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Posted Date: 20 February 2025

doi: 10.20944/preprints202502.1605.v1

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

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Featured Application: This study provides important insights about access to diagnostic imaging modalities, specific to road traffic crash (RTC) injuries in Ghana, with a focus on the Ashanti region. The findings can inform health policy makers, hospital administrators, emergency medical services and biomedical engineers on the gaps in the availability and functionality of the imaging equipment to guide resource allocation, equipment maintenance strategies and policy interventions to improve trauma care. Additionally, the research supports evidence-based decision- making for optimizing emergency response systems and strengthening infrastructure to improve patient outcomes.

Abstract: Diagnostic imaging technologies have enhanced the understanding and management of road traffic crash (RTC) injuries and are essential to guiding injury diagnosis. Despite their importance few studies regarding their accessibility to crash- prone areas are available. This study sought to investigate the accessibility, availability and functionality of 4 essential imaging modalities (ultrasound, plain x-ray, computed tomography and magnetic resonance imaging) for RTC injury management in the Ashanti Region of Ghana. A cross-sectional quantitative study was conducted covering 38 public, private, and mission-based hospitals, and 7 diagnostic centers. Data were collected with a structured questionnaire on equipment availability, functionality, and maintenance status. Spatial distance and time analyses were done, and statistical comparisons were performed using Wilcoxon signed-rank tests. The study found only 1 of the 3 functional MRIs available in the public sector. While 60% of CTs (n=12) were found in the private sector, 59% of x-rays (n=61) and 62% (n=108) of ultrasounds were in the public sector. Due to non-functionality, travel distance to CT machines increased by 2.8 kilometers ($p<0.000$). In-house hospital- based biomedical engineers had technical expertise in maintaining x-ray and ultrasound machines but not CT or MRI. While X-ray and ultrasound modalities were well-distributed, CT and MRI access was limited.

Keywords: access to care; diagnostic imaging equipment; Ghana; road traffic crashes; spatial distribution; ultrasound; x-ray; CT; MRI

 doi:10.20944/preprints202502.1605.v1

1. Introduction

Death by road traffic crashes (RTC) is a major public health challenge globally [1,2], in low-middle income countries (LMIC) and especially in Africa [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 but when they do occur, minimizing the consequences of severe injuries by providing care to the injured significantly contributes to reduction in morbidity and mortality [6–10]. Poor access to emergency medical services, prehospital care and medical imaging modalities needed for efficient diagnosis in health facilities contribute to preventable deaths that occur in the trauma setting, especially in Africa [11,12].

When injured RTC victims are admitted to the emergency room in a hospital, they are often unconscious, in shock, disoriented or intubated. Depending only on clinical examinations alone has been shown to be unreliable for ruling out traumatic injuries [13,14]. Diagnostic imaging techniques have proven to help in confirming the suspicions of the clinicians and helping guide treatment pathways resulting in reduced treatment costs and improved outcomes [15]. Improvements in imaging technologies over the last few decades have enhanced the understanding and management of trauma patients and have proven to be essential to guide diagnosis thereby lessening the risk of mortality and morbidity [16–19].

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 and is based on the fundamental principle of rapid assessment and resuscitation of patients in the window of opportunity, widely known as the "Golden Hour" to lessen the risk of morbidity or mortality [20]. 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 antero- posterior (AP) chest radiograph, pelvic radiograph and/or lateral cervical spine radiograph to check for fractures and other life- threatening injuries and abdominal sonography (known as FAST: Focused Assessment with Sonography in Trauma) to quickly detect free intra- peritoneal fluid which may indicate abdominal bleeding. These essential diagnostic examinations offer critical information to the clinicians to support resuscitative measures [21]. The adjuncts to the secondary surveys include specialized diagnostic tests such as whole/ total body CT scan (using the computed tomography machine) to rule out cranio-cerebral, cervical or thoraco-abdominal injuries, or magnetic resonance imaging (MRI) scans if brain injuries are suspected [13,17,20]. These essential diagnostic tests make imaging equipment vital to the initial assessment of RTC victims. Despite the apparent advantages diagnostic imaging offers to the clinician in the trauma environment, resource-limited settings have faced significant challenges in improving access to these necessary diagnostic equipment. Some of the barriers relate to the cost of the equipment, the lack of infrastructure needed to support their use (water, electricity, internet, access roads, etc.), poor maintenance regimes due to lack of trained biomedical engineers, insufficient radiologists, to mention a few [22–25].

