ASEAN
Journal of Scientific and Technological Reports
Online ISSN:2773-8752

Research article

The Design and Development of a Prototype Stretcher Cum Wheelchair for Radiographic Purposes

Boriphat Kadman[1], Danu Prommin[2], Parinya Junhunee[3], and Supawitoo Sookpeng[4*]

[1] Faculty of Allied Health Sciences, Naresuan University, Phitsanulok, 65000, Thailand
[2] National Metal and Materials Technology Center, National Science and Technology Agency, Pathum Thani, 12120, Thailand
[3] National Metal and Materials Technology Center, National Science and Technology Agency, Pathum Thani, 12120, Thailand
[4] Faculty of Allied Health Sciences, Naresuan University, Phitsanulok, 65000, Thailand
* Correspondence: supawitoos@nu.ac.th

Citation:
Kadman, B.; Prommin, D.; Junhunee, P.; Sookpeng, S. The desing and development of a prototype stretcher cum wheelchair for radiographic purposes *ASEAN J. Sci. Tech. Report.* **2025**, *28*(3), e255648. https://doi.org/10.55164/ajstr.v28i3.255648.

Article history:
Received: August 25, 2024
Revised: April 27, 2025
Accepted: May 12, 2025
Available online: May 31, 2025

Publisher's Note:
This article is published and distributed under the terms of Thaksin University.

Abstract: Background: In the hospital emergency department, X-ray imaging was crucial for ensuring the precise and prompt diagnosis of patient accidents. Recognizing the potential discomfort and risk of injury associated with transferring patients from transport beds to X-ray tables, the RT (Radiological Technology) Wheelchair was conceived and implemented as a solution to address this concern. Methods: The features and design of the RT Wheelchair were aligned with the guidelines outlined in the International Electrotechnical Commission (IEC) 60601-1 standard. The quality assessment of the carbon fiber material used in the backrest and seat cushion was conducted by evaluating X-ray transmission ratio, exposure index (EI), and image quality. Results: The reduction in radiation attenuation of the carbon fiber sheets did not exceed eight percent. The EI and image quality remained within acceptable thresholds. Consequently, the resultant images were deemed adequate for the radiologist's diagnostic purposes. Conclusions: A Stretcher Cum Wheelchair for Radiographic Purposes enhances the convenience of staff and ensures the safety of patients by minimizing the need for movement during X-ray exposure.

Keywords: Stretcher cum wheelchair; emergency department; radiography; X-ray imaging; RT wheelchair

1. Introduction

Accidents and injuries often necessitate immediate medical attention, with X-ray imaging being a fundamental diagnostic tool upon patients' arrival at hospitals [1]. Achieving proper positioning for radiographic imaging in patients with mobility limitations, such as those confined to wheelchairs or bedridden, including individuals with disabilities, accident victims, and the elderly, profoundly influences diagnostic accuracy and subsequent clinical treatment [2]. However, the process of obtaining X-ray images typically entails transferring the patient to a radiographic table, followed by repositioning the patient back onto a wheelchair or, in cases of immobility, lifting the patient's body to place the imaging receptor [3-4]. This procedure often necessitates the assistance of at least two personnel. It may lead to repeated patient injuries and distortions in X-ray images due to misalignment between the X-ray beam and the image receptor, particularly challenging for capturing images in certain positions [5]. Presently, general hospitals utilize three primary types of equipment for patient transfer: wheelchairs, wheelchair cum stretchers, and patient stretchers [6]. However, these methods may induce further pain in patients [7], with individuals with recent falls and impaired mobility facing a heightened risk of further accidents, including falls from stretchers and examination tables [8]. Moreover, Inaccurate patient positioning can significantly degrade radiographic image quality, leading to misdiagnoses, increased repeat imaging, and unnecessary radiation exposure. Studies have identified positioning errors as a major cause of image rejection and diagnostic inaccuracies across various fields [9].

In response to the government's call for driving economic growth through innovation and Thailand's impending transition into an aging society, preparing for medical innovation becomes imperative to support the aging population's impact on the healthcare system. Recognizing the pivotal role of radiography in diagnostics, our research team has developed a specialized wheelchair, the RT (Radiological Technology) Wheelchair, tailored for radiographic imaging of elderly patients. The project aims to develop a wheelchair cum stretcher for radiographic imaging of elderly patients and analyze its operational outcomes in the field. The anticipated benefits of the RT Wheelchair for the elderly include reducing movement and time, minimizing injuries associated with patient transfers, enabling radiographic imaging directly on the wheelchair, and facilitating imaging in various positions from seated to fully reclined.

