ORIGINAL ARTICLE

Atlas table: a dynamic innovative support device for the coming obesity epidemic

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ABSTRACT
With obesity rates increasing rapidly, the Atlas table, a modular table overlay, was developed to address the unmet medical need of the inability of current interventional tables to support patients weighing more than 450 lbs. Current procedural tables have a posted weight limit of 500 lbs. In practice, this limit is 450 lbs due to the permanent installation of a 50 lb dye injector at the foot of the table. Instability is reported in patients in the range of 250–450 lbs, resulting in the need to modify how the table is placed over the base. Additional weight and mobility limitations exist due to the cantilever beam design of the existing table that allows movement of the C-arm fluoroscope to move around the entire table. A clinical device should bear all of the weight of an 800 lb patient, without failing during emergency chest compressions, which makes the weight capacity necessary 1200 lbs. This must be accomplished without obstructing the movement of the C-arm of the existing table or requiring a more than 2% increase in radiation. Our table overlay design features a lightweight, radiolucent tabletop and four modular height-adjusting legs that move with the existing table and do not require separate controls. The legs clamp to the radiolucent tabletop securely but not permanently so that they can be moved when needed, with buttons that swing out and cause the table to raise or lower by being trigger by contact from the existing table. The proposed design safely holds and lifts 1200 lbs.

INTRODUCTION
The 2011–2014 National Health and Nutrition Examination Survey reported the prevalence of obesity was 36.5% among US adults[1] and that by 2030, 51.1% of all American adults will be obese with associated obesity healthcare costs ranging from \$860 to \$956 billion.[2]

Procedures in an integrated imaging operating room are performed using an X-ray fluoroscope mounted on a mobile C-arm, and a cantilevered, or shaped like a diving board, procedural table for the patient. It has been found that the current equipment does not securely support patients with a body mass index (BMI) greater than 40, resulting in potential damage to the equipment, increased safety risk to both patients and staff and compromised quality of care for heavier patients, if they can be treated at all. Current procedural tables have a posted weight limit of 500 lbs, although this number drops to 450 lbs after accounting for the weight of the dye injector to the base of the table (Z Bercu, J Martin, J Newsome, personal conversation, March 3, 2017).

The C-arm is a revolutionary advancement in X-ray imaging devices that can provide high-resolution images in real time at almost any angle. Mounted to the ceiling, the C-arm is shaped as a semicircle and can move in three different planes of axis. Due to the width of some heavier patients, physicians are often unable to conduct lateral scans.[3]

The current design of the table also increases the likelihood of deflection at the free end during procedures, due to a concentration of force on one end of the table.[4] Repeated use of tables for heavier patients creates significant wear-and-tear, with increased frequency of maintenance needed for the table's hydraulic base (Z Bercu, J Martin, J Newsome, personal conversation, March 3, 2017).

Figure 1 Crack in the base attachment to an existing table.

An example can be seen in the break in figure 1, where the cantilever table meets the base. This is the point of highest stress on the table and the most likely point of failure.

METHODS

Attention was turned to building a new table that moves along with the existing device. Design inputs were analysed (table 1). Static analysis of the system showed that the thickness of the table should be increased to achieve increased engineering advantage of the resulting device by thereby increasing the moment of inertia of the table. Materials to maximise radiolucency of the device, including acrylic, polyurethane foam and carbon fibre, were preferred. These materials were also analysed and compared for their inherent stiffness values. Materials were evaluated under X-ray to determine their radiolucency and appropriateness for surgical use. Also emphasised was the importance of the table and C-arm moving frequently during procedures, in that the designed table must be completely integrated with the movement of the existing table (table 2).

