0)	67 (62.0)
Functional status				
FIU	3 (100.0)	8 (66.7)	50 (82.0)	95 (88.0)
FNIU	-	-	2 (3.3)	5 (4.6)
NF	-	4 (33.3)	9 (14.7)	8 (7.4)
Mean age (years)	9.7	6.5	7.8	4.8

Note: CHAG: Christian Health Association of Ghana, CT: computed tomography, FIU: functional and in use, FNIU: functional but not in use, MRI: magnetic resonance imaging, and NF: not functional. Numbers in brackets represent percentages.

Comparative Analysis of Ownership, Functionality, and Maintenance Status

Figure 2 shows the functional status of the modalities with respect to ownership, while Table 3 lists the reasons for non-functionality. There were more non-functional CT machines in the public sector, while the majority of X-ray machines in the public, private, and faith-based facilities were functional and in use.

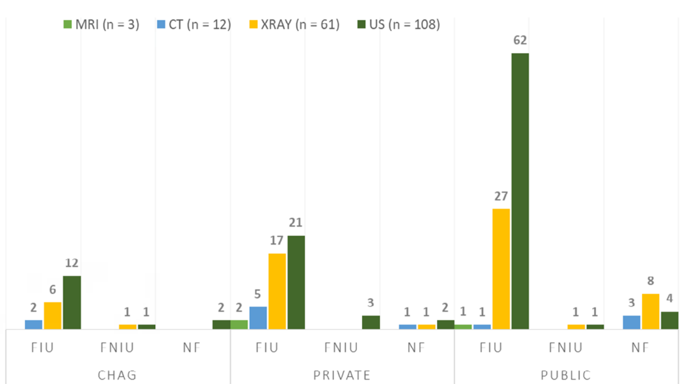

FIGURE 2. Distribution of ownership and functional status of diagnostic imaging equipment in the Ashanti region of Ghana. (FIU: functional and in use; FNIU: functional but not in use; NF: non-functional. All FNIU units were X-ray and ultrasound machines which were operational but available as back-up units.)

TABLE 3. Reasons for non-functionality and non-utilization of imaging equipment.

(a) Non-functionality		
Ultrasound	**X-ray**	**CT**
•Faulty electronic board	•Faulty detector. Awaiting new detector	•Damaged spare parts. Awaiting import of new parts
•Outmoded software	•Faulty X-ray machine. Yet to conduct troubleshooting	•Damaged UPS[a] system
•Uninstalled units	•Damaged X-ray processor	•Damaged tube
•Faulty printer	•Faulty installation. Machine has not been used since	
•Faulty unit	•Stolen parts from equipment	
(b) Non-utilization (functional but not in use) Some health facilities had functional X-ray and ultrasound machines which were used as backup to other functional units hence their non-utilization. Most of these facilities had more than one unit.		

Note: [a]: uninterruptible power supply.

Figure 3 shows the proportion of the imaging modalities that had some maintenance cover. MRIs were mostly covered under comprehensive service contracts, while CTs were largely not covered at all (45%) or had a labor-only coverage (18%). One-third of CTs were, however, found to be covered comprehensively. More than half of X-ray machines (56%) were covered comprehensively, with a significant number of facilities reporting callouts to external technical teams for support. The in-house biomedical engineering teams had technical expertise to maintain ultrasound and X-ray machines but not CT or MRI.

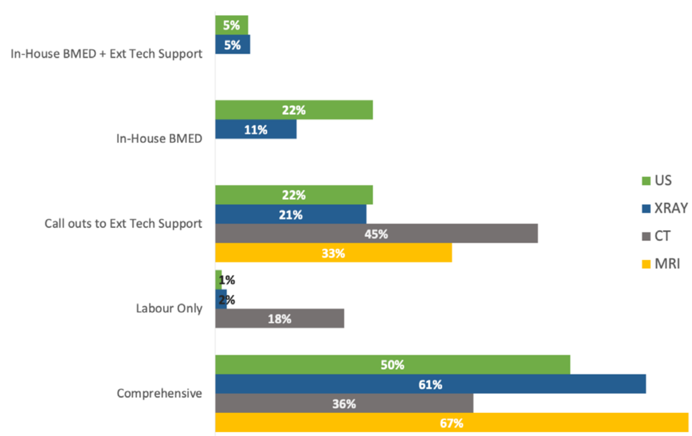

FIGURE 3. Types of maintenance cover for MRI, CT, and X-ray equipment in the Ashanti region of Ghana.

