REDESIGNING THE MEDICAL EXAMINATION TABLE

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By

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Redesigning the Medical Examination Table

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Abstract

The inaccessibility of the medical examination table contributes to both fewer and lower quality physical examinations, resulting in substandard medical care for persons with physical disabilities, as well as for elderly and obese patients. Design research to create a more physically and fiscally accessible medical examination table has been identified as the most direct method to remove this physical barrier to accessing equitable medical care. Therefore, an iterative design process has been employed to develop and optimize a medical examination table design, adhering to design specifications identified by both the design team, as well as by national accessibility standards. Several iterations were qualitatively compared before establishing a final design. This design was transformed into a fully functional 3-dimmensional computer-animated model to simulate its utility within a clinical setting. If fully realized, this design would employ motorization to ensure height-adjustability and maximal accessibility. Finite element analysis was used to ensure the structural integrity of the table, illustrating its ability to withstand up to 1500 Newtons, or roughly 300 pounds. Additionally, materials analysis and cost analysis were performed to verify this design's feasibility in large-scale manufacturing and distribution. Relying on published literature and competitive products, the total cost of materials was estimated to be $480.04, establishing this design as a realistic option for healthcare providers. This design has the propensity to create a more equitable healthcare landscape for a large demographic of both patients and providers. Future work includes the project's expansion into a multiyear project incorporating a full-sized prototype and patient studies within the University of Virginia Health and Family Medicine Clinic.

Keywords: Medical Examination Table, Physical Examination, Equitable Medical Care, Disability Advocacy, Increased Accessibility

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Introduction

Sitting at the center of almost any examination room, the medical examination table is a medical device that many patients have interacted with from a young age; however, the medical examination table has been repeatedly named the largest barrier to patients with physical disabilities accessing reliable medical care[1]. While mounting a medical examination table may be easy for most young, able-bodied patients, this action can in fact be challenging for various patient demographics such as elderly, obese, and mobility-limited patients. A 2004 survey of accessibility of medical devices found that of the 93% of participants who had used medical examination tables before, 34% found them moderately difficult to use, 33% found them extremely difficult to use, and, 8% of participants cited that current medical exam tables were "impossible to use" due to their disability[2] . Furthermore, it is estimated that only 8.4% of all medical provider sites across the United States have access to at least one physically accessible medical examination table[3]. The lack of accessible medical diagnostic equipment, most notably medical examination tables, has been proven to result in missed or delayed disease and illness diagnosis and subsequent substandard medical care[4].

This inaccessibility has massive negative ramifications on health-outcomes in a variety of different fields of medicine. For example, a prenatal care survey of women with physical disabilities found that the majority of prenatal clinician's offices had fixed-height medical examination tables, similar

Fig. 1. Transfer Height Discrepancies. Accessible height medical examination table (left) versus wheelchair height (center) versus fixed height table (right)[6].

to the table pictured in Figure 1[5]. Physicians are therefore forced to perform unsafe transfers of persons with physical disabilities, with multiple reports of patients being dropped[5]. This scenario poses serious risk of injury and to both fetal and maternal health. Furthermore, ambulatory patients are more than three times more likely to receive a mammography exam and over five times more likely to receive a cervical smear test than non-ambulatory patients[7]. These tests are representative of essential preventative and diagnostic measures that could lead to lifesaving treatments, illustrating the current state of substandard medical care for persons with physical disabilities. Additionally, it has been shown that persons with physical disabilities are less likely to work and more likely to have lower incomes and be reliant on state and federal funding for medical care[4]. Therefore, the goal for this project is to redesign the medical examination table to increase both the physical and fiscal accessibility for not only persons with physical disabilities, but for all patient demographics in hopes of improving national healthcare standards.

