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Design, development, and analysis of an imaging compatible patient transfer device: Roller PATH

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Abstract

Patients with disabilities ranging from morbid obesity to Pervasive Developmental Disorders (PDDs), including autism and Rett Syndrome, have long been denied the benefits of medical imaging technologies. Current imaging systems require patients to mount the imaging device table and then remain static for a time period ranging from a few minutes to an hour for appropriate imaging accuracy and reliability. More and more Americans are unable to complete these tasks as the morbid obesity levels are rising above 3 million, and the birth rate of autistic children is quickly approaching 1 in 250. Ideally, what is needed is a device that meets both these needs. To date, however, none exists. Here, we report the design, construction, and testing of a novel device, called the “Roller PATH” [for Patient Aid and Transfer Help], that will meet these requirements. The design is comprised of three components: a mobile patient transfer table, an imaging bed track and a hospital bed track. Material composition is entirely comprised of non-ferrous, radiolucent elements including HDPE, nylon, vinyl, and HD foam. Initial calculations show a theoretical maximum deflection of 0.4249 cm under a distributed load of 2135 N on the patient transfer table. Test results indicate a deflection of 0.3289 cm. Dropouts and image artifacts are not present upon inspection and SNR analysis of MR and CT data. Usability and safety testing demonstrates a safe, comfortable transfer for both the patient and imaging technician based on survey responses.

Keywords: Patient transfer, Positioning aid, Medical imaging, Obesity, Pervasive developmental disorders

1. Introduction

Between 1962 and the year 2000, the number of obese Americans grew from 13% to an alarming 31% of the population. Sixty-three percent of Americans are overweight with a Body Mass Index (BMI) in excess of 25.0. Thirty-one percent are obese with a BMI in excess of 30.0. Childhood obesity in the United States has more than tripled in the past two decades (American Sports Data, Inc., 2004). Pervasive Developmental Disorders (PDDs) are on the rise as well. As of 2003, 1 in 250 births resulted in an autistic child, showing an annual growth of 10 – 17%. Based on the 2000 US Census figure of 280 million Americans, 1 to 1.5 million Americans suffer from autism (Autism Society of America, 2003). With these elevated numbers, the percentage of Americans unable to benefit from medical imaging diagnosis (MR, CT, PET) and treatment is increasing. These members of society are ultimately unable to meet one or both of the requirements for them to be scanned: mounting the imaging bed, or remaining static throughout the data acquisition process. A novel device designed to aid individuals in meeting both these requirements is

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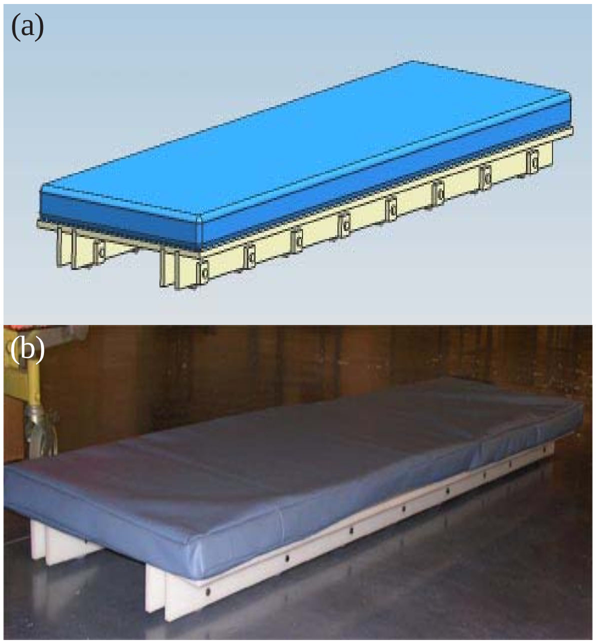

Fig. 1. Drawing (a) and picture (b) of the patient transfer device. The drawing emphasizes the additional HDPE structures added to the transfer device for wheel support to ensure safety and durability of the design. Final dimensions of the transfer prototype were 189 cm x 59 cm x 13 cm with a weight of less than 222.4 N.

comprised of two components: a transfer design and a static aid. Current devices offer one function or the other.

With the advent of medical imaging, the number of patient transfers that a nurse has to perform has increased. Due to the intense physical workload that the nursing profession requires, it ranks second only to industrial workers in that respect and is obviously a high-risk for back injury. Nurses have approximately 30% more days off due to back pain acquired during patient movements as compared with 8% for the general population. From these figures, it is evident that a more effective methodology for patient transfers is required. Researchers John D. Lloyd and Andrea Baptiste evaluated friction-reducing devices for lateral patient transfers. They concluded that a roller device would be the best for lateral transfers from bed-to-stretcher (Lloyd & Baptiste, 2003).