Effect of Non-functionality on Access to Diagnostic Imaging Equipment from Blackspots

Table 4 reveals the effect of non-functionality on access to imaging services by RTC victims. It shows the geographical proximity (by travel distance) of three diagnostic imaging modalities. The distance from a blackspot to a health facility where an X-ray machine was available and definitive care could be given to victims was found to be about 9 km, assuming that all the X-ray machines were functional in those hospitals. The same analysis carried out excluding the non-functional equipment found a nonsignificant change in distance of about 20 m. However, the same analyses conducted on CT machines revealed a statistically significant travel distance increment of nearly 3 km. Owing to the statistically significant impact of non-functionality on CT access, the study went further to investigate the distribution of blackspots around health facilities that had an installed CT machine (Table 4).

TABLE 4. The distance that RTC victims cover from crash sites to hospitals with diagnostic imaging equipment because of broken down equipment.

	Distance (km)			
	Distance to All Hospital-Based Machines n (SD)	Distance to Only Functional Hospital-Based Machines n (SD)	Change in Average Distance	*p* value[b]
X-ray[c]	8.68 (5.15)	8.70 (5.12)	+ 0.02	0.068[a]
CT[d]	26.82 (19.04)	29.63 (19.41)	+ 2.82	0.001[a]
MRI[e]	35.43	35.43	0.00	NA

Note: [a]: the Wilcoxon Signed-rank test; [b]: analyzed at 95% confidence level (95% CI); [c]: there were 54 hospital-based X-rays, with eight non-functional machines; [d]: there were eight hospital-based computed tomography machines, with four non-functional ones; and [e]: there were two hospital-based magnetic resonance imaging machines; both were functional.

The results of the GIS closest-facility analysis for CT machines are shown in Table 5.

Seven of the eight health facilities with CT machines were discovered to be close to all the 104 blackspots identified in the Ashanti region; however, three health facilities (HFCT-02, HFCT-08, and HFCT-10) were closest to a combined majority (80%) of the known blackspots. Repeating this analysis exclusively on health facilities with only functional CTs revealed a redistribution of blackspots to four facilities only, with three of them being close to 99% of all blackspots.

TABLE 5. Non-functionality of CT machines affecting the distribution of blackspots around health facilities.

Health Facility Code	Number of Blackspots Closest[a] to Facility, Assuming All CTs Were Functional	Number of Blackspots Closest to Functional CTs only	Percentage Change in Number of Blackspots	Number of Slices of CT	Age of CT	Type of Maintenance Cover
HFCT-01	6	44	633%	16	11	Compre -hensive
HFCT-02	27	-		16	2	Compre -hensive
HFCT-04	10	36	260%	16	7	Compre -hensive
HFCT-05	4	-		128	12	Call outs to external team
HFCT-06	1	5	400%	32	2	Call outs to external team
HFCT-08	38	-		6	5	Labor only
HFCT-10	18	19	56%	32	1	
Total	104	104				

Note: [a]: the closest facility solver calculates the shortest path between a blackspot and facilities with CT machines available using distance or time as impedance. This study chose time as impedance. CT: computed tomography.

DISCUSSION

This study aimed to analyze accessibility of essential diagnostic imaging equipment to RTC victims to support efficient diagnoses and treatment of their injuries. As part of a larger study on the efficiency of emergency medical services, we investigated the availability and functionality of MRI, CT, X-ray, and ultrasound machines for road traffic injury management in health facilities in Ashanti region, the region with the highest number of road crash fatalities in Ghana.

Magnetic Resonance Imaging

Figure 1(a) shows the sparsity of MRI technology in the Ashanti region of Ghana. The WHO determines accessibility by calculating the number of machines per million people (pmp). This study discovered that Ashanti region's three

MRI machines equated to a density of 0.55 pmp, which was lower than South Africa's 3.00 pmp[38], similar to Zimbabwe's 0.50 pmp[39], but higher than Ghana's overall 0.08 pmp[35] and Sub-Saharan Africa's (SSA) 0.04 pmp.[40] Even though this could be considered a good density for a geographical region, the data revealed that in reality, only one MRI existed in the public sector to support diagnostics, and was installed in the only public tertiary facility. While the ATLS recommends MRI scans for severely injured patients, the Royal College of Radiologists emphasizes that MRI is rarely indicated in the acute trauma setting except in some specific cases, such as epidural hematoma or when brain or spinal injuries are suspected.[41] Longer MRI image acquisition period and the need to make the patient stable hemodynamically before MRI scanning require that other forms of diagnostic tests, such as CT scan, and treatment be done prior to an MRI to prevent delays.[14]

The average travel distance from a blackspot to an MRI machine of 35 km in Ashanti region could be attributed to the fact that most of the blackspots are in the peri-urban and rural areas, whereas few available MRI machines are concentrated in the central urban part of the region. The pressure on these services requires that these machines must always be functional and available to render services.