The growing role of medical imaging in the management of trauma victims, along with the development of more sophisticated technologies, is supporting the clinician to better depict life-threatening diagnoses. Even though the need for imaging equipment for early and efficient diagnosis of RTC injuries has been well documented, there is paucity of knowledge regarding where they are located with respect to RTC, their functional state and how accessible they are to crash- prone areas (also known as blackspots) in Ghana.

This study covered four (4) imaging modalities; ultrasonography (US), radiography (x-ray), computed tomography (CT) and magnetic resonance imaging (MRI). The findings of this study will reveal the current situation in the Ashanti region and help policy makers decide on ways to improve the situation. For this study, an equipment is functional if it is operational, produces reliable and accurate images, is available for use when needed and safe to use by its operator [26]. A summary of these modalities and their usefulness in the management of RTC injuries is presented in Table 1.

 doi:10.20944/preprints202502.1605.v1

This study is part of a larger one that sought to investigate accessibility of emergency medical services to road traffic injury victims within the Ashanti region. The objective of this current study was to investigate the availability and functionality of essential imaging equipment in health facilities for RTC injury management in the Ashanti region.

Table 1. Summary of essential diagnostic imaging modalities for RTC injury management[13,27–31].

	Magnetic Resonance Imaging	**Computed Tomography**	**Radiograph**	**Ultrasound**
Type of emission	Magnetic fields and radio frequency 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-ray are collected and analyzed with complex algorithms into 3D images for viewing.	High voltage electrons from cathode collide with metal anode to produce x-ray. Attenuated x-ray 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 various biological material is processed and converted into images
Type of body part most suitable for use	Soft tissue especially the brain and spinal cord	Whole body	Skeletal frame, chest	Abdominal (for intra-peritoneal fluid check)
Organs of interest in RTC patients	Brain	Brain, spinal cord, chest, soft tissue organs	Skull, pelvic, chest, extremities	kidney, liver, spleen, pancreas, bladder
Indication for use	Suspected neurological injury in severely injured patients	Suspected brain or spinal injury	Suspected bone fracture, haemothorax, pneumothorax	Blunt abdominal injury
Some Advantages	High resolution No ionizing radiation	Non- invasive Whole body scan in a single exam Consistent quality	Quick to perform Readily available	Non-invasive Real time Portable Cost-effective

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	Magnetic Resonance Imaging	Computed Tomography	Radiograph	Ultrasound
	Penetration of bone and air without attenuation	3-dimensional imagery Less dependent on operator Reproducible High resolution		Versatile FAST[a] scans excellent for detecting abdominal fluid in trauma patients
Some Disadvantages	*Unsuitable for patient 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

[a]FAST- Focused Assessment with Sonography for Trauma.

2. Methods

The Ashanti region is Ghana's third largest out of the sixteen regions covering a land surface of 24,389 km2. Lying between longitudes 0.15W and 2.25W and latitudes 5.50N and 7.46N, the region has a population of 5.44 million persons making it the most populated region [32]. Ashanti boasts of 658 health facilities with 53% being privately- owned, 33% being government- owned, 11% being quasi- governmental and 3% being faith- based facilities. The Ghana Health Service and the Ministry of Health have oversight responsibility of all government-owned facilities [33].

This study was a cross-sectional one 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. (2024) [34]. The essential imaging modalities of interest were ultrasound (US), radiography (x-ray), computed tomography (CT) and magnetic resonance imaging (MRI) because they are recommended for the initial evaluation of trauma patients involved in high-energy vehicular crashes [20]. A structured questionnaire adapted from the World Health Organization (WHO)'s Harmonized Health Facility Assessment (HHFA) tool [35] was used to collect data on the facilities and equipment availability, functionality and maintenance status from the preselected facilities. The study questionnaire was administered by 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, the presence and functional status of the equipment. Geolocation data of all the imaging equipment identified during the study were collected and mapped. 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 geospatial data of all crash-prone areas in the Ashanti region were sourced from Mesic et al. (2024). The type of facility at which the equipment was located was classified as either

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"health facility" (clinic or hospital) or "diagnostic center", which implies a location where diagnostic tests are performed, but where other care is not provided.

