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Palliative-pushing and cycling (Pal-PAC) © exercise device

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Abstract
BACKGROUND: Exercise devices are generally designed for healthy individuals. Most of these devices are built for fitness purpose. However, studies from exercise physiology indicate that exercise is important for maintaining normal physiological functions, such as increasing circulation to the vital organs and improve comfort level. Designing an exercise device that can be used for people with mobility issues or other health issues can be challenging. METHOD: Creating such a device that could be used in bed for exercise and that would be easily assembled by one person is the main objective for our design. We have designed an exercise device named Palliative-Pushing and Cycling (Pal-PAC) © specifically geared toward the population with mobility issues. CONCLUSION: The device is dual purpose, offering both pushing and cycling exercises. The device has a simple, adjustable conversion mechanism that enables the user to change the mode from pushing to cycling, or vice versa. Pal-PAC will help patients to regain some of their independence, distract them from their condition and worries, and promote better quality of life.

1. Introduction

Exercise in healthy population can be easily carried out. Mobility in terms of individual's willingness and physical tolerance to exercise is the key to any health maintenance strategy. The abundance of exercise modality provides many options for the normal population. However, to those who are debilitated physically, such options can be very scarce. One such population that is forgotten in the exercise arena is those who are in palliative or hospice care setting. These patients become mentally strained with issues related to death and dying and physically debilitated, thus, exercise in this population can be extremely challenging. An easy solution that addresses these issues could be a device that can be used in-bed, independently by the patient with minimum assistance. Currently, there is no such device specifically designed for these patients to re-condition their debilitated bodies and promote a new way of adaptation.

1.1. Mind/Body Integration from Birth to Death

Cancer, congestive heart failure, and chronic obstructive pulmonary disease comprise the majority of diseases that palliative and/or hospice care patients suffer from. Mind and body exercise has been emphasized as the most important part of maintaining healthy living throughout the life span. Mind/body exercise cannot be viewed separately; rather, it is mind/body integration. Other than the typical avoidance of bedsores and muscle atrophy resulting from prolonged disuse of the extremities, depression rates among these types of patients must be addressed. The life span for these particular palliative care patients are typically only 6-12 months, so obtaining extreme fitness goals are not the primary focus of the device. Physical exercise will help distract patients from wherever their minds are and help promote mind/body health. The goal of this design was to develop a device that could be used to act as motivation for these patients, by providing a sense of independence and purpose for patients who are confined to their beds. Daily use of the device requires it to be durable, but comfortable for continued usage. It should also be easily assembled without using of outside help.

1.2. Design Research/Investigation Methodologies

Prior to the designing process, random interviews of multiple patients in the palliative care unit at the Atlanta Veterans' Affairs Medical Center were conducted to gather information on specifics such as patients' needs and desires in the device. Specific questions that were asked included, but were not limited to, the following: "If there was an exercise machine recommended to you, would you use it?", "What sorts of exercises are your favorite?", "If you had an exercise device, where would you likely want to use it?", "Suppose you were promised some sort of reward for using the device, would this entice you to use it more often?". The answers given provided two main exercise design considerations; (1) the patients wanted a device that could be multimodal, (2) there was more emphasis on the need to work one extremity over another, mainly the patients wanted to work their lower extremities more so than their upper limbs. Patients also answered that they were interested in some form of "chair yoga", though we wanted to constrain the device to just the hospital bed in this phase of the design so as to achieve a more universal application.

The device is named Pal-PAC©, which stands for Palliative-Pushing and Cycling, stemming from its duel effects. The device needed to be portable, and can be securely fixed to the hospital bed, often in a palates fashion. One of the most important design considerations was how to achieve resistance for a cycling component. Patents No.929 and Patent No.223 are examples of using a fan and flywheel to provide resistance in an exercise device, although a pulley system was used to rotate the fans or flywheel.[1,2] Any leg press design would have to be reliant on the surrounding structures, such as the footboard itself. The dimensions of the footboard, 35.5 x 15 inches, served as a template to constrict the design the device. To achieve resistance in the longitudinal direction, various kinds of springs were considered, such as torsion springs and compression springs, used in tandem. This creates an opening in the market that the team could design towards. Most in bed exercise device patents include cycling components, but do not have any resistive leg press capabilities.

1.3. Engineering Design Specifications (EDS)

Anthropometric data was gathered for the target demographic, which were palliative care patients who were 50 years of age and older. The average range of length of the appendages was used in considering the range of adjustability of the device. The mean arm span for males within the target demographic, with a mean age of 66.9 years, is 62.4 ± 2.3 inches.[3] The mean arm span of females within the target demographic, with a mean age of 62.4 years, is 58.5 ± 1.9 inches.[3] The mean male knee height is 18.9 ± 1.0 inches.[3] The mean female knee height of this is 17.6 ± 0.9 inches.[3] The mean male sitting height is 32.9 ± 1.5 inches. The mean female sitting height is 30.6 ± 1.2 inches.[3]Hand grip strength is a useful gauge of overall strength as it has been found to be correlated to various other muscle groups.[4] The average left- and right-hand grip strength of elderly men between the ages of 61 and 91 years ranges from 10 to 46 kg.[5] The average left- and right-hand grip strength of women in the same age group is approximately 20 ± 4.0 kg.[5] These values were used to determine the maximum weight the machine should be as seen in Table 1.