Table 1 Engineering design inputs

Engineering requirements	User need(s)	Design input(s)
Physical embodiment	Support patient weight up to 800 lbs	Support 1200 lbs
Chemical/biological	N/A	N/A
Environmental	IR operating room	Sterile and radiolucent
Sterility	Sterile operation	American Society for Testing and Materials (ASTM) Standard E1766
Performance	Does not fail during procedure	No failure after 6 hours use
Safety	Does not fail during procedure	No failure after 6 hours use
Reliability and maintenance	Lasts 2–3 procedures a week	6 hours use six times a week
Packaging and labelling	Infinite shelf life	Infinite shelf life
Interfacing devices	Interventional Radiology (IR) tables (Siemens, Phillips and so on) Modular overlay	IR tables Modular overlay
Interfacing requirement	Meets height and width of each	Height and width of both
Human factors	Easy to use	Clear instruction
Regulatory considerations	Food and Drug Administration (FDA class I	FDA class I
Other	Patient rotation	Rotate patient 90°

Modular stretcher tabletop overlay

The portion of the device the patient is laid on is designed to be a lightweight, stiff, durable and radiolucent tabletop that can be used as a stretcher if needed. It would measure 108 inches long by 25 inches wide by 1 inch thick. The length corresponds with the cantilevered length of the existing table so that the Atlas overlay does not cover the controls at the end of the table (figure 2). It also allows the table to support patients of any height. The width of 25 inches allows for the legs to fit underneath the overlay and next to the existing table and keeps the width of the overlay within the 27 inch span of the X-ray plates on the C-arm so that the C-arm can still be rotated to perform cone beam imaging. The thickness was determined by the allowance of 2 inches described by the surgeons and technicians, as well as for the fact that increasing this dimension increases the moment of inertia of the table six-fold, from 186 in^4 to 1152 in^4. To function without obstructing the radiological imaging of soft tissue, the material needs to be radiolucent. For this purpose, the team chose carbon fibre and a rigid polyurethane foam also known as sawbone. Carbon fibre is the material currently used for radiology tables as it has the highest stiffness value combined with the lowest radiodensity[5 6] The rigid polyurethane foam was chosen for its stiffness, incompressibility, light weight and radiolucency. This material is commonly known as sawbone as it is used for materials testing and surgical training to simulate bone. The composition of the table would be two ⅛ inch slabs of carbon fibre with ¾ inch of the sawbone. The choice to use two materials was to be able to increase the thickness to a full 1 inch while minimising cost, as carbon fibre is a very costly material, costing $24 for a ⅛ inch thick 12 inch by 4 inch piece. Combined, the stretcher material increases the stiffness value (moment of inertia * Young's modulus) of the table by a factor of 6, from 4046560.2 lb/in to 25062566.4 lb/in. A 6 inch by 4 inch by 1 inch sample was made (figure 3), weighed and tested for radiolucency. It weighs 100 g at these dimensions, meaning a full-sized table would weigh roughly 9 kg. The sample was passed through

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Table 2 Selection criteria used to determine concept scoring

Selection criteria	Design input	Weight (%)	Description
Weight capacity	<1200 lbs	25	Effect of modification on weight capacity.
Radiation attenuation	<1% increase	15	Effect of modification on reducing radiation penetration.
Durability	<6 hours continuous, repeat use	15	Ability of modification to support large weight loads for continuous periods of time repeatedly.
Staff manoeuvrability	–	15	Effect of modification on physicians', techs' and nurses' ability to move around the patient and access certain parts of the body.
Fluoroscope manoeuvrability	–	10	Effect of modification on fluoroscope's ability to move as needed.
Ease of use	–	5	Time, effort and number of potential complications associated with modification during procedure.
Ease of set up	<10 min <5 parts	5	Time, effort and number of potential complications associated with modification prior to procedure.
Ease of manufacturing	–	2	Time and resources associated with manufacturing modification.
Lateral rotation of patient	–	5	Effect of modification on ability to turn patients laterally for better access to certain areas of the body.
Patient comfort	ASTM Standards	3	Degree of comfort offered to patients by modification.

the X-ray field with a volunteer hand on top to test the radiolucency (figure 4). This was confirmed as acceptable by the technicians and surgeons.