All the imaging modalities were geospatially mapped with ESRI's ArcGIS Pro software version 3.3.2, after which geolocations of all 104 blackspots were superimposed on the data set. A proximity tool (Near Analysis) was conducted to determine the travel distance between 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 Microsoft Excel spreadsheet version 16.92 (Microsoft Corporation, Redmond, Washington, USA) for analysis and visualization.

Another 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 the differences in access were examined. The analysis was based on imaging modality types, ownership, age from year of installation, type of maintenance cover and functional status. Comparative analysis of ownership/ functionality and maintenance cover type/ modality were 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).

3. Results

Figure 1 shows the geographical spread of the imaging modalities with respect to injury blackspots in the Ashanti region.

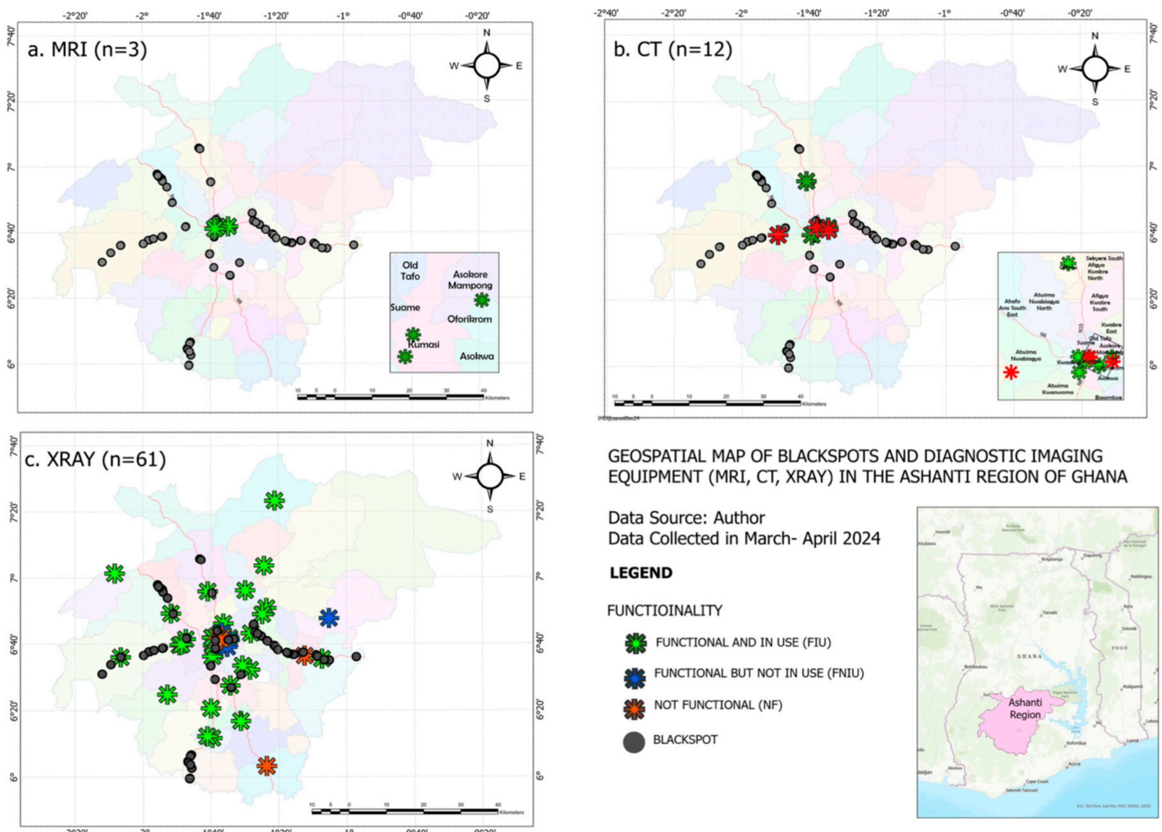

Figure 1. shows the geospatial locations of (a)MRI units with blackspots, (b)CT units with blackspots and (c) X-ray units with blackspots in the Ashanti region of Ghana. The map of ultrasound machines was left out as it is the replica of the x-ray machines; all x-ray locations had an ultrasound machine. Secondly, locations with ultrasound machines ONLY were not included in the study as they were likely to be maternity clinics,

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gynaecological scanning diagnostic centres or private hospitals without emergency departments for RTC patient management.