Static aid designs, including foam wedges and wrap-around coils, have been proven to be successful in the past in maintaining static patient position. These aids, in cooperation with a transfer design, will potentially contribute to the proper diagnosis and treatment of the increasing percentage of an expanding population that is currently unable to benefit from medical imaging. The following novel design and series of tests are aimed at developing such a system.

2. Materials and methods

Theory of the design

The Roller PATH design consists of three parts: a patient transfer table with a mattress (Fig. 1a and b), an imaging bed track and a hospital bed track. The patient transfer table contains two long columns of wheels on the underside of the frame to allow for easy transfer from one track to the next. A patient is transferred to the imaging room on a stretcher containing the transfer table on the hospital bed track. Inside the imaging room, the two tracks are aligned and locked in place. The wheel locks are removed and the patient table is transferred by a technician from the hospital bed to the imaging bed. This allows patient transfer without the individual physically moving while easing the physical burden on the technician.

The unobstructed top of the transfer device is designed such that multiple static aids already available on the market may be implemented to control patient movement during the scan. Such validated static components include foam neck supports for head position and stability and medical grade sandbags for limb placement and immobility.

Materials and construction

High density polyethylene (HDPE), high density (HD) foam, nylon, vinyl, and hook and loop cloth fasteners were chosen as materials to construct a functional prototype based on their compatibility within the three imaging modalities. HDPE was used to construct the patient table based on average heights and weights of adult radiology patients. A piece measuring 189 cm x 59 cm x 1.27 cm was cut, and four tracks were milled lengthwise across the board measuring 1.27 cm wide and 0.635 cm deep. Axial beams measuring 189 cm x 6.86 cm x 1.27 cm were screwed into the milled tracks to provide extra support in framing the wheels. Eight wheels were fastened into each set of the axial beams and a square of 1.27 cm HDPE was added to the outside of each axial beam for additional support. Six hand holes were cut along the edges of the patient table to provide easy guidance for the technician during patient transfer.

Two tracks were constructed from HDPE; one for use on a hospital bed and the other for the imaging table. Two channels were milled in each track to match the wheel placement on the patient table. The hospital bed track had dimensions 189 cm x 43.2 cm x 1.27 cm. The channels measured 2.86 cm wide by 0.635 cm deep. The imaging bed track had dimensions 244 cm x 43.2 cm x 1.27 cm. The channels measured 2.56 cm wide by 0.635 cm deep. All dimensions used were based on average hospital and imaging equipment beds.

Wheel locks were constructed from HDPE to lock the patient table in place before and after transfer. HDPE was also used to implement a mechanism for locking the imaging track and hospital bed track together during transfer.

The hook and loop cloth fasteners, HD Foam and vinyl were used to construct and attach a foam pad that covered the surface of the patient table.

Mechanical testing

Mechanical testing was also conducted on the bed to ensure the material strength as well as patient safety under a range of loads. This test consisted of deflection, creep and hysteresis. Deflection was tested by measuring the change in height at different weight increments. Material creep was tested by measuring the amount of time the bed took to stop deflecting when the total weight of 2135 N was placed on it. Hysteresis was tested by comparing deflection at different weights while increasing the weight versus removing the weight.

Image testing

Image testing was performed in the MR and CT environments to evaluate the quality and integrity of the design based on signal to noise ratio (SNR) calculations. An initial scan was taken with only a phantom within the gantry of the system. A second scan was taken with both the phantom and the Roller PATH device. For both CT and MR environments, the SNR was compared between the two scans to determine if the device affected the quality of the image. Additionally, a qualitative analysis was done by a trained professional to confirm that no dropouts (MR) or artifacts (CT) were present in the scans.

In MR testing, two sets of pulse sequences, which are performed during most clinical scans, were used: the Fast Spin Echo (FSE) and Gradient Echo (GRE). A simple SNR analysis was done using ImageJ. A region of interest (ROI) was drawn within the phantom and the mean number of photon counts was measured. Then an ROI of the same size was drawn over the background of the scan and counts were measured. Calculations were done taking the ratio of the phantom mean to the background mean.

For CT, two scans were done of the phantom: one with the device and one without. Analysis of the images was done using the same technique described for MR. Calculations were done differently as the background counts provide a negative value. Scaling was performed on these values. A ratio of the phantom mean to the background mean was generated to determine if the addition of the device affected the image quality with respect to the phantom.