The first aim of the project was to redesign the medical examination table through an iterative design process. The researchers proposed a design process consisting initially of 2-dimensional sketches; from these sketches, a final design was selected and subsequently translated into a 3-dimensional model in Autodesk Fusion 360, a computer-aided design (CAD) application. The researchers also proposed that finite-element analysis and free-body diagrams could be used to estimate the needed load capacity of the redesigned medical examination table, with the hopes of this virtual model being translated to a physical model and used in clinical settings in the future.
The second aim was to create an animation of the 3D CAD table to simulate how it would work in a clinical setting with the goal of creating a table that can lower to an acceptable transfer height, revolve, and adjust the angle of its head, back, seat, arm, and leg pieces to improve doctor-patient interaction. This animation was created for the purposes of showing it to an audience at a capstone symposium; however, for the purposes of this paper, images depicting various positions that the table can be set to as well as a table describing the movements of each joint are shown to illustrate how this model would work.

The third aim of this project was to optimize materials for the medical examination table and perform cost analysis for future large-scale manufacturing. This aim largely relies on current literature describing materials used for other competitively priced medical examination tables. Additionally, this information will inform the feasibility of not only manufacturing, but also project realization and distribution.

The results of this project include a finalized medical examination table design, a fully functional computer-animated design model and simulation of the finalized medical examination table, and an analysis including estimated cost of raw materials to inform large-scale manufacturing of the table. Equitable standard of care remains a largely unmet problem in the current American healthcare system. By addressing a significant physical barrier to access for persons with physical disabilities, this research aims to combat discriminatory healthcare practices in the United States to create a more equitable national healthcare landscape.

Materials and Methods

Initial Research

The technical advisor for this project, Dr. Masahiro Morikawa, M.D. at UVA Family Health, cited issues with the current medical examination design. Most notably, the difficulty of patient use and the bulkiness of the current medical examination tables hinder the doctor-patient interaction. Using these issues as guidelines, the team consulted existing literature to expand upon specific areas for change in the medical examination table. A survey at an ambulatory care center asked patients to rate their level of exertion and level of difficulty required to mount a medical examination table, as well as their feelings of safety during this process. The study found that when using an adjustable-height examination table, patient exertion decreased by 72%, difficulty decreased by 64%, and patients felt 42% safer[8]. Thus, height adjustability was considered a key objective for the redesign of the medical examination table, and the team decided that to accomplish this goal, the table would need to have a motor and remote-control that could adjust the table according to physician input.

In addition to height adjustability, the width of the table was also identified as a potential issue. A study of accessible medical examination tables found that the two factors that healthcare providers found most helpful in these tables were height-adjustability and increased width[9]. Providers also noted that these features specifically helped elderly, obese, mobility-limited, and pediatric patients, indicating the potential for increased width to target the demographics that are currently excluded by the medical examination table[9].

A final consideration in the initial research phase was to limit the bulkiness of the medical examination table, as requested by the technical advisor of the project. In order to do this, the team decided to adopt a chair-like design for the table, as opposed to a flat and boxy design that is typically seen in doctor's offices. By using a chair design, the team was able to incorporate a range of motion in the head, back, seat, and leg pieces that allows for that doctor to position the patient as desired, as opposed to patients either laying down or supporting themselves sitting up on a flat medical-examination table bench. Because a motor and remote-control had already been decided upon for the height-adjustability component, the team decided that the motor could also be responsible for adjusting the positions of the table according to remote-control input, as well. The final design specifications decided upon in the initial research phase are shown in Table 1.

Lastly, typical box type tables are priced around $1,500 but can cost upwards of $7,000 depending on the level of complexity and functionality[10–14]. Creating a table that allows all healthcare facilities the ability to purchase this redesigned medical examination table allows a wide range of facilities and regions to benefit from this design and to improve the doctor-patient relationship, so minimizing cost was identified as an objective, as well.

Need #	Design Constraint	Unit of Measure	Marginal (Acceptable) Value	Ideal Value
1	Minimum Height	Inches (in)	17-19	18
1	Maximum Height	Inches (in)	31-35	33
2	Range of Motion of Foot and Head Rests	Degrees (°)	90 - 180	90 - 180
3	Bacteria Removed after Sanitization	Percentage (%)	> 95%	> 99%
4	Width	Inches (in)	28-32	30
4	Length	Inches (in)	71-75	73
5	Total weight	Pounds (lbs)	< 250	200
6	Weight limit	Pounds (lbs)	> 350	400
7	Total Cost	Dollars ($)	< $2000	< $1500
8	Aesthetically Pleasing	N/A	N/A	N/A
9	Product Lifespan	Years	8-15	10

Table 1. Design Specification Table. Design constraints for the final table were determined, with two of the most important considerations for accessibility being increased width and height adjustability.