All of the MRI machines 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 not functional. X-ray machines were sufficiently spread around most of the blackspots in the region.

Forty-eight (48) facilities were visited and a response rate of 93.8% was achieved of which 84.4% (n=38) were health facilities and 15.6% (n=7) were diagnostic centers. From Table 2, two of the three MRIs in the region were in the health facilities; 1 in a public and the other in a private hospital. At the time of data collection, all three were functional and in use with an average age of almost 10 years. No faith-based facility owned an MRI machine.

Table 2. Characteristics of diagnostic imaging equipment in the Ashanti region.

	MRI n (%) 3	CT n (%) 12	X-ray n (%) 61	US n (%) 108
Availability				
Health facility	2 (67.0)	8 (60.0)	54 (88.5)	97 (89.8)
Diagnostic centre	1 (33.0)	4 (40.0)	7 (11.5)	11 (10.2)
Ownership				
CHAG[d]	-	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[c]				
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

[c]FIU- Functional and in use; FNIU- Functional but not in use; NF- Not Functional; [d]CHAG- Christian Health Association of Ghana; Functional equipment were those that were operational, produced reliable and accurate images, was available for use when needed and safe to use by its operator.[e]Availability represents the number of equipment found in health facilities and diagnostic centres.

The CTs that were found in this study were primarily in health facilities (60%) and in the private sector. Majority (66.7%) were found to be functional and in use with an average 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. A significant majority (82%) of x-ray units were found to be functional and in use with an average age of 7.8 years. (Table 1)

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

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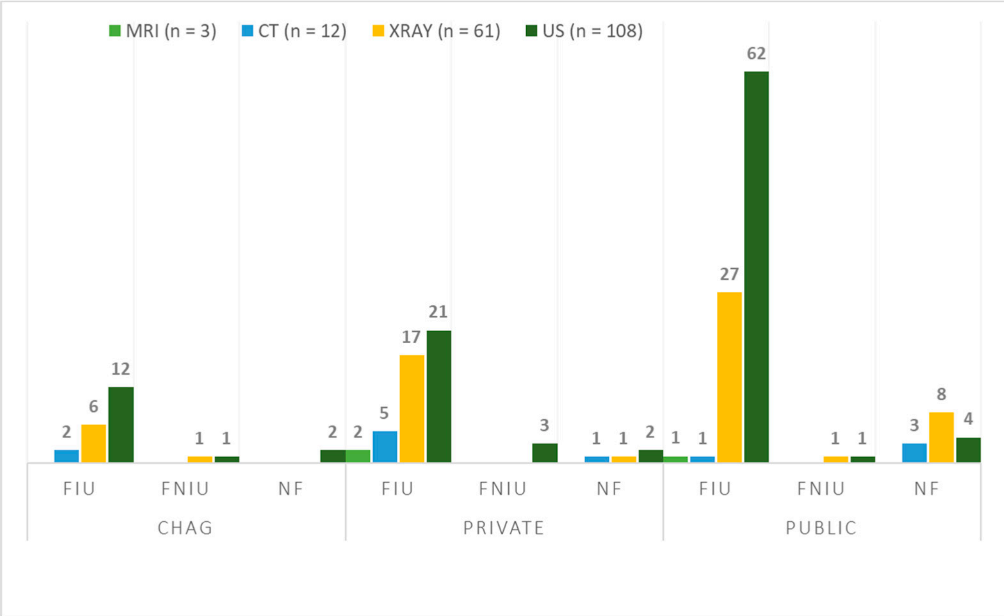

Figure 2. Distribution of ownership and functional status of diagnostic imaging equipment in the Ashanti region of Ghana (FIU- Functional and in use; FNIU- Functional but not in use; NF- Not functional; All FNIU units were x-ray and Ultrasound machines which were operational but used as backup units).

Table 3. Factors affecting imaging equipment functionality and utilization.

(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 CT tube
• Faulty Printer	• Faulty installation. Machine has not been used since.	•
• Faulty unit	• Stolen parts from equipment	
(b) Non- utilization		
Functional x-ray and ultrasound machines were used as backups to other functional units. Most of these facilities had more than one unit.		