2. Materials and Methods

2.1 Feature and Safety System design

The institution granted ethical approval for this research study involving human subjects under the Certificate of Approval (COA) No. 390/2020. The study focused on selecting primary materials used in developing the structural and supportive components for X-ray imaging. Carbon fibers (CFs), known for their high strength-to-weight ratio, excellent corrosion resistance, and radiolucency, were selected as the primary material for the backrest and seat cushion of the Stretcher Cum Wheelchair for Radiographic Purposes [10,11]. These properties ensured patient safety, device durability, and optimal image quality, with minimal interference during radiographic imaging. Following material selection, the design and development of the RT Wheelchair were systematically carried out. The three seating components—the backrest, seat cushion, and support for the lower extremities—were structured considering anatomical support and compatibility with imaging requirements. Each carbon fiber panel was designed with an integrated slot to place the image receptor, thereby minimizing the risk of introducing additional artifacts. Moreover, the RT Wheelchair was modularly organized into principal structures: the mobile base frame, which houses the motor and battery system; the adjustable seating system, facilitating transition between lying and sitting positions; and the integrated support system for the image receptor, ensuring alignment with the path of the X-ray beam. Each component's function and material selection aligned with the safety requirements outlined in IEC 60601-1 for medical electrical equipment.

Ensuring electrical safety was a paramount concern during development. Therefore, the research protocol was designed to comply with IEC 60601-1 standards, delineating the minimum safety and performance requirements for medical devices before marketing and sale [12]. The RT Wheelchair incorporates folding armrests designed following clause 5.9 of IEC 60601-1, addressing patient-contacting parts [13]. The overall mechanical system includes the design of a lifting system for adjustable lying-sitting positions, an energy supply system, and a motion control system to enhance ease of operation during clinical use. Furthermore, the wheelchair was engineered to integrate a radiation-receiving panel and an adjustable support mechanism to maintain precise positioning during imaging. After design completion, comprehensive laboratory testing was conducted to validate the safety and functional performance of the RT Wheelchair. Testing included evaluations of weight-bearing capacity, radiation attenuation of materials, comparative image quality between conventional X-ray imaging and imaging performed using the RT Wheelchair, and electrical safety verification. The RT Wheelchair's ability to support a maximum patient weight of 150 kilograms was tested with a safety factor 1.5, simulating a load of 225 kilograms. Body weight distribution was based on standards from JIS T 9201:2016 and ISO 7176-11:2012, partitioned into 60% for the upper body (approximately 135 kilograms) and 40% for the lower body (approximately 90 kilograms) using a dummy model. Further testing involved positioning a simulated human body (Randy from SIMULAIDS, INC.), weighing 75 kilograms, with the same distribution assumptions and an additional load applied to the support structure to achieve 135 kilograms. The wheelchair was evaluated over 24 hours, with adjustments to the tilt-in-space angle at 0 and 30 degrees and the sitting position at 85 degrees. A measuring device calibrated the support system to the required angles.

2.2 The effects of material on X-ray transmission

2.2.1 X-ray transmission of carbon fiber sheets

The quality of carbon fiber sheets in terms of X-ray transmission was evaluated by comparing the amount of radiation obtained from the radiation image detector when it did not pass through the material and when it passed through the material, as shown in Figure 1. This was done using voltage differences of 70, 80, and 90 kVp, tube current and exposure time values ranging from 2 to 10 mAs. The quality of the material was assessed based on the image quality using the Exposure Index (EI) value in radiographic imaging of simulated body parts, including hands, hips, and chests. A comparison was made between images obtained without passing through the carbon fiber sheets and images obtained after passing through the carbon fiber sheets.

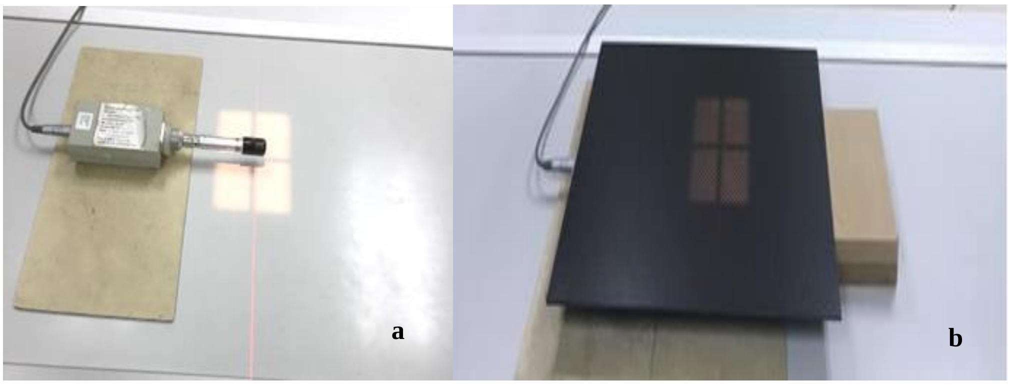

Figure 1. The radiation quantity is measured without passing through the carbon fiber sheet (a), while in the image on the right, it is measured after passing through the carbon fiber sheet (b).