3-Dimensional Virtual Modeling and Animation

The final design was realized after several weeks of brainstorming and an extensive iterative design process involving the team and the technical advisor. A design sketch that was believed to optimize the primary aims set out for the project was decided on. The next step was then to create a three-dimensional model in Autodesk Fusion 360 CAD based on the final sketch and predetermined dimensions. The details of the design sketch were rudimentary, establishing the primary components of the table, the dimensions of those components, and the various degrees of motion that each component needed to have. Because of these basic constraints, there was a lot of freedom in the design of the ergonomics of the chair's components. Through researching a wide range of comfortable chair types and their shapes and curves, the curvature of the head, back, seat, and leg pieces were curated. These pieces were connected by various types of hinges to create a 3-D virtual model that not only visually represented the redesigned table but also could be animated to demonstrate the proposed functions of the table. This design was then further validated through finite element analysis in Autodesk Fusion and a free body diagram to give context to the amount of force the table would need to withstand in a clinical setting.

Materials and Cost Analysis

Materials and initial cost analysis relied heavily on current literature and state-of-the-art research. This included materials research and analysis of a wide breadth of both stationary and dynamic medical examination tables, including final and wholesale costs. The cost of the raw materials for the medical examination table, excluding the motor and electrical components that would be needed to control this model in a clinical setting, was estimated by using the known surface areas and volumes of the final 3-D model in CAD, as well as the prices of raw materials, including foam, medical-grade vinyl, and stainless steel. Additionally, state and national medical-grade materials regulations were taken into consideration, as this table aims to support a variety of patient and doctor demographics nationwide. Furthermore, tax credits for increasing accessibility and physical barrier removals for persons with physical disabilities in healthcare settings have also been included in this analysis, contributing to the goal of designing both a physically and fiscally accessible medical examination table.

Results

Initial Design Iterations

To produce a finalized design of the redesigned medical examination table that accurately addressed the design specifications initially outlined at the beginning of the year, an iterative design process was followed. This extensive process involved several cycles in which designs were drafted and then subject to feedback from the team, other students within the capstone small group, and advisors. In this manner, several rounds of changes were included in the final design, allowing for an extensive brainstorming and review period. Preliminary designs resemble more closely to the typical exam table design in which it is more of a flat bench and less of an adjustable chair (Figure 2A, B). However, this design was rather bulky and allowed less freedom of movement for physicians when attempting to examine their patients. After receiving inspiration from exam tables such as dentist chairs, the design was altered to promote greater freedom of movement and utilized fewer materials. A more updated table design was then produced as a result of the insight obtained from previous designs (Figure 2C, D). In this more updated design, the table has a round, swivel base to promote stability and rotation of the table, as well as adjustable back and leg supports that can extend to double as stirrups for gynecological examinations, as shown in Figure 2D. This iterative process allowed for continual improvements to the table until a fully analyzed and refined final design was produced.