[a]UPS- 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 mainly not covered at all (45%) or had a labour-only cover (18%). A third of CTs were however found to be covered comprehensively. Over half of x-ray machines (56%) were covered comprehensively with a significant number of facilities reporting callouts to external technical teams for support. The two modalities that in-house biomedical engineering teams had technical expertise to maintain were the ultrasound and x-ray machines.

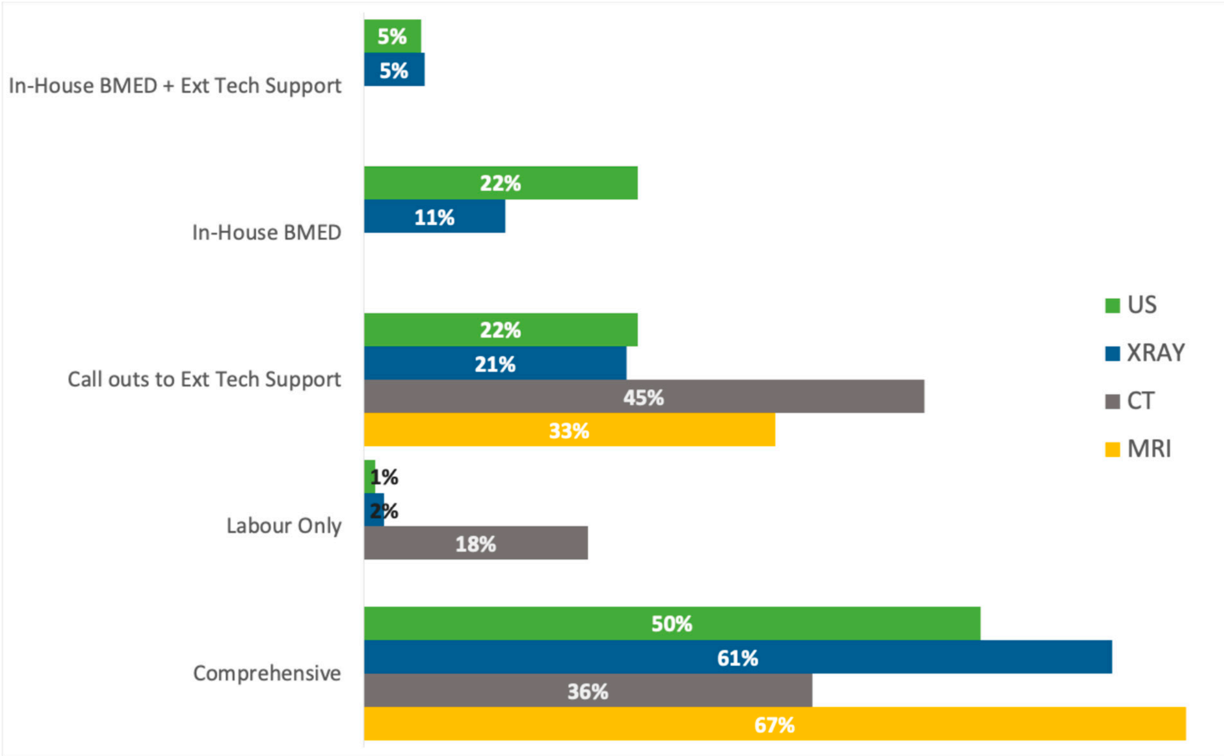

Figure 3. Types of maintenance cover for MRI, CT, X-ray equipment in the Ashanti region of Ghana.

Table 3 reveals the impact of non-functionality on access to imaging services by RTC victims. It shows the geographical proximity (by travel distance) of the 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 9km assuming that all the x-ray machines were functional in those hospitals. The same analysis carried out excluding the non-functional equipment found a non-significant change in distance of about 20meters. However, the same analyses conducted on CT machines revealed a statistically significant travel distance increment of nearly three (3) kilometers of travel. Due 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 a CT installed (Table 4).

Table 4. How much longer will RTC victims travel to from crash sites to hospitals with diagnostic imaging equipment due to broken down equipment?