Ergonomic testing

Once the bed was complete, the usability, safety, and comfort were evaluated from the point of view of the patient and technician. A test transfer was carried out involving participants from the undergraduate

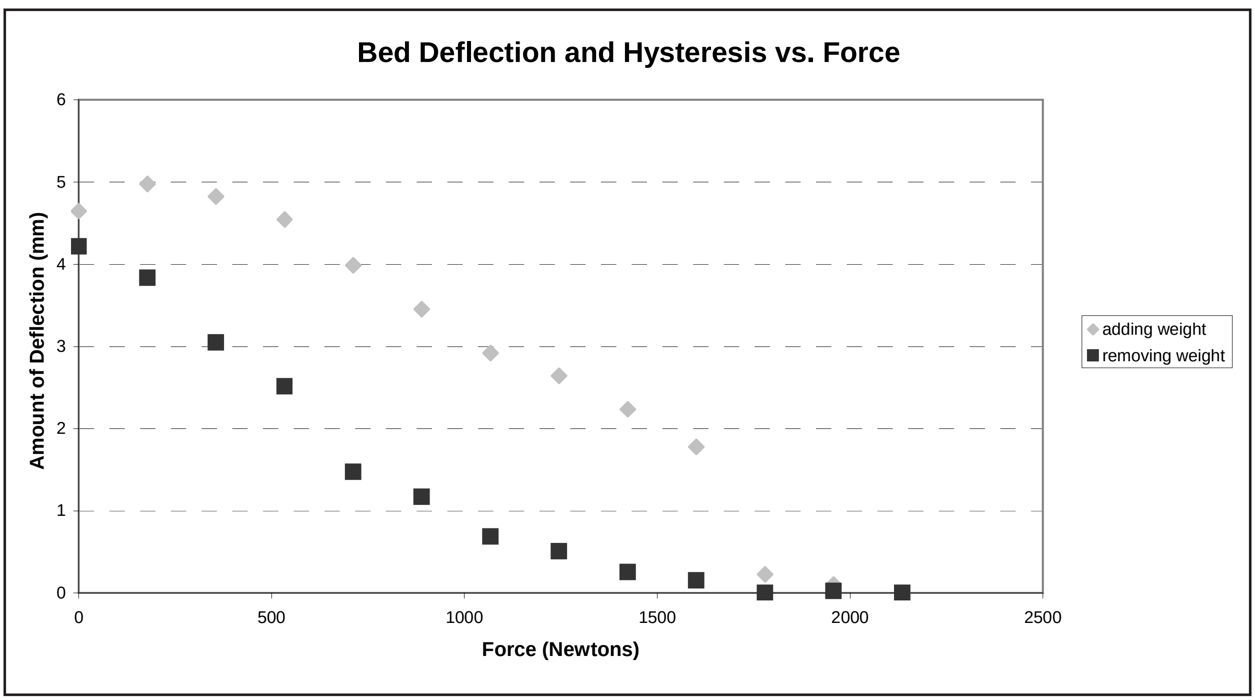

Fig. 2. Deflection for the loading and unloading (hysteresis) of the bed at 177.9 Newton increments, ranging from 0 to 2135 N.

biomedical engineering design course. They were asked to lay on the transfer bed while members of the design team acted as technicians and transferred them from the hospital bed track to the imaging bed track. Subjects were then asked to rate on a scale from one to five the level of comfort of the mattress, device stability and movements felt during the transfer, and overall safety of the transfer. Using the same scale, the technicians rated the ease of transfer and the handle grip comfort. Values greater than 3.5 were desired.

3. Results

Mechanical testing

The observed maximum bed deflection under 2135 Newtons was 3.29 mm. Additionally, the creep test showed that it took the bed 20 minutes to stop deflecting and reach a constant height.

The results for the deflection and hysteresis mechanical testing are plotted on Figure 2.

Image testing

The SNRs obtained in the MR environment were very similar between scans with and without the device. In the FSE pulse sequence the SNRs were 14.9 and 15.6 with and without the device, respectively. In the GRE pulse sequence the SNRs were 42.9 and 42.7 with and without the device, respectively.

The SNRs obtained in the CT environment were also very similar: 32.8 and 32.9 with and without the device, respectively. These values are listed in Table 1.