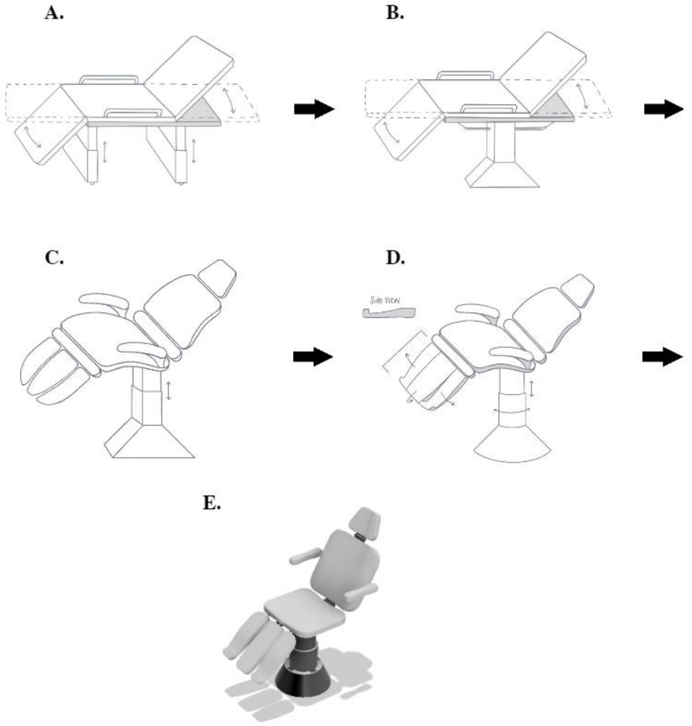


Fig. 2. Project Progression. A. Iteration 1, an early design concept. B. Iteration 2, showing a redesigned base. Iteration 3, showing increased range of motion and improved ergonomics. D. Iteration 4, the final iteration showing the incorporation of stirrups in the foot piece. E. The final CAD model.

3-Dimensional CAD Model and Animation

After weeks of brainstorming design ideas, a final design was selected to virtually model in Autodesk Fusion 360. The final design consists of eight pieces that are in contact with the patient - the head piece, back piece, seat piece, three leg pieces, and two armrests - in addition to the round base mechanism (Figure 2E). This sketch was then used to create a virtual model which is designed to be controlled by a remote-control, which is depicted in Figure 3. This remote- control has 22 distinct options for controlling and repositioning the chair in a customizable fashion, as well as three preset positions that allow the physician to quickly set the table to positions that are commonly used in family medicine. The preset options depicted in Figure 4 include a flat option, similar to the style in most practitioner's offices, an inclined seat option, similar to a dentist's chair, and a gynecological examination option, in which the stirrups are extended upward and outward. From these presets, practitioners can choose to make additional adjustments to the patient's position for comfort or improved access using any of the switches on the remote-control. The head hinge can be adjusted from 180º (forming a single plane with the head and back pieces) to 110º if the head requires lifting. The back hinge can be adjusted from 180º (forming a single plane with the back and seat pieces, parallel to the floor) to 110º as an upright seated position. The armrest hinges can be adjusted from 0º (flush against the back piece) to 90º. The three leg pieces can be adjusted both together and individually, where the center leg piece may rotate between 150º and 270º (where 180º indicates forming a single plane with the seat piece, parallel to the floor), and the two outer leg pieces can be adjusted both vertically and horizontally to give them the functionality of stirrups. Specifically, these hinges can rotate vertically between 110º and 250º (again where 180º indicates a single plane with the seat piece, parallel to the floor) and horizontally between 180º and 150º, otherwise measured as parallel with each other and rotated 30º outwards (Table 2). The two outer leg pieces also have indents approximately where the patient's heel would rest to provide additional comfort and stability for the patient.

Most importantly, the table met the key objective of being adjustable in height and having an increased width. The table's stand is comprised of two cylinders, with the lower one being anchored into the base and the upper/inner one being capable of raising and lowering. The lowest height this upper cylinder can go is 19 inches off the ground, which is in line with the design specs shown in Table 1 and consistent with the ADA accessible table in Figure 1. The table has an increased width of 30 inches, and the armrests can lie flat against the chair back to allow for additional width to accommodate wider patients. Adhering to these two design specifications greatly improves the accessibility of the medical examination table as it is known today.