	Distance measurement in kilometres			
	Distance to ***ALL*** hospital- based machines n (SD)	Distance to ***ONLY*** functional hospital-based machines n (SD)	Change in av. 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	0.000[a]
MRI[e]	35.43	35.43	0.00	NA

[a]The Wilcoxon signed rank test; [b]analyzed at 95% confidence level; [c]There were 54 hospital-based X-rays with 8 non- functional. [d]There were 8 hospital-based CT machines with 4 non-functional; [e]There were 2 hospital-based MRIs; both were functional.

 doi:10.20944/preprints202502.1605.v1

Table 5. How does non-functionality of CT machines affect 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	# of slices of CT	Age of CT	Type of maintenance cover
HFCT-01	6	44	633%	16	11	Comprehensive
HFCT-02	27	-		16	2	Comprehensive
HFCT-04	10	36	260%	16	7	Comprehensive
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	Labour only
HFCT-10	18	19	56%	32	1	
TOTAL	104	104				

[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.

The results of geospatial closest-facility analysis for CT machines are shown in Table 4. Seven (7) of the eight (8) health facilities with CT machines were found to be close to all the 104 blackspots identified in the Ashanti region however, three (3) health facilities- HFCT-02, HFCT-08 and HFCT-10- were closest to a combined majority (80%) of the known crash-prone areas. Repeating this analysis exclusively on health facilities with only functional CTs revealed a redistribution of blackspots to four (4) facilities only, with three (3) of them being close to 99% of all the blackspots.

4. Discussion

This study aimed to analyze accessibility of essential diagnostic imaging equipment to RTC victims to support efficient diagnoses 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 in health facilities in Ashanti region, the region with the highest number of road crash fatalities in Ghana.

4.1. MRI

Figure 1a shows the sparsity of MRI technology in the Ashanti region of Ghana. The World Health Organization (WHO) determines accessibility by calculating number of scanners per million people (pmp). This study found that the Ashanti region's three MRI machines equated to a density of 0.55 pmp which is lower than South Africa's 3 pmp [36], similar to Zimbabwe's 0.5 pmp [37] but higher than Ghana's overall 0.08 pmp [34] and Sub- Saharan Africa (SSA)'s 0.04 pmp [38]. Even though this could be considered as good density for a geographical region, the data revealed that there really is only one MRI in the public sector to support diagnostics and is installed in the only public tertiary facility. While the ATLS recommends MRI scans for severely injured patients, the Royal College of Radiologists emphasize 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

 doi:10.20944/preprints202502.1605.v1

suspected [40]. Longer image acquisition times and the need for patient stability hemodynamically before MRI scanning require that other forms of diagnostic tests, such as CT scans, and treatments be done before an MRI [14].

The average travel distance from a blackspot to an MRI machine in the Ashanti region could be attributed to the fact that most of the crash- prone areas are in the peri-urban and rural areas, whereas the MRI machines are concentrated in the central urban part of the region. The pressure on these services requires that these machines be functional always and available to render service, as was found to be the case in the region.

All 3 MRI machines, with an average age of approximately 10 years, were functional and in use and were mainly under comprehensive maintenance contract. Complexities involved in maintaining this capital- intensive technology has forced owners to utilize the services of external contractors which end up being costly over the long term. None of them were maintained by the in-house biomedical engineering team. This may be due to expertise residing with private medical equipment distributors, a finding which corroborates what was found in a survey of MRI machines in Africa [39]. In addition to this, the extremely high cost of the equipment, poor infrastructure (unreliable electricity, water, poor internet connectivity, expensive setup costs, and so on) including a dearth in radiographers and radiologists to support the utilization of this technology have been identified as barriers to MRI access [38].

4.2. CT

Figure 1b shows the geographic spread of all 12 CT machines. Similar to findings from Kenya [40], majority of the CT machines were found in the central and urban part of the region, with 2 on the outskirts, one of which was non-functional. The number of CT units translates to 2.21pmp, less than South Africa's 5.0 pmp [36] and Kenya's 3.9 pmp [40] but greater than Ghana's national total of 1.46 pmp [34], Zimbabwe's 1.5 pmp [37], Zambia's 0.79 pmp, Uganda's 0.6 pmp and Tanzania's 0.42pmp [41].

Despite the higher availability, majority of the units are in the private sector which is similar to what these other countries reported. This could be due to the high cost of ownership of a CT machine, considering factors such as infrastructure, maintenance, spare parts, training, and so on, an investment which is relatively easier to make in the private sector than public, especially in LMICs. Majority of the CT units were functional and in use (Figure 2) which could be attributed to the comprehensive maintenance cover most of them had, a service being delivered by contracted private companies.