The X-ray transmission rate was investigated for performance produced using carbon material [14]. Each measurement was conducted three times following established radiation measurement standards to enhance reproducibility and minimize random errors. The X-ray transmission rate is calculated using the following equation 1.

$$\text{Ratio of X-ray transmission} = (I_1/I_0) \times 100 \quad (1)$$

I_1 is the transmission value measured after passing through the carbon fiber sheet and I_0 is the initial value without passing through the carbon fiber sheet.

2.2.2 X-ray transmission of carbon fiber with human body phantom

The human body phantom was close to human attenuation. Radiographic imaging of simulated body parts, including the skull, chest, hips, and knees, was performed using conventional imaging and imaging with the RT Wheelchair at Thammasat University Hospital, employing identical exposure parameters (kVp, mAs). Although identical exposure parameters (kVp, mAs) were applied for both imaging methods, the initial radiation outputs (I_0) of the two X-ray systems were not independently measured before imaging. This may introduce variability due to inherent differences in machine output. Nevertheless, efforts were made to standardize imaging conditions, and the comparison was interpreted considering this potential limitation. Regarding patient positioning, the simulated body parts for conventional radiographic imaging were done using a radiographic table. In contrast, the positioning for radiographic imaging on the RT Wheelchair was done on the wheelchair itself, as shown in Figure 2.

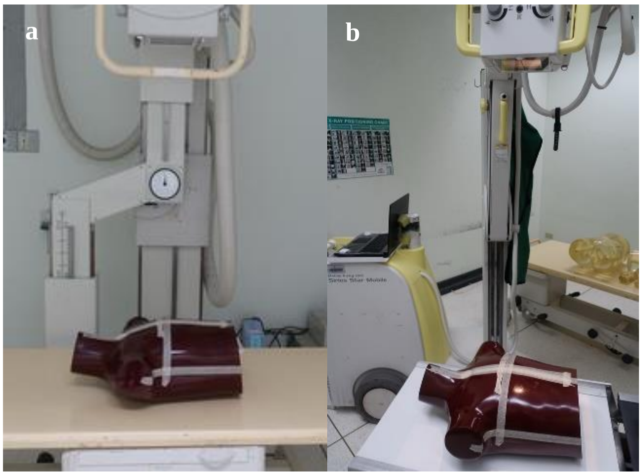

Figure 2. Evaluation of image quality of characteristic of x-ray transmission of carbon fiber with human body phantom. Comparison between exposure on the radiographic table (a) and passing through the carbon fiber sheet of the RT Wheelchair (b).

2.3 Device Satisfaction Assessment

The study incorporates user acceptance testing through interviews and satisfaction questionnaires. Participants in the research comprised three radiologists, porter staff members, and seven radiological technologists. Training and demonstration sessions for utilizing the RT Wheelchair were provided to radiological technologists and porter staff members. Satisfaction assessment encompasses various aspects, including the design, size, and appearance of the structure, the functionality of the positioning system, the usability of X-ray imaging, and overall benefits. Radiologists were interviewed regarding their satisfaction with image quality. The Likert scale was employed for scoring each item, with ratings ranging from 5-point scales with the given question, where 1-5 denotes very dissatisfied, dissatisfied, neutral, satisfied, and very satisfied, respectively [15]. Volunteer patients undergoing X-ray imaging at Phitsanuvej Hospital, Phitsanulok province, Thailand, were included in the study. X-ray imaging procedures encompassed examinations of the upper limb (hand, arm, or elbow), lower limb (foot, knee, leg, or ankle), supine chest X-ray, supine abdominal X-ray, and lateral decubitus X-ray. Volunteers capable of assisting themselves or performing activities such as sitting up, standing, and walking easily were selected to ensure safety during the preliminary testing phase.