All three MRI machines, with an average usage age of approximately 10 years, were functional and in use and were mainly under a comprehensive maintenance contract. However, complexities involved in maintaining this capital-intensive technology have forced owners to utilize the services of external contractors, which end up being expensive over a long period. The results showed that none of them was maintained by the in-house biomedical engineering team. This finding corroborates the observations made by Anazodo et al. in a survey of MRI machines in 49 SSA countries[42], and could be due to the availability of expertise, mainly with private medical equipment suppliers and distributors. In addition to this, the extremely high cost of the equipment, poor infrastructure (unreliable electricity and water, poor Internet connectivity, expensive setup costs, and so on), including a dearth of radiographers and radiologists to support the utilization of this technology, have been identified as barriers to MRI access.[40]

Computed Tomography

Figure 1(b) shows the geographic spread of all 12 CT machines found in the region. Similar to the findings from Kenya[43], the majority of the CT machines were in the central and urban part of the region, with only two on the outskirts, one of which was non-functional. The number of CT units translates to 2.21 pmp, less than South Africa's 5.00 pmp[38] and Kenya's 3.90 pmp[43] but greater than Ghana's national total of 1.46 pmp[35], Zimbabwe's 1.50 pmp[39], Zambia's 0.79 pmp, Uganda's 0.60 pmp, and Tanzania's 0.42 pmp.[44]

Despite relatively higher availability, the majority of the units were in the private sector, which was similar to the reports from other countries. This could be due to the high cost of owning a CT machine, considering factors such as infrastructure, maintenance, spare parts, training, etc., an investment that is relatively easier to make in the private sector than in the public, especially in LMICs. The majority of the CT units were functional and in use (Figure 2), which could be attributed to their comprehensive maintenance cover. This cover is usually a service delivered by contracted private companies.

Furthermore, the study assessed spatial distance to CT machines in health facilities. The average distance from the 104 blackspots to a health facility with a CT machine was found to be 27 km, assuming all eight CTs were functional. However, when the same analysis was restricted to only four functional units, the average travel distance increased by 2.83 km ($p < 0.001$), highlighting the impact of non-functionality on RTC patient access. This delay in reaching care could worsen outcomes in case of severely injured RTC victims, as an increase in transportation time is linked to reduced odds of survival.[45] These findings emphasized the urgent need for improved maintenance of CT machines to enhance trauma care.

Analyzing the accessibility to hospital-based CT machines from blackspots, this study sought to further find the health facilities with CT machines closest to blackspots. The results showed that, assuming all units were functional, seven out of eight hospital-based CT machines were close to all 104 blackspots, with four of them close to the majority (89%) of blackspots (Table 3). When the non-functional hospital-based units (n = 3) were isolated from the analysis, the study showed a significant redistribution of blackspots onto four hospitals with functional units. This analysis also revealed the great impact of non-functionality on the options of suitable health facilities where severely injured RTC victims could be taken to within the region. Therefore, this implied that these four hospitals with functional units could be under immense pressure from RTC injuries, bearing in mind that these blackspots are crash-prone areas where severe injuries are known to occur frequently. Of particular note are the two hospitals, HFCT-02 and HFCT-08, which were close to more than half (n = 65) of the blackspots, but whose CT machines were non-functional, thereby contributing to the redistribution of pressure onto the other four hospitals with functional units.

Some of the reasons for the non-functionality of CT machines, as discovered by the study, were faulty tubes, faulty parts, and damaged uninterruptible power supply (UPS; Table 2), among others. None of these units was maintained by in-house biomedical engineering departments, a situation which could be an indication of the lack of technical capacity available among biomedical engineers in hospitals that own CT machines. Several studies have discussed the challenges of technically sustaining expensive diagnostic imaging equipment, and one of the barriers, in addition to high investment cost, is the lack of training of local biomedical engineers to carry out planned preventive maintenance. Most hospitals have no choice but to rely on expensive distributors/agents to provide this expensive technical service, thereby causing significant periods of non-functionality (downtime). With an average age of 6.5 years, which is relatively low, one would have expected more of functional units.