Ergonomics testing

On a scale from one to five, comfort, movements felt during the transfer, overall stability, and safety were rated by participants (n = 10). The mean values, as shown in Table 2, are 4.8, 4.1, 4.4, and 3.8, respectively. Test patient ranged in height from 157.5 cm to 203.2 cm and in weight from 556 N to 1001 N. Also for each transfer, those playing the role of the technician rated ease of transfer and handle comfort on the same scale. The mean values were 4.8 and 5, respectively.

Table 1
These signal-to-noise ratio numbers were obtained from scans with and without phantoms on different imgaing modalities.

MR Scan Type	**SNR**
FSE: Phantom with Device	14.9
FSE: Phantom without Device	15.6
GRE: Phantom with Device	42.9
GRE: Phantom without Device	42.7

CT Scan Type	**SNR**
Phantom with Device	32.8
Phantom without Device	32.9

Table 2
Average values for the comfort, stability, and steadiness experienced by patients during 10 trial transfers. Survey values from the technicians ratings of ease of transfer and handle grip comfort are also provided.

n = 10 (1 = negative, 5 = positive)				
	Mean	Max.	Min.	Std. dev.
Patient comfort	4.8	5	4	1.58
Patient steadiness	4.1	5	4	1.42
Patient stability	4.4	5	3	0.73
Patient safety	3.8	5	2	0.78
Technician ease	4.8	5	4	0.41
Technician comfort	5	5	3	0.98

4. Discussion

Mechanical testing

In order for the bed to be considered safe for human use, the device had to pass a certain set of mechanical criteria. For the deflection analysis, the pass/fail testing criteria was based on the material properties of HDPE. Using a Young's modulus of 0.86 GPa, it was found that the maximum allowable deflection under a distributed load of 2135 N was 4.20 mm. For creep testing, it was necessary to ensure that the bed did not continue to deflect for more than 30 minutes. With continuous loading and unloading, an extended creep could lead to permanent deformation. The hysteresis criteria requires that the bed deform back into its original shape after the maximum weight is removed. This guarantees that the material is remaining within the elastic limits and is not undergoing permanent plastic deformation.

Based on these criteria, the bed passed each of the mechanical tests. The maximum observed deflection under 2135 N was 3.29 mm. Under the maximum load, the bed only took 20 minutes to reach a constant height. Last, as shown in Fig. 2, the bed deflected back to the original height measured before loading. These results imply that the bed is safe for extended use with patients weighing up to 2135 N.

Image testing

MR signal to noise (SNR) ratio results were normal. As seen in Table 2, differences between SNRs of the same pulse sequences for scans with and without the device were less than 1, indicating that the device will not affect image quality. The results for the two different sequences showed dramatic contrasts. This is a consequence of each image acquisition and calculation using a variable level of excitation. A FSE consists of a 90 degree RF pulse followed by a 180 RF pulse. A GRE is simply one RF pulse less than 90 degrees. Thus, they elicit different contrasts and different SNRs.

For CT, the SNRs achieved in the scans with and without the device were similar. Values are listed in Table 2. Thus, the device does not affect the image quality of a CT scan.

A scan was not conducted to validate the system in conjunction with PET based on the signal properties of PET. A PET scanner records annilation events between positrons and electrons. In order for there to be an event, a positron emitter must be within the body of the patient. There are two types of scans that are performed: a transmission scan and an emission scan. A transmission scan takes into account the attenuation of the patient's body as well as anything that might be positioning the individual. An attenuation map is then created that is used during the reconstruction of the image. After the transmission scan, the PET scanner reads annilation events via the emission scan. The scanner takes the attenuation information that was recorded during the transmission scan and matches it with the emission information from the body. This creates a PET image of activity within the body. As the device does not contain a positron emitting isotope, a PET scan was unrealistic. Additionally, the reconstructed image would take into account the attenuation sum of the body and the positioning device for every individual scan. In reality, the SNR originates from the patient's body and not the imaging modality. Unlike MR and CT, a PET scanner reads the signal from the body and anything blocking the signal is accounted for in every scan.

Ergonomics testing

The mean values obtained for the transfer were well above the established limit of 3.5. The comfort and stability of the bed were more than satisfactory to the test patient. There appeared to be no correlation between height and weight and the comfort rating. Thus, the bed works for a variety of patient sizes and weights. The movements felt during the transfer and the overall safety were rated slightly lower. The safety rating may be somewhat skewed as the transfer occurred non-traditional setting (approximately 1.5 meters high). An additional factor that may have affected the safety rating was the failure to sense the wheel locks at the end of the track; those patients felt as if they would keep moving off the track and reflected that feeling in their rating.

The technicians found the hand holes to be satisfactory and that the difficulty the of transfer was proportional to the patient weight.

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