Modular height adjustable legs

The legs (figure 5) were designed to be vertical linear actuators with low friction feet to enable the Atlas table to move in all the directions that the existing table is currently able to move. The low-friction feet allow the Atlas table to slide forward, back and side to side along the arc that the existing table can move, centred at the base. To raise and lower with the table, the legs were built to be vertical linear actuators with a steel threaded rod that is rotated by a motor that turns forward and backward to raise or lower the table by rotating the rod through a threaded piece of Delrin plastic. The motor has a driver and data board with Arduino board in an attached housing that is powered by a rechargeable 12-volt battery activated by a switch. This allows for each leg to be powered independently and eliminated the concern for plugging in any or all the legs to a power source. Once the battery has been switched on, the legs can be activated by one of two buttons. The buttons are off until pressed, and once pressed, they tell the data board and Arduino which direction the motor should spin. The data board sends a positive multiplier to the driver to rotate the motor forward and a negative multiplier to rotate the motor backward. The buttons are designed to be activated by the existing table. They are placed on the ends of a sideways U-shaped attachment (figure 5), which is on a hinge attached to the exterior of the leg that goes above and below the existing table. Therefore, when the surgical technicians raise the existing table, it will rise and activate the top button, and the legs and Atlas table will rise. The same principle lowers the Atlas table and legs when the existing table lowers and activates the lower button. If neither button is being actively pressed, the motor will not be activated and the legs will not move. The motor used is a NEMA 23, 1.8° stepper motor, capable of providing the 285 Nm torque needed to lift the 1200 lbs load anticipated. The chassis of the leg would be built from aluminium 80-20, which is designed as a reinforced vertical I-beam for maximum strength.

Figure 2 The Atlast table as is fits over the existing table.

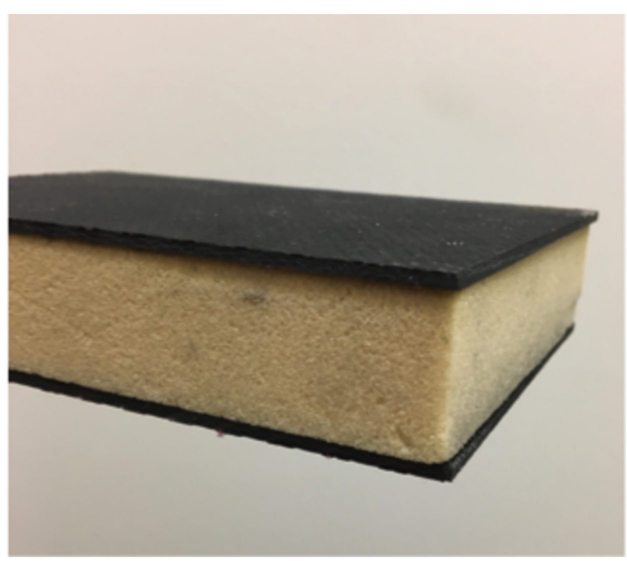

Figure 3 Sawbone core with carbon fibre lining.

Figure 4 Representative X-ray of material.

Figure 5 Bracketed motorised leg.

Usability

The design's modular aspect allows it to be broken down for easy storage and for use of single components when desired, such as when a single leg can be used to steady the existing table for a patient with a BMI between 40 and 45. One person can place the lightweight stretcher onto the top of the existing table, although the length means that it may be easier to place with one person at either end. Since the memory foam on the existing table is not permanently attached, it can be removed and slid on top of the Atlas table. Once the overlay is in place, the four legs can be placed on wherever is needed for the load of that specific patient or for that procedure. The button attachments should be flipped out, parallel with the width of the leg. As the legs are not permanently attached, they can be moved at any point to allow for the movement of the C-arm around the patient as needed for different procedures. When the legs are attached, the existing table can then be lowered, leaving the Atlas table standing on its own and no weight transferred to the existing table. The U-shaped button attachments can then be flipped forward on their hinge to be perpendicular with the width of the leg, so that the buttons are swung out to be above and below the existing table (figure 5).

RESULTS

Multiple iterations were designed and built (figure 6). Three types of feet were tried: plastic low friction sliders, felted sliders and wheels. The felted sliders rolled up almost instantly and were dismissed as a possibility. The wheels made the attachment of the legs difficult as the legs were difficult to stand. This meant that any wheels incorporated into the design would need fail-proof brakes that would have to be latched for every leg when needed. This introduced a higher chance of operator error, as attempting to move the bed without releasing the brake on a single wheel could potentially cause a collapse and drop the patient. This brought the team to the conclusion to use the third option—the low friction sliders. While they do scratch up, increasing their coefficient of friction, there was no significant impact on the floor and their low cost means that they can be replaced easily and cheaply.