3. Results and Discussion

3.1 Feature and Safety System design

The researcher considered the materials and properties used in developing the RT Wheelchair, as shown in Figure 3. The main structural components that can adjust between lying and sitting positions are made of aluminum and stainless steel, which provide strength, corrosion resistance, and durability. The body support areas that come into contact with X-rays are made of carbon fiber panels with low radiation attenuation properties, allowing X-rays to pass through without increasing the radiation dose compared to normal X-ray imaging. The wheelchair has a transparent slot for the X-ray imaging panel, which can be adjusted for lying positions, and it utilizes a guided navigation system with the X-ray panel and a mechanism to adjust the height of the body support. In this study, the X-ray transmission measurement described in Section 2.2 focused specifically on the carbon fiber components because these areas directly interact with the X-ray beam during imaging. Although aluminum and stainless steel were used in the frame structure, their placement was designed to avoid the primary X-ray exposure field. It did not block or overlap with the radiation pathway during clinical use. Therefore, their contribution to overall X-ray attenuation was considered negligible when evaluating transmission through the patient-contact regions directly exposed to the X-ray beam.

Figure 3. Positions of stretcher cum wheelchair for radiographic purposes driven by electronic motor. The base is made from stainless steel, the body made from 3 carbon fiber plates: the low extremity, the body, and the head part. The lower part of all fiber carbon plates has a slot for the image receptor. The motor driver can adjust the position of the image receptor.

3.2 The effects of material on X-ray transmission

3.2.1 X-ray transmission of carbon fiber sheets

The radiation reduction testing found that the difference in radiation quantities in microgray (μGy) did not exceed 8 percent. An analysis of X-ray transmission through carbon fiber sheets is detailed in Table 1.

Table 1. Exposure technique and dose between without passing and passing through the carbon fiber sheet.

Exposure Technique		Dose		Dose differences (%)	X-ray transmission
kVp	mAs	Without passing through the carbon fiber sheet (μGy)	Passing through the carbon fiber sheet (μGy)		
70	2	78.7	72.5	-7.8	92.1
	4	158.1	146.3	-7.5	92.5
	5	196.1	182.3	-7.0	93.0
	10	392.7	365.2	-7.0	93.0
80	5	267.1	249.8	-6.5	93.5
	10	536.1	500.0	-6.7	93.3
90	5	329.2	309.4	-6.0	94.0
	10	659.9	614.9	-6.8	93.2

3.2.2 X-ray transmission of carbon fiber with human body phantom

The Exposure Index and image quality evaluation results showed that the EI values obtained from photography were still within acceptable standards (Table 2), and the images' quality still showed complete anatomy, which passed the acceptance criteria. Therefore, carbon fiber sheets can be used as the main material for fabricating RT Wheelchairs and the backrest and seat cushion, which are the parts used to support organs that take X-ray images. There is no need to increase the radiation dose.

Table 2. Exposure Index (EI) values of radiographs of models of various organs when not passing through the carbon fiber sheet.

Part of the phantom	Exposure Technique	Exposure index (EI)		Criteria (EI=1800-2200)
		Without passing through the carbon fiber sheet	Passing through the carbon fiber sheet	
Hand	70 kVp, 1.4 mAs	2195	2158	Pass
Hips	85 kVp , 22 mAs	1967	1919	Pass
Thorax	66 kVp , 6.3 mAs	2198	2182	Pass

The results of the image quality assessment revealed that the anatomical features could still be observed, meeting the acceptance criteria. Therefore, carbon fiber can be used as the primary material in constructing the wheelchair frame, support parts, and seating. These components support organs during X-ray imaging without increasing radiation exposure compared to normal imaging and imaging with an RT Wheelchair, as shown in Figure 4.