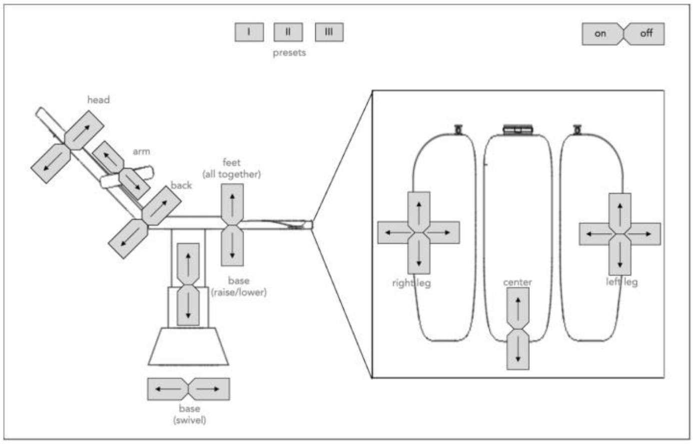


Fig. 3. Remote-Control. Proposed design for the remote-control pad. Switches with corresponding motions are shown in gray.

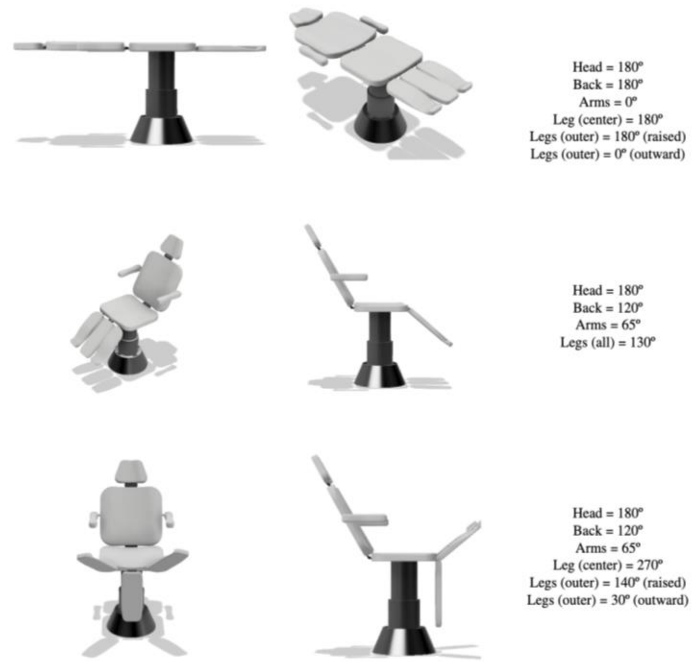


Fig. 4. Final 3D Model Rendering of Remote-Control Presets. Position set by remote-control preset 1 (top). Position set by remote-control preset 2 (middle). Position set by remote-control preset 3 (bottom). The right column indicates the angles of each hinge at the given preset.

Finite Element Analysis and Free Body Diagram

To validate the integrity of the redesigned table in clinical settings, the design was subject to finite element analysis testing in Autodesk Fusion CAD. Finite element analysis

Hinge	**Degrees of Motion**	
Head	110º - 180º	
Back	110º - 180º	
Leg (center)	150º - 270º	
Leg (right and left)	0º - 30º *(in/out)*	110º - 250º *(up/down)*
Arms	0º - 90º	

Table 2: Hinge Degrees of Motion. 180º indicates the hinge is open "flat" and <180º indicates folding the top faces of the joined components toward each other. The outer leg pieces are at 0º when parallel with the center leg piece and can rotate 30º away from the center leg piece. For the arm hinges, 0º indicates being flush against the back piece whereas 90º indicates perpendicular.

was performed on the seat and stand of the table independently of the entire assembly for simplicity, with the goal of this analysis being to simulate the stress on the upper cylinder in the stand of the table when a roughly 400-pound patient sits on the table. A downward force of 1500 N was simulated in the center of the seat; this force translates to roughly 330 pounds, assuming that the patient distributes some of their weight to the seat back. The bottom of the stand and the rotating cylinders were given fixed constraints to simulate the electric/motorized braking force that would be applied to the chair in a clinical setting.

The results of this analysis indicated that while the inner cylinder experiences stress of roughly a magnitude of 0.085 MPa during this action, this stress is not enough to cause catastrophic failure, as shown in Figure 5. To better safeguard against possible plastic deformation of this cylinder, which would interfere with proper raising and lowering of the table, the thickness of the hollow inner cylinder could be increased so that the force felt by the stand is distributed over a greater surface area and volume.