The frame of the leg was four 2-foot sections of aluminium 80-20. Two pieces, hereafter called the inner leg, were connected by 4 inch brackets at the top and bottom. The other two pieces, hereafter called the outer leg, were connected by 6 inch brackets at the top and connected by 2 inch brackets to the inner leg,

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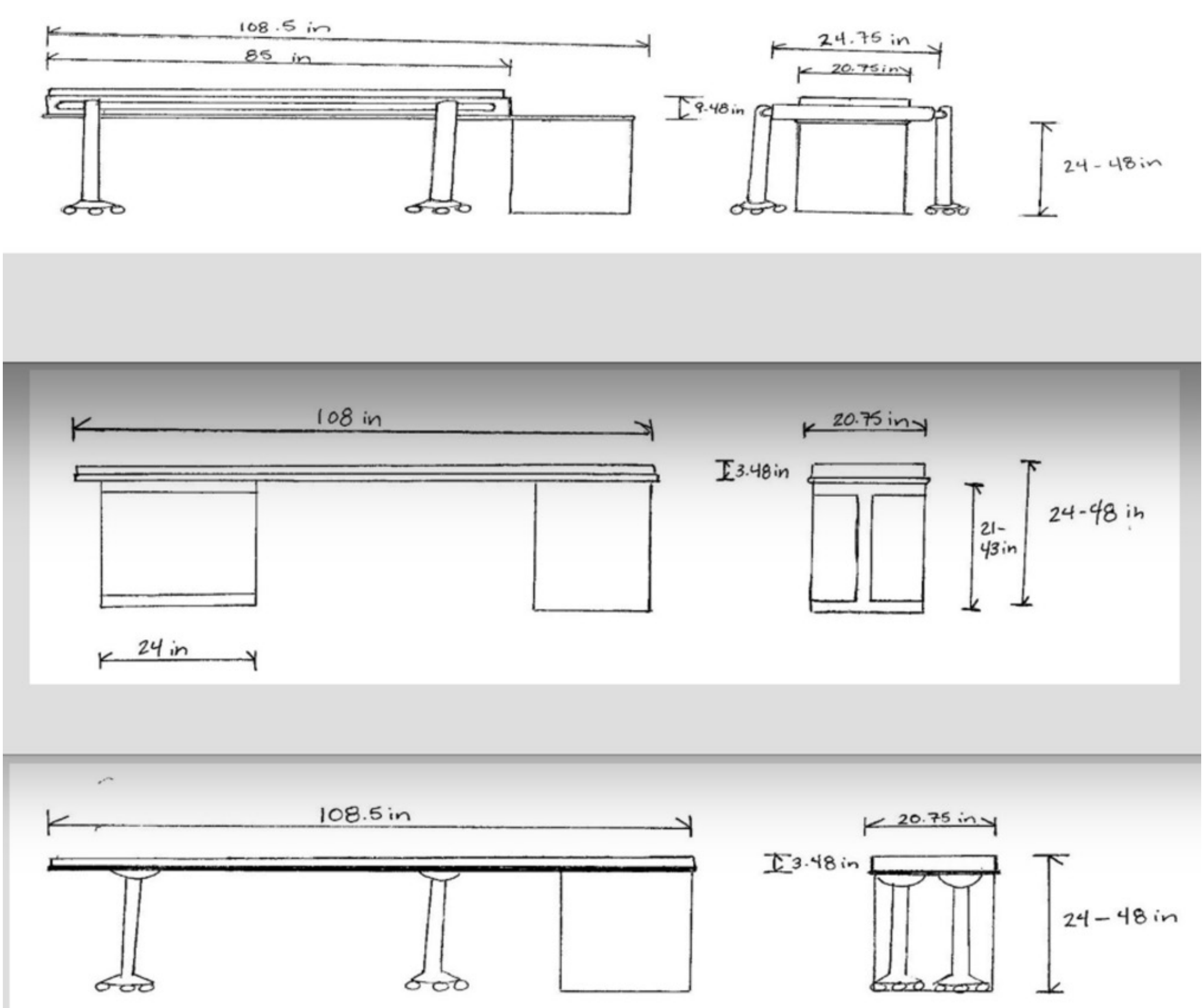