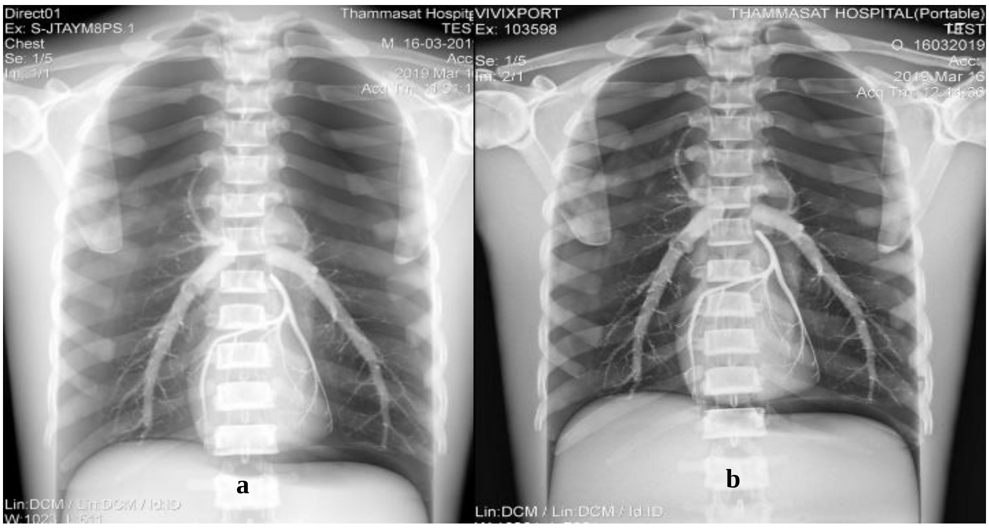

Figure 4. Chest AP 85 kV, 2.69 mAs by (a) normal imaging by exposure on the radiographic table and (b) imaging with RT wheelchair. The results of the image quality assessment revealed that the anatomical features could still be observed, meeting the acceptance criteria.

The wheelchair base is enclosed in a housing designed to prevent the spread of fire, complying with electrical safety standards for medical devices (IEC 60601-1). It is made of polycarbonate and has a lockable plastic cover. The interlock system separates the functions between usage and battery charging. The wheelchair also has a remote-control system to control the operation of the body support and the transmission of the X-ray imaging panel, as well as an electric motor system for propulsion. Electrical components and other electronic devices that control the machine are tested for electrical safety according to medical device electrical safety standards (IEC 60601-1), including protection against electromagnetic interference, as shown in Table 3.

Table 3. Specification of RT wheelchair.

Features	Details
Wheelchair weight	70 kilograms
Height in the lying position and the sitting position	80 centimeters in height (lying position) and 125 centimeters in height (sitting position)
Width	Width of 60 centimetres
Length in the lying position and the sitting position	Length of 175 centimetres (lying position) and 115 centimetres (sitting position)
Maximum patient weight capacity	Maximum weight capacity of 150 kilograms (multiplied by the Safety Factor)
Battery	24-volt dry acid battery; 21 Ampere-hours (Ah)
Degree of tilt-in-space	Tilt-in-space range of 0 to 90 degrees
Degree of leg rest adjustment	Leg rest adjustment range of 0 to 90 degrees
Maximum motor speed	Maximum speed of 12 kilometres per hour
Drive system	Electric motorized wheels without carbon brushes on both sides 24 volts and 250 watts per side
	Option to operate with electricity or manually, according to user preferences

In addition to the mechanical specifications, preliminary results from observations and inquiries regarding using the RT Wheelchair over two months (November to December 2020) were obtained. The sample group consisted of 89 volunteer participants. Among them, there were 24 elderly volunteers. The image quality of the X-ray images met the quality standards at a 100% rate. These results further underscore the effectiveness of carbon fiber materials in preserving diagnostic image quality while ensuring structural safety. Previous studies have also extensively investigated carbon fibers' mechanical and radiological properties. Unterweger et al. [16] conducted a comprehensive study employing techniques such as X-ray photoelectron spectroscopy (XPS) and scanning electron microscopy (SEM) to characterize surface properties of different types of carbon fibers. Similarly, Ho et al. [17] demonstrated that carbon fiber/polyetheretherketone (CF/PEEK) constructs enhanced biomechanical performance and minimized imaging artifacts. The widespread adoption of carbon fiber in radiotherapy couches is attributed to its superior physical resilience, reduced weight, and low beam attenuation [16,18]. However, attention must be given to dose variations introduced by carbon fiber structures, particularly at joint interfaces, necessitating accurate manufacturer data on absorption rates to ensure clinical safety [19-21].

3.2.3 Device Satisfaction Assessment

The satisfaction levels of various stakeholders concerning the RT Wheelchair were assessed, as shown in Table 4. Volunteer patients expressed that the structure's design, size, and appearance were satisfactory (4.29 ± 0.10 and 4.37 ± 0.33, respectively). Porter staff reported that the structure's design, size, and appearance were neutral level (3.45 ± 0.15) and satisfied level (3.70 ± 0.10). Radiological technologists indicated that satisfaction levels regarding the design, size, and appearance of the structure, as well as the usability of X-ray imaging and benefits, were neutral level (3.25 ± 0.34, 3.32 ± 0.40, 3.13 ± 0.18, and 3.07 ± 0.38, respectively). There were additional feedback from such as 1) The sharp edges of carbon fiber sheets cause skin abrasions during RT wheelchair use 2) The exposure factors for radiographic imaging need to be increased in certain cases 3) X-ray imaging in large-bodied patients is not feasible due to the structure of the wheelchair and the limited space for the image receptor 4) Cross-table lateral X-ray imaging is not feasible 5) Skull X-ray imaging in tall patients is not feasible 6) When adjusted to a reclined position, there is a gap between the backrest and the seat, leading to artifacts in Pelvis imaging 7) The positioning of the image receptor along the horizontal axis of the RT wheelchair is not precise during operation.