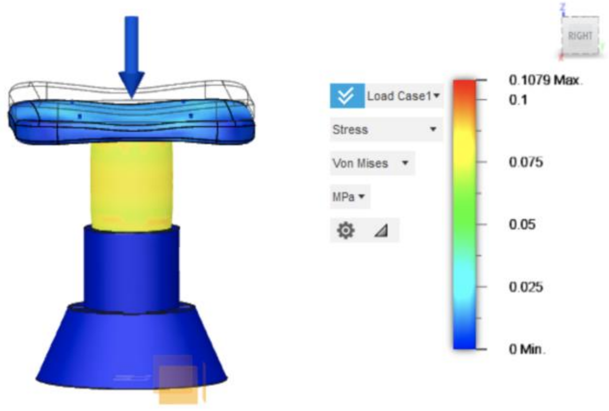


Fig. 5. Finite Element Analysis on Seat Base. In order to simulate the downward force of a patient sitting on the base of the table, a downward force of 1500 N was applied to the top of the seat using Finite Element Analysis in Autodesk Fusion. The scale to the right shows the stress to the inner cylinder of the base as the force is applied.

To accommodate for the fact that performing finite element analysis on the entire assembly in Fusion was increasingly complex and required too many assumptions and constraints to be realistic, a free body diagram was used to analyze the force and power that the motor of the medical examination table would need to supply to support the back of the chair. The back of the chair is connected to the seat portion via a cylindrical hinge, meaning that for it to stay upright against gravity and the patient's weight, a force would have to be applied from the motor to the hinge/back of the chair. In Figure 6, the force F_{body1} and F_{stand} are in equilibrium, with F_{body1} being the force of the patient sitting on the chair and F_{stand} being the normal force applied by the stand. F_{body2} represents the perpendicular force of the patient on the back of the chair, which is inclined at an angle of Θ degrees from the horizontal, and $F_{g\ back}$ represents the force of gravity on the back of the chair. L is the length of the back and head pieces and F_{hinge} is the force that the hinge has to supply to keep the chair back in equilibrium.

$$0=\Sigma F_x= -F_{body\ 2}\sin(\Theta) + F_{hinge\ x}$$
$$0=\Sigma F_y= -F_{body\ 2}\cos(\Theta) - F_{g\ back} + F_{hinge\ y}$$
$$0=\Sigma \tau_p= -F_{body\ 2} * L/2 - F_{g\ back}/\sin(\Theta) * L/2 + \tau_{hinge}$$

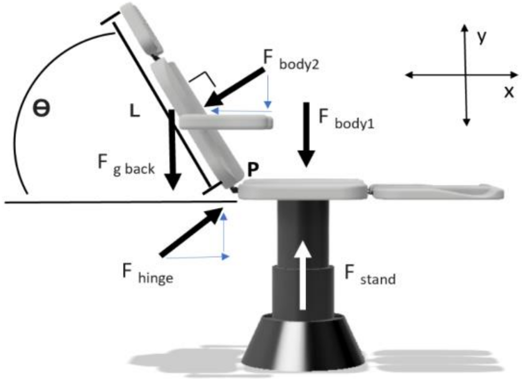


Fig. 6. Free Body Diagram. The forces shown in black and white arrows represent forces that the chair would experience when a patient is sitting in it. Blue arrows are resultant components for each force along the x- and y- axes. This diagram allows for estimation of the force needed by the motor to keep the chair back at an angle of Θ.

By breaking up each force into its resultant components along the x- and y-axes (shown in blue), it was deduced that the motor must provide a force in the positive y-direction equivalent to both the weight of the chair and the vertical component of F_{body2}, which is a function of cos(Θ) and a portion of the patient's weight. Additionally, the chair must provide a force in the positive x direction equivalent to the horizontal component of F_{body2}, which is a function of sin(Θ) and a portion of the patient's weight. These forces must also be applied in a way such that they counteract the torque on the seat back due to a component of $F_{g\ back}$ and F_{body2}, estimated at a distance of L/2 from the hinge. If these conditions are met by the chair's internal motor and braking mechanisms, the chair will be in equilibrium. It is important to note that even if the table were completely horizontal (Θ=0), a braking mechanism would still be required to apply a force to the chair to keep the seat back from hanging down vertically because the back of the chair hangs above the ground and does not experience a normal force.