X-Ray

Figure 1 shows a generous distribution of X-rays around blackspots in the Ashanti region. Indeed, the distribution was so uniform that the average travel time from a blackspot to a hospital-based X-ray machine was found to be about 8 km, which is considered as near[45], a far cry from 26 km and 35 km for CT and MRI machines, respectively. Plain radiography has been identified by the ATLS as one of the recommended critical primary survey diagnostic tests conducted to confirm, among other things, the presence or absence of fractures in the extremities of severely injured RTC victims. So important is this that WHO's Guidelines for Trauma Care also recommend X-ray scans during the initial assessments executed for all serious trauma victims.

The Ashanti region of Ghana can boast of an X-ray availability index of 11.21 units pmp, which is higher than Tanzania's 9.00 pmp but significantly lower than Zimbabwe's 26.00 pmp[39] and South Africa's 34.80 pmp.[38] Interestingly, the majority (82%) of these units were discovered to be functional and in use (Table 1), which could be attributable to the type of maintenance cover, as lack of maintenance is the core reason for high proportions of non-functional medical equipment in LMICs. It is noteworthy that the X-ray was one of the two modalities that in-house biomedical engineering teams felt confident in supporting technically, as can be seen in Figure 3.

The impact of this high functionality proportion is shown in the statistically nonsignificant (p = 0.068 at 95% CI) average change in distance from blackspots to all X-ray machines (assuming 100% functionality) and from blackspots to functional X-ray machines (82%). It was interesting to note also that the majority of X-ray machines, as well as functional units, were in the public sector, a situation at variance with other modalities, the majority of which were in the private sector. Indeed, this implies that the majority of health facilities with X-ray units, which can quickly reveal life-threatening chest and pelvic injuries in trauma patients, are more accessible to the public, because they are near, as well as functional, to most of the blackspots.

Ultrasound

The near ubiquitous ultrasound machine plays a critical role during the primary care of trauma patients through FAST, which was introduced several decades ago to support trauma assessment, diagnosis, and management.[17] In a survey conducted on ultrasound utilization across 62 LMIC, it was discovered that 43% of respondents used an ultrasound machine (FAST) in a trauma setting.[46] Owing to its portability, low cost, non-invasiveness, and relative ease of use, the ultrasound machine is commonly known as the "surgeon's stethoscope of trauma", acting as a practical tool to quickly detect free fluid in the pericardial space, pleural cavity, and abdomen.[14,47] It is a valuable tool for ruling in and not ruling out an injury.

Unlike X-ray and CT machines, the ultrasound machine does not emit any radiation, so it does not need to be registered by Ghana's Nuclear Regulatory Authority prior to use. Currently, no database exists regarding its usage, because its portability makes it difficult to track and build a national database for its usage.[35]

Even though this study recognizes the critical role of an ultrasound machine in the diagnosis of trauma injuries, the data collected were not specific to this modality, as the availability of an ultrasound machine alone was not enough to classify a health facility as suitable to receive RTC victims. Indeed, most of the ultrasound-alone facilities were maternity clinics or family practices without emergency departments. Therefore, the ultrasound data presented in this study were those found in hospitals that had one or more of the other modalities. For this study, the majority of ultrasound machines were in the public sector and health facilities, and were functional. This study also discovered that local in-house biomedical engineers were adequately trained to provide preventive and corrective maintenance of ultrasound machines in the health facilities of the Ashanti region; this could account for a high proportion of functionality of this modality.

CONCLUSION

The findings of this study underscore the very important roles of diagnostic imaging modalities in the efficient diagnosis of injuries in trauma patients. It reveals that the Ashanti region of Ghana has a good spatial distribution of ultrasound and X-ray modalities with respect to blackspots. Both modalities were largely found in hospitals and not in diagnostic centers. Both were functional and in use, and maintained adequately well by in-house biomedical engineering teams in partnership with external firms. The predominance of X-ray and ultrasound modalities in the public sector suggests a deliberate attempt at maximizing coverage and accessibility for patients, observing that public hospitals are the first points of contact for RTC victims. This distribution could ensure that essential X-ray and ultrasound services are available to a broader segment of the population, especially those who may not have access to private healthcare facilities. The ability of in-house biomedical engineering teams to maintain them ensures the sustainability of the technology for its lifetime, thereby reducing downtime and service disruptions.