These user comments highlight several practical challenges that were not fully captured under controlled experimental conditions. In particular, the need to increase exposure factors reported by radiologic technologists can be attributed to limitations encountered during simulated use, such as phantom or volunteer body size variations, positioning difficulties, and structural interferences associated with the RT Wheelchair design. Although Exposure Index (EI) measurements under standard phantom conditions suggested that a dose increase was unnecessary, simulated practice with phantoms and volunteers revealed that certain imaging scenarios required dose adjustments to achieve acceptable image quality. This discrepancy underscores the importance of considering operational variability and user feedback before translating prototype performance into future clinical applications. The evaluation results of X-ray images conducted by radiologists underscored the high level of maneuverability and ease of use attributed to the RT Wheelchair. Despite potential concerns regarding its aesthetic appeal, the wheelchair was perceived as robust and sturdy. Crucially, the X-rays' image quality was clear and consistent, falling within the standard range and closely resembling that of conventional X-ray images. These findings affirm the practicality and efficacy of the RT Wheelchair in facilitating diagnostic imaging procedures, thereby contributing to its viability as a valuable tool in clinical settings.

In addition to the independent evaluation of images obtained using the RT Wheelchair, a comparative analysis was conducted against conventional radiographic techniques without the device. Radiologists scored the images based on positioning accuracy, anatomical visibility, and overall diagnostic acceptability. The results demonstrated no significant difference in image clarity between the two methods; however, the RT Wheelchair group exhibited improved consistency in positioning accuracy, particularly in challenging imaging views such as lateral hip and cross-table projections. This direct comparison further substantiates the RT Wheelchair's contribution to enhancing the reproducibility and reliability of radiographic positioning, supporting its potential utility in clinical practice.

Table 4. The results of satisfaction levels of various stakeholders concerning the RT Wheelchair

Stakeholders	Design and size	Appearance of the structure	X-ray imaging	Benefits
Volunteer patients	4.29 ± 0.10	4.37 ± 0.33	n/a	n/a
Porter staffs	3.45 ± 0.15	3.70 ± 0.10	n/a	n/a
Radiological Technologists	3.25 ± 0.34	3.32 ± 0.40	3.13 ± 0.18	3.07 ± 0.38

X-ray images are regarded as integral components of routine patient care. They play a pivotal role in diagnosing broken bones due to their decreased discomfort, enhanced precision, and superior lesion detection capabilities [22]. The acquisition of X-ray images facilitates prompt diagnosis by healthcare professionals, thereby expediting the commencement of treatment for patients. The RT Wheelchair, which focuses on a Stretcher Cum Wheelchair designed for Radiographic Purposes, serves as a preventive measure against patient falls within healthcare facilities. Hence, radiology departments must prioritize fall prevention and deploy interventions to mitigate harm. The initiation of preventive measures commences within emergency settings, where risk factors can be identified through appropriate tools and patient engagement [8].

Moreover, the RT Wheelchair offers versatility by seamlessly transitioning from sitting to reclining. Its carbon fiber support structure beneath the backrest facilitates precise positioning for X-ray examinations. Minimizing patient movement during diagnostic imaging procedures can significantly aid physicians in rendering timely diagnoses, potentially preserving patients' lives. The RT wheelchair has successfully undergone testing following IEC 60601 standards, which delineate safety and performance criteria for medical electrical equipment. Nevertheless, adherence to the guidance provided by regulatory bodies such as the Food and Drug Administration (FDA) is imperative for ensuring that RT Wheelchairs marketed to the intended demographic comply with safety and efficacy requisites [23]. When considering the benefits of utilizing the RT Wheelchair compared to conventional X-ray procedures, it is observed that there is no need to relocate patients to the X-ray bed. This reduces the personnel required for the procedure from 2 individuals to just 1. Additionally, the imaging time for X-ray procedures is decreased from 10 minutes to only 2 minutes.