Materials and Cost Analysis

The overwhelming majority of medical examination and procedure tables consist of three primary materials: a steel frame, a foam cover, and vinyl upholstery[15]. Furthermore, although medical examination tables are classified by the FDA as Class I devices, it is important that if novel materials were used, they pose no additional risk of disease transmission or infection. Therefore, industry standards involving the three materials listed above will be followed.

Analysis of the finalized CAD model revealed area and volumetric estimates to inform the required materials for manufacturing as shown in Table 3. The amount of steel needed was taken using the volume of the base and stand of the table as well as the surface area of the back of the table, assuming a 1-inch thick plate of steel serving as the frame. The required area for the 2-inch foam covering and subsequent upholstery was estimated using the surface area of the upward-facing table faces when the table is completely extended, encompassing any area that may be naturally touched by a patient in a supine position. Unit prices of each material were found to be \$0.02175/in^2, 0.05792/in^3, and \$0.50/kg for vinyl, foam, and steel respectively[16–18]. These costs were multiplied by the computed areas, volumes, and masses (using the density of steel to convert to mass, in the case of steel) to estimate the total cost required of each material. Therefore, the final estimated cost of materials was found to be \$480.04.

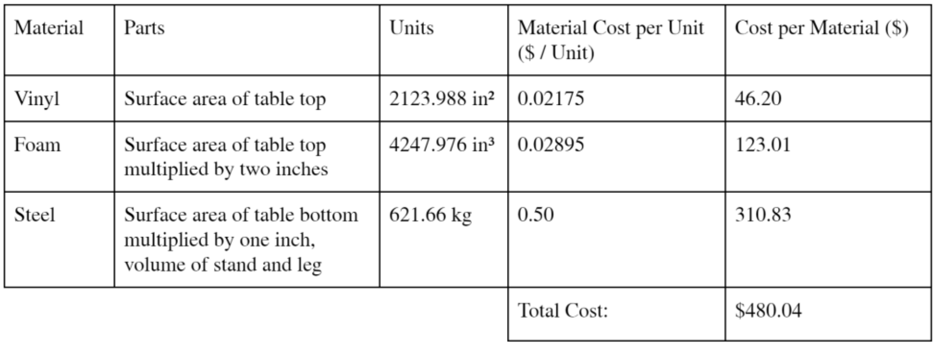
Although this analysis does not account for the cost of manufacturing, including specialized manufacturing tools, methods, machinery, and assembly, this materials and cost analysis acts as a baseline estimate for cost of materials for one medical examination table. A significant portion of the cost that is not accounted for within this analysis is the cost of the motor and electrical components responsible for repositioning the table according to physician input via the remote-control; however, because the raw materials for the frame of the table are relatively low cost, the team is confident that the total cost including that of the motor and circuitry would not cause the table to be more expensive than those that are commercially available and used in clinics today, making this table fiscally viable at this stage in the design research.

Additionally, because a large goal of this project was to ensure this table remains fiscally accessible for a variety of healthcare provider sites, tax breaks and other incentives have been identified in order to further low the cost of this novel design. In 2017, the Patient Protection and Affordable Care Act (ACA) added an amendment to the Rehabilitation Act to develop accessibility standards for medical diagnostic equipment (MDE)[19]. Medical examination tables fall under the category of MDE, as MDE encompasses equipment that is commonly used for diagnostic purposes[6]. Although this amendment represents guidelines of best practices, these proposed standards will likely be federally enforceable in the coming years, encouraging healthcare providers to turn to this affordable and accessible medical examination table. Additionally, Section 44 and Section 190 of the IRS code assists businesses with complying with the ADA in undertaking barrier removal processes to improve accessibility by providing them with a tax credit[20]. This credit would cover 50% of eligible expenditures, allowing this table to reach provider sites with lower spending budgets.