Furthermore, the study assessed spatial distance access 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 an average of 27km, assuming all the eight CTs were functional. However, when restricting the analysis to only the four functional units and the average travel distance increased by 2.83km ($p<0.000$) highlighting the impact of non-functionality on RTC patient access. This delay in reaching care could worsen outcomes for severely injured RTC victims as increase in transport time is linked to reduced survival odds [42]. These findings emphasize the urgent need for improved maintenance of CT machines to enhance trauma care.

Analyzing access to CT machines from blackspots from another perspective, this study sought to find out the health facilities with CT machines which were closest to blackspots and found that, assuming all units were functional 7 out of the 8 hospital-based CT machines were close to all 104 blackspots with 4 of them close to majority (89%) of the blackspots (Table 3). When the non- functional hospital-based units (n=3) were isolated from the analysis, the study saw significant redistribution of blackspots to four hospitals with functional units. This analysis reveals 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. This could imply therefore that these four hospitals would be under 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 hospital HFCT-02 and HFCT-

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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 on to the four hospitals with functional units.

Some of the reasons for non-functionality were faulty tube, faulty parts and damaged UPS (Table 2). None of these units was maintained by in-house biomedical engineering departments, a situation which could be an indicator of the lack of technical training provided to 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 the 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 technical service at a high cost which causes significant periods of non-functionality (downtime). With an average age of 6.5 years which is relatively low, one would have expected the functional units to be more.

4.3. X-Ray

Figure 1 shows a generous distribution of x-ray around the 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 device was found to be about 8km, which is considered as near [42] a far cry from the 26km and 35km for CT and MRI machines respectively. 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 the WHO's Guidelines for Trauma Care also recommends x-ray scans during the initial assessments carried out for all serious trauma victims. The Ashanti region can boast of an x-ray availability index of 11.21 units pmp, which is higher than Tanzania's 9 pmp but significantly lower than Zimbabwe's 26 pmp [37] and South Africa's 34.8 pmp [36]. Interestingly, majority (82%) of these devices were found to be functional and in use (Table 1), which could be attributable to the type of maintenance cover, as maintenance is the core reason for the high rates of non-functional medical equipment in LMICs. It is noteworthy that the x-ray modality was the only one which in-house biomedical engineering teams felt confident in supporting technically as can be seen in Figure 3.

The impact of this high functionality is shown in the statistically non-significant ($p = 0.068$ at 95% confidence interval) average change in distance measure from blackspots to all x-ray machines (assuming 100% functionality) and from blackspots to only functional x-ray machines (82%). It was interesting to note also that majority of the x-ray were in the public sector and majority of the functional ones were also found in the public sector, a situation which is at variance to the other modalities, majority of which were in the private sector. Indeed, this could imply that majority of the health facilities with x-ray units which can quickly reveal life-threatening chest and pelvic injuries in trauma patients are more accessible to the general public because they are near most blackspots and are functional.

4.4. Ultrasound

The near ubiquitous ultrasound machine plays a critical role during the primary survey of the trauma patient via the Focused Assessment with Sonography for Trauma (FAST) which was introduced to support trauma assessment, diagnosis and management several decades ago [20]. In a survey conducted across 62 LMIC on ultrasound utilization, it was discovered that 43% of respondents used the ultrasound machine (FAST) in the trauma setting [43]. Due 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 [14,18]. It is valuable for ruling in an injury but not ruling it out.

 doi:10.20944/preprints202502.1605.v1

Unlike the x-ray and CT machines, the ultrasound machine does not emit any radiation so does not need to be registered by Ghana's Nuclear Regulatory Authority before use [34]; its portability makes it difficult to track and build a national database for [34].

Even though this study recognizes the critical role of the ultrasound machine in the diagnosis of trauma injuries, data collected were not specific to this modality as the availability of the 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. The ultrasound data therefore presented in this study were those found in hospitals that had one or more of the other modalities in question. For this study majority of ultrasound machines were in the public sector, in health facilities and functional. This study also found that local in-house biomedical engineers were adequately trained to provide preventive and corrective maintenance on ultrasound machines in the health facilities in the Ashanti region; this could account for the high rate of functionality of this modality.

4.5. Clinical Implication

The findings from this study underscore the very important roles of ultrasound and x-ray in the efficient diagnosis of injuries in trauma patients. It reveals that the Ashanti region has a good spatial distribution of these modalities with respect to blackspots, they are largely found in hospitals and not diagnostic centers, 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 seeing 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 the 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.