Figure 6 Multiple Atlas table design iterations.

allowing them to slide as the leg goes up and down. A 2 inch piece of Delrin was milled to have a perfectly centred and vertical hole, and then tapped to create the threads for the rod to follow. This piece was placed securely between the 4 inch brackets at the top of the inner leg and the 2 feet threaded rod inserted. Another 2 inch section of Delrin was milled lengthwise the width of the motor shaft. It was then milled halfway down the width of the rod, and the wider half tapped. This piece was used as a coupler to attach the motor shaft to the rod. Set screws were then placed to ensure that when the motor shaft turned, it moved the coupler with it, instead of spinning inside of it. The motor was held in place on the bottom by two metal bars and on the top by a three-dimensional (3D) printed piece held by the 6 inch brackets at the top of the outer leg. It was determined that the Delrin in the top of the inner leg was a point of weakness, as it could pop out of place when weight was applied to the top of the leg, so it was bolted into place in the bracket. A second piece of Delrin was machined to act as a guide at the base of the rod to ensure that it stayed perfectly vertical during operation. However, they were determined to hold the rod too tightly and were removed. The machined Delrin pieces were the lowest tolerance pieces of the leg, as they ensured the rod stayed vertical and therefore reduced strain on the motor.

Screw clamps were epoxied to be 1.5 inches apart and then attached to the top of the metal leg by brackets (figure 5). These served as the non-permanent attachment to attach the legs to the table. Two clamps were placed on each leg. All the electrical components were placed into a plastic housing that was screwed into the 3D printed piece above the motor. The motor was wired in through a hole drilled into the back, and the buttons through two holes in the side. The switch was placed in a hole cut into the top and wired to the battery inside. The driver was wired to the battery and motor, as well as a data board that was wired to the buttons. The data board had connections for each button to inform the attached Arduino which button had been pressed. A full-scale model of the carbon fibre and rigid polyurethane foam overlay was built. Mechanical legs were built.

DISCUSSION

One alternative solution to addressing this clinical problem is to replace the current procedural table with a bariatric table, an investment costing around $10 000 and one that many hospitals and clinics cannot afford, especially for a small number of patients every week.[5 7–9] The bariatric table is also shorter by almost 2 feet, which does not solve the problem of getting access to the entire anatomy of overweight patients. The installation of a procedural table with increased weight capacity could be extended to all surgical specialties, not just interventional radiology, provided those procedures can be performed in the room where the table has been installed.

Alternatively, the cost to manufacture to our team was estimated to be roughly $1150. This breaks down to $150 per leg and $550 for the overlay. With a dedicated manufacturing process, this cost would likely be reduced, and with a 100% markup comes in at an anticipated cost to the hospital of $1500. The Atlas table would cost 15% of the bariatric table and comes without the need to make any permanent changes to the current surgical environment. Furthermore, except for using the aluminium legs in an MRI room, any part of this design can be used in any surgical environment, increasing the overall value to the hospital.

The Atlas table is a prototype that can meet five critical needs: support an 800 lb patient, support the patient in an emergency situation requiring chest compressions, never drop the patient, does not injure staff or break equipment and does not require the increase of radiation dose more than 2% to the patient (S Lee, personal conversation, March 11, 2017). Our design is simple enough that it can be easily transported, set up and removed in little time, without adding any significant, extra tasks to either the physicians or the technicians during operation. It also integrates with the mobility of the table and does not impair the functionality or mobility of the C-arm. The prototype can be used with many different types of imaging equipment and tables.

Limitations of our study include that this device has not yet been tested with patients. Although the clinical setting has been replicated for testing, no patients have undergone procedures on the Atlas table.

Contributors The design concept was jointly created and tested by AS, JM, JN and ZB. AS was the primary author of the manuscript. HS was a contributing author and major contributor of medical and population data to the manuscript. JN and ZB were contributing authors to the manuscript. JM co-authored, edited and submitted the manuscript.

Competing interests None decalred.

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