Stakeholder satisfaction evaluations confirmed the RT Wheelchair's practical utility in hospital settings, with volunteer patients, porter staff, radiological technologists, and radiologists providing positive scores as documented in Table 3. Their valuable feedback identified several necessary improvements, including reducing carbon fiber edge sharpness, modifying the structure to accommodate horizontal 14×17-inch image receptors with grid capability, developing equipment for lateral cross-table imaging positioning, creating accessories for skull imaging in tall patients, extending the seamless seating area over the pelvis region, minimizing the gap between seat and backrest, and redesigning for more precise image receptor positioning during use. Incorporating these improvements is expected to enhance user satisfaction, optimize imaging workflows, and broaden the clinical applicability of the RT Wheelchair across a broader range of patient groups and radiographic techniques. Nevertheless, a limitation of this study is the absence of direct measurement of the initial radiation output (I_0) for the two X-ray machines. Although identical exposure settings were employed, variations in intrinsic output between systems may have influenced dose measurements. Future studies should include I_0 verification to strengthen the validity of cross-system comparisons.

4. Conclusions

Implementing the RT Wheelchair within the emergency X-ray department has effectively mitigated risks associated with patient transfers for radiographic procedures. The wheelchair's design facilitates direct radiographic imaging, enhancing workflow efficiency and reducing potential patient discomfort. Furthermore, the RT Wheelchair has successfully met the safety and performance standards mandated for medical electrical equipment. Evaluation of EI and image quality has demonstrated adherence to acceptable standards, affirming its suitability for clinical use. Significantly, the satisfaction and feedback received from volunteer patients, radiologists, radiological technologists, and porter staff members have played a pivotal role in informing and refining subsequent stages of development. Their insights have been instrumental in identifying areas for improvement and enhancing overall efficiency in the device's functionality and usability. Continuing collaboration with stakeholders and incorporating their feedback will be essential for further optimizing the RT Wheelchair's performance and ensuring its continued effectiveness in clinical settings.

5. Acknowledgements

We would like to thank the administrators and staff of at Thammasat University Hospital and Phitsanuvej Hospital for providing assistance to the research team in collecting data regarding this research.

Author Contributions: Conceptualization, Sookpeng, S.; Kadman, B.; methodology, Kadman, B.; Sookpeng, S.; Prommin, D.; and Junhunee, P.; formal analysis, Sookpeng, S.; Kadman, B.; Prommin, D.; and Junhunee, P.; writing—original draft preparation, Sookpeng, S.; Kadman, B.; writing—review and editing, Sookpeng, S.; Kadman, B.; Prommin, D.; and Junhunee, P.; supervision, Sookpeng, S. All authors have read and agreed to the published version of the manuscript.

Funding: The authors did not receive support from any organization for the submitted work.

Conflicts of Interest: The authors have no relevant financial or non-financial interests to disclose.

Ethical clearance: This study received ethical approval from the Institutional Review Board of Naresuan University.

Informed consent: Written informed consent was obtained from all stakeholders.

References

[1] Warren, R.A.; Ferguson, D.G. Why do accident and emergency doctors request X-rays? *Emerg Med.* **1984**, *1*(3), 143-150. https://doi.org/10.1136/emj.1.3.143.

[2] Story, M.F.; Luce, A.C.; Leung, A.; Omiatek, E.M.; Lemke, M.R.; Rempel, D.M. Accessibility of radiology equipment for patients with mobility disabilities. *Hum Factors.* **2008**, *50*(5), 801-810. https://doi.org/10.1518/001872008X354174.

[3] Conrad, B.P.; Rechtine, G.; Weight, M.; Clarke, J.; Horodyski, M. Motion in the unstable cervical spine during hospital bed transfers. *J Trauma Acute Care Surg.* **2010**, *69*(2), 432-436. https://doi.org/10.1097/TA.0b013e3181e89f58.

[4] Story, M.F.; Schwier, E.; Kailes, J.I. Perspectives of patients with disabilities on the accessibility of medical equipment: Examination tables, imaging equipment, medical chairs, and weight scales. *Disabil Health J.* **2009**, *2*(4), 169-179.e1. https://doi.org/10.1016/j.dhjo.2009.05.003.

[5] Dean, E.R.; Scoggins, M.L. Essential elements of patient positioning: A review for the radiology nurse. *J Radiol Nurs.* **2012**, *31*(2), 42-52. https://doi.org/10.1016/j.jradnu.2011.08.002.

[6] Wallin, A.; Gustafsson, M.; Anderzen, Carlsson, A.; Lundén, M. Radiographers' experience of risks for patient safety incidents in the radiology department. *J Clin Nurs.* **2019**, *28*(7-8), 1125-1134. https://doi.org/10.1111/jocn.14681.