However, the same was not observed for the availability and functionality of MRI and CT. These limitations present challenges in providing a comprehensive scope of diagnostic imaging services, potentially leading to suboptimal outcomes, especially for severely injured trauma patients. While X-ray scans provide sufficient insights into the bone structure and chest injuries, ultrasounds show the presence or absence of free fluids, especially in the abdomen, while CT provides a detailed assessment of potential internal injuries in soft tissues and organs. In trauma patients where neurological or spinal injuries are suspected, MRI scans are indicated. Despite concerns regarding substantial radiation exposure during diagnostic imaging, especially during CT scans[27], improvements in all these imaging techniques that have occurred in the last few decades have significantly contributed to the understanding and efficient management of trauma patient.[14] A lack of full complement of these diagnostic services could result in misdiagnosis, delayed treatments, and ultimately poor patient outcomes.

Recommendations

This study highlights the critical gaps in diagnostic imaging availability and functionality in the Ashanti region of Ghana. Although X-ray and ultrasound modalities are well distributed across the region, their diagnostic scope is limited, hence the need for the other less available CT and MRI modalities as a complement. Addressing these gaps requires a multi-pronged approach.

In the short term, the Ministry of Health could prioritize the repair and maintenance of non-functional CT machines in the three health facilities identified, to improve access.

In the medium term, hospitals could establish collaborations with private diagnostic imaging centers within the region to provide interim imaging solutions, although trauma patients with injuries would have to be stabilized first prior to visiting private diagnostic centers for CT and MRI scans. Diagnostic centers located near hospitals without CT machines could establish formal referral and prioritization arrangements, enabling timely imaging for hospital patients and the efficient electronic transmission of reports to clinicians.

It is also recommended that the proposed modern 500-bed Afari Military Hospital[48] and 100-bed Obuasi Trauma Hospital currently under construction in Ashanti region, both with MRI, CT and X-ray machines, among other modalities, be completed and operationalized to improve access to critical care.[49]

Finally, there must be a long-term strategic effort to invest in additional CT machines, especially in the high-risk, crash-prone areas. Efforts must be made to build capacity in local biomedical engineers for the maintenance of all imaging modalities, especially CT and MRI machines. The current study clearly observed that only X-ray and ultrasound technologies were maintained by in-house biomedical engineering teams. Building hospital in-house capacity can help reduce complete reliance on private service providers, whose services, usually expensive, contribute to the high total cost of ownership.

Limitations

This study focused on ultrasound, X-ray, CT, and MRI machines. There are other useful modalities for the diagnosis of trauma patients, such as mobile X-ray units, fluoroscopy, and C-Arms. Future studies on the availability and functionality of these modalities could provide a bigger picture of the state of diagnostic imaging equipment in the region.

Future Studies

Future studies could investigate the proportion of trauma victims that actually present at the emergency departments of these hospitals that have been identified to be closer to RTC blackspots in Ashanti region. An analysis of the diagnoses and the types of imaging scans recommended to trauma patients would lend some insights into the patient pathway. In addition, trauma patients referred to private diagnostic centers for scans could be studied to assess the demand of diagnostic imaging services within the region. Finally, future studies could investigate the cost-effectiveness of different imaging modalities in trauma care and explore innovative solutions to improve access in resource-limited countries such as Ghana.

AUTHOR CONTRIBUTIONS

Conceptualization, A.B.P, E.T, A.G, E.E.K, C.M and P.D.; Methodology, A.B.P, C.M and P.D; Validation, A.B.P, B.B, E.T, E.E.K, A.G, C.M and P.D; Formal analysis, A.B.P; Investigation, A.B.P; Resources, C.M and P.D; Data curation, A.B.P; Writing—original draft preparation, A.B.P; Writing—review and editing, A.B.P, B.B, E.T, E.E.K, A.G, C.M and P.D; Visualization, A.B.P; Supervision, E.T, E.E.K and A.G; Funding acquisition, C.M and P.D.

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DATA AVAILABILITY STATEMENT

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

CONFLICTS OF INTEREST

The authors declare they have no competing interests.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This study was approved by the Ghana Health Service Ethics Review Committee (GHS-ERC:024/10/23), the Komfo Anokye Teaching Hospital Institutional Review Board (KATH.IRB/AP/014/24) and the Ethical Committee for Basic and Applied Science of the College of Basic and Applied Science, University of Ghana (ECBAS 006/23-24)

CONSENT FOR PUBLICATION

Not applicable.

FURTHER DISCLOSURE

The paper has been uploaded to or deposited in a preprint server (https://www.preprints.org/manuscript/202502.1605/v1 DOI: 10.20944/preprints202502.1605.v1)

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