Same can, however, not be said 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 provide sufficient insights into the bone structure and chest injuries, ultrasounds show the presence or absence of free fluids especially in the abdomen area while CT provides detailed assessment of potential internal injuries in soft tissues and organs, and when neurological or spinal injuries are suspected in the trauma patient, 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 patients' injuries. A lack of the full complement of these diagnostic services may result in misdiagnosis, delayed treatments and ultimately poor patient outcomes.

5. Conclusions

This study highlights the critical gaps in diagnostic imaging availability and functionality in the Ashanti region, particularly for CT and MRI. Although X-ray and ultrasound modalities are well-distributed, their diagnostic scope is limited. Addressing these gaps requires a multi-pronged approach. In the short term, the Ministry of Health could prioritize the repair and maintenance of the non- functional CT machines in the 3 health facilities to improve access.

In the medium term, hospitals could establish partnerships with private diagnostic imaging centers within the region could also help provide interim solutions, although patients would have to be stabilized first before visiting private diagnostic centers for CT and MRI scans. Diagnostic centers that are close to hospitals without CT machines could have arrangements to prioritize the facilities' patients and even send reports electronically to clinicians in the hospitals in an efficient manner.

 doi:10.20944/preprints202502.1605.v1

It is also recommended that the proposed 500- bed Afari Military Hospital [44] and 100- bed Obuasi Trauma Hospital currently under construction in the Ashanti region, both of which have diagnostics centers with modalities including MRI, CT and x-ray machines, among others [45], be completed and operationalized to improve access to care.

Finally, there has to be a long- term strategic effort to invest in additional CT machines, especially in the high- risk, crash- prone areas and also build capacity in local biomedical engineers in the maintenance of all the imaging modalities, especially CT and MRI machines. From this study, it was noted that only x-ray and ultrasound technologies were the ones maintained by inhouse biomedical engineering teams. Building hospital in-house capacity can help reduce total reliance on private distributor companies whose services are usually expensive which contributes to the high cost of ownership.

5.1. Limitations

This study focused on ultrasound, x-ray, CT and MRI machines. There are other modalities which are useful in 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 on the state of diagnostic imaging equipment in the region.

5.2. Future Studies

Future studies could investigate the proportions of trauma victims that actually present at the emergency departments of these hospitals that have been identified to be close to RTC in the Ashanti region. An analysis of the diagnoses that were given and the types of imaging scans that were recommended to the trauma patients would lend some insights into the patient pathway. Also the trauma patients referred to the 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 the different imaging modalities in trauma care and explore innovative solutions to improve access in resource- limited settings 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.

Funding: Please add: This research was funded by the Fogarty International Center of the US National Institutes of Health, grant number D43-TW007267. The APC was funded by Fogarty International Center of the US National Institutes of Health.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Ethics Review Committee of the GHANA HEALTH SERVICE (protocol code GHS-ERC:024/10/23 on the 22nd December 2023), the Institutional Review Board of the KOMFO ANOKYE TEACHING HOSPITAL (protocol code KATH.IRB/AP/014/24 on the 22nd March 2024) and the Ethical Committee for Basic and Applied Science of the COLLEGE OF BASIC AND APPLIED SCIENCE OF THE UNIVERSITY OF GHANA (protocol code 006/23-24 on the 20th of November 2023) for studies involving humans.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

Acknowledgments: This study was funded by a grant (D43-TW007267) from the Fogarty International Center of the US National Institutes of Health. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

Conflicts of Interest: The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

Abbreviations

The following abbreviations are used in this manuscript:

AP	Anterior- Posterior
ACS	American College of Surgeons
ATLS	Advanced Trauma Life Support
CHAG	Christian Health Association of Ghana
CT	Computed Tomography
ESRI	Environmental Systems Research Institute
FAST	Focused Assessment with Sonography in Trauma
FIU	Functional and in use
FNIU	Functional but not in use
HHFA	Harmonized Health Facility Assessment
LMIC	Low Middle-Income Country
MRI	Magnetic Resonance Imaging
NF	Non- functional
RTC	Road Traffic Crash
UPS	Uninterruptible Power Supply
US	Ultrasound
WHO	World Health Organization

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