[7] European Society of Radiology, European Federation of Radiographer Societies. Patient safety in medical imaging: A joint paper of the ESR and the EFRS. *Radiography.* **2019**, *25*(2), e26-e38. https://doi.org/10.1016/j.radi.2019.01.009.

[8] Grossman, VA. Hot topics: Promoting patient safety in the radiology setting. *Insights Imaging.* **2019**, *10*(1), 1-2. https://doi.org/10.1186/s13244-019-0721-y.

[9] European Federation of Radiographer Societies. The assessment of image quality and diagnostic value in X-ray images. *Insights Imaging.* **2022**, *13*(1), 1-10. https://doi.org/10.1186/s13244-022-01199-5.

[10] Diaz, A.; Guizar-Sicairos, M.; Poeppel, A.; Menzel, A.; Bunk, O. Characterization of carbon fibers using X-ray phase nanotomography. *Carbon.* **2014**, *67*, 98-103. https://doi.org/10.1016/j.carbon.2013.09.066.

[11] Wang, Y.; Yang, Y.; Zong, Z. Carbon fiber-reinforced polymer composites for X-ray transparent medical devices. *J Compos Mater.* **2019**, *54*(1), 39-50. https://doi.org/10.1177/0021998319862295.

[12] Grob A, Biersach B, Peck J. Risk management and IEC 60601-1: Assessing compliance. *Biomed Sci Instrum.* **2013**, *49*, 55-59. https://doi.org/10.2345/0899-8205-49.s1.55

[13] Eubanks F, Masters M. Assurance cases: A new form of requirements traceability matrix for medical devices. *INCOSE Int Symp.* **2011**, *21*(1), 1134-1144. https://doi.org/10.1002/j.2334-5837.2011.tb01271.x.

[14] Lee, S.J.; Chung, I.S. Optimal design of sandwich composite cradle for computed tomography instrument by analyzing the structural performance and X-ray transmission rate. *Materials (Basel).* **2019**, *12*(2), 286. https://doi.org/10.3390/ma12020286.

[15] Taherdoost, H. What is the best response scale for survey and questionnaire design: Review of different lengths of rating scale/attitude scale/Likert scale. *Int J Acad Res Manag.* **2019**, *1*(2), 1-10.

[16] Unterweger, C.; Duchoslav, J.; Stifter, D.; Fürst, C. Characterization of carbon fiber surfaces and their impact on the mechanical properties of short carbon fiber reinforced polypropylene composites. *Compos Sci Technol.* **2015**, *108*, 41-47. https://doi.org/10.1016/j.compscitech.2015.01.004.

[17] Ho, D.; Phan, T.H.T.; Mobbs, R.J.; Reddy, R. The use of radiolucent (carbon fibre-reinforced polymer) pedicle screw fixation for serial monitoring of clear cell meningioma: A case report. *J Surg Case Rep.* **2020**, *2020*(12), rjaa510. https://doi.org/10.1093/jscr/rjaa510.

[18] Sedaghatian, T.; Momennezhad M, Rasta S, Makhdoomi Y, Abdollahian S. An update of couch effect on the attenuation of megavoltage radiotherapy beam and the variation of absorbed dose in the build-up region. *J Biomed Phys Eng.* **2017**, *7*(3), 279-286.

[19] Munjal, R.; Negi, P.; Babu, A.; Sinha, S.; Anand, A.; Kataria, T. Impact of 6MV photon beam attenuation by carbon fiber couch and immobilization devices in IMRT planning and dose delivery. *J Med Phys.* **2006**, *31*(2), 67-71. https://doi.org/10.4103/0971-6203.26690.

[20] Kong, F.; Lu, M.; Dong, J.; Wang, D.; Shi, J.; Li, Z. Effect of linear accelerator carbon fiber couch on radiotherapy dose. *PLoS One.* **2022**, *17*(11), e0277332. https://doi.org/10.1371/journal.pone.0277332.

[21] Hufton, A.P.; Russell, J. The use of carbon fibre material in table tops, cassette fronts, and grid covers: Magnitude of possible dose reduction. *Br J Radiol.* **1986**, *59*(698), 157-163. https://doi.org/10.1259/0007-1285-59-698-157.

[22] Howell, J.D. Early clinical use of the X-ray. *Trans Am Clin Climatol Assoc.* **2016**, *127*, 341.

[23] Miller, D.L.; Kakar, S., Jiang, L., Spelic, D.C.; Burk, L. The US Food and Drug Administration's role in improving radiation dose management for medical X-ray imaging devices. *Br J Radiol.* **2021**, *94*(1126), 20210373. https://doi.org/10.1259/bjr.20210373.