Discussion

Final Product Considerations

The final product modeled in Autodesk Fusion 360 fulfills the aims and that were set out at the onset of the project. The table is handicap accessible, easily adjustable, easily sanitizable, and overall would improve the doctor-patient interaction throughout a medical examination. The table is able to be lowered to a height that facilitates mounting the table from a wheelchair, and the width of the table is greater than average medical examination tables to better



Material	Parts	Units	Material Cost per Unit ($ / Unit)	Cost per Material ($)
Vinyl	Surface area of table top	2123.988 in²	0.02175	46.20
Foam	Surface area of table top multiplied by two inches	4247.976 in³	0.02895	123.01
Steel	Surface area of table bottom multiplied by one inch, volume of stand and leg	621.66 kg	0.50	310.83
			Total Cost:	$480.04

Table 3. Materials & Cost Analysis Results. Prices of each material included in the table design were computed by determining the total areas and volumes for each piece and multiplying by the respective unit cost.

accommodate obese patients. The pieces of the chair were ergonomically designed to maximize comfort for all patient demographics.

Impact

A more accessible medical examination table has the potential to benefit a wide variety of patient demographics within the United States healthcare system. When this table is implemented in a clinical landscape, the standard of medical care has significant potential to improve. Patients who are elderly, physically disabled, and otherwise mobility-limited will have increased access to physical examinations fostered by this accessible medical examination chair design. This is a vast improvement from prior risky patient transfers that cause an increased risk of injury, or lack of patient transfers causing missed or delayed diagnoses and decreased likelihood of timely implementation of lifesaving treatments. This improved accessibility will raise the standard of care by cultivating the doctor-patient interaction and allowing patients to receive important preventative screenings and diagnostic tests that they might not otherwise have been able to receive.

Limitations

Several limitations throughout the course of this year required the team to adjust the deliverables of the project and the methods in which they were accomplished. The biggest constraint to the project was time; initially the team had hoped to produce a scaled down three-dimensional model of the table using 3D-printing, incorporating a miniature motor to simulate how the chair would work in a clinical setting. However, due to the extensive and lengthy iterative design process, the team chose to prioritize developing a robust design that addressed the design specifications, rather than attempting to print the model. This contributed to the inability of the team to incorporate a proper motorized function within the design of the table, and the team decided to instead develop virtual animations of how the model should work on Autodesk Fusion CAD. Additionally, while the materials analysis allowed the team to estimate the cost and materials that would be used for the final design, this analysis does not include manufacturing costs or the cost of developing and incorporating a motor in the table. There was also an inability of the team to test the table model in a clinical setting due to the lack of a physical, full-scale model, which could not have been produced on the timeline of a capstone project. Thus, clinical trials and patient satisfaction could not be gauged, but the team is hopeful that the design specifications determined at the onset of this project would correlate to improved patient satisfaction during clinical trials.

Future Work

While the team managed to accomplish the aims of this capstone project, further work is needed to bring the redesigned medical examination table to life in a clinical setting. The next most crucial step is the production of a full-scale physical model from the CAD model, including the use of steel, foam, and vinyl components. Once this frame has been brought to life, motorized components must be included in the design so that it can function in response to a remote-control. The team has proposed that this would include the incorporation of a motor within the hollow stand of the medical examination table, and that the motor would contain sufficient wiring and braking mechanisms to control the adjusting of various components of the medical examination table electronically. After a full-scale physical model has been produced, clinical trials would be needed to determine if the table improves patient experiences. While clinical trials are not needed for this device to go to market because it is a Class I FDA device, these trials would provide critical insights into the effectiveness of this design, as well as inform any redesigns, if needed. By spreading awareness about this design through clinical testing and patient feedback, the team is hopeful that this device may one day be adopted into mainstream healthcare practices, thus improving the standard of care received by all patients.

End Matter

Author Contributions and Notes

Bosworth C., Cobb, S., Harvey, V., and Louw, L. developed the CAD model and animations, conducted the materials analysis, and wrote the final report. Morikawa, M. advised on the design of the device. The authors declare no conflict of interest.

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