A standard Hill-Rom VersaCare® Med Surg Bed system was used to constrain the size limit of the device. The bed sleeping area was measured using a tape measure. The dimensions are 35.5" x 75" but can be extended to 35.5" x 86" to accommodate taller patients. With regards to the anthropometric data, 90% of patients in this design scope will not cover the whole sleeping area. This allows for the footprint of the device to have a maximum dimension of 35.5" x 15" to be used at the footboard (or base) of the bed. The height limit will vary with the restrictions of weight and material.

Manufacturing cost was calculated based on similar product comparison. Typical small exercise machines cost between 90-110 dollars, dependent on the exercise and the added components such as calories burned and distance traveled. Because of these competitive products, the target cost of the proposed device will be the average of similar products with similar components, which is approximately $100.00. The target manufacturing cost will be at least below the target cost by 15%.[6,7] Manufacturing costs will be alleviated through manufacturing processes and purchasing raw bulk material. Similar to other portable exercise machines, this device will have a standard 1-year warranty and will be packaged pre-assembled and stored at room temperature.[6] As it is not considered “durable medical equipment”, the device would not be covered in many insurance policies.

Table 1. *Pal-PACparameters and specifications.*

PARAMETER	METRIC
Size	Maximum (l x w): 15 in. x 35.5 in.
Weight	Maximum: 20 lbs.
Safety	FDA Standards
Adjustable	Height Range: 54 in. – 78 in. Arm Span Range: 54 in. – 72 in.
Manufacturing Cost	$100 ± 15%
Power Requirement	Voltage Range: 100-240V AC for rechargeable batteries 20 (Dependent on choice of components)
Leg Press Resistance	15 ft-lbs

By clinical observation, we concluded that it was necessary for the device to include both a leg press mechanism as well as a cycling mechanism for exercise variability. The device originally had a 50 ft-lb gas spring resistance system to accommodate the hospital bed. The leg resistance was later changed to a 15 ft-lb gas spring, which offered increasing resistance as the spring is compressed to accommodate for the patient’s usage.

2. Design Concepts

Four concept designs were considered after researching prior art, the details of each are as follows. Design concept 1 was a portable, torsion spring push pedal system that hooks onto the footboard of the bed, and included resistance band attachments for arm exercises. Design concept 2 was a collapsible cycling device that utilized electromagnetic or centrifugal force to create pedal resistance. Design concept 3 was a dual exercise machine that contained a roll out mat for user support and would be able to switch between cycling and leg presses. Design concept 4 was a fully collapsible, portable, spring resistance joint exercise device that could be used for the arms or legs depending on the position of the device. The four design concepts can be seen in Figure 1.

Table 2. *Pugh Decision Matrix analyzing the various design concepts on each criterion compared to a simple cycling machine such as that of Patent No. ‘571.*

Criteria	Weight (%)	Design 1	Design 2	Design 3	Design 4	Final Design	Simple Cycling Machine
Size	12.5	-1	-1	-1	1	1	0
Weight	12.5	1	1	1	1	1	0
Safety	15	0	0	0	0	0	0
Usability Range	10	1	2	1	1	1	0
Price	7.5	0	0	0	1	0	0
Exercise Variability	10	2	2	1.5	0	2	0
Enjoyment	12.5	1	1	0	0	2	0
Interest	12.5	1	0	1	0	1	0
Aesthetics	7.5	1	1	0	-1	0	0
Net Score:	100	0.625	0.6	0.375	0.35	0.925	0
Rank	---------	2	3	4	5	1	N/A

All design concepts were taken into consideration and a Pugh decision matrix was used to weigh out each design. Aspects of each design that were evaluated through the matrix, in order of importance were: safety, size, weight, usability range, exercise variability, price, and aesthetics. A generic cycling machine was used as the simplest reference to compare with the design concepts. After analysis through the Pugh Matrix, it was determined which design concepts were most viable and how the synergetic design fared with the individual designs, as seen in Table 2. As a result, different design concepts from each individual design were used to make up the first prototype. The device incorporated both cycling and leg press exercises, of which each operated independently. The user has the option to switch between cycling and push. Both the pedals and the leg press exercise can use a joint resistance system or two independent resistance systems. Ideally, the joint resistance system is preferred as to reduce manufacturing cost, device weight, and possible mechanical system errors. The whole system will be packaged into a lightweight, durable case of which the patient can carry with a maximum weight of 20 lbs. There will be minimal assembly for each use so the patient can set-up and store the device with ease.

3. Final Design

The final design of the device consisted of a multimodal cycling and leg press device that would simulate bicycling, lunges, and squats, while the user remained in a supine or reclined position in the hospital bed. This was accomplished by having an axle that held crank arms and pedals to apply resistance from the exercise device to the user’s legs. The position of the pedals needed to be adjustable in order for them to be able to be on the same plane and axis for when the user wishes to perform leg presses. Human factors, such as safety, usability and various other restraints were taken into account when creating the final design of the device. Size and weight were still of much concern, as the user would need to be able to pick up and move the device as needed for use and storage. Thus the final device was constrained to 20 pounds, with overall dimensions of 14 x 4 x 10 inches when collapsed, and 22 x 4 x 10 inches when fully extended (in the cycling position). The device needed a means to guide it back and forth as the user performed leg presses/lunges that would maintain the device's structural integrity. Making the device safe was of the utmost importance, as is the case with any device design that will have human interaction. To ensure a high level of safety, all parts were designed to move easily when required to move, and to remain stationary or fixed when necessary. All edges and corners of the device were designed to be smooth or rounded, so as to not bring harm to the user. Levels of resistance were chosen to be within certain scopes, as previously mentioned in the EDS section, so as to not overstrain the user, but to provide a sensible amount for exercise.

4. Prototype

Each component needed to be sturdy and durable enough to endure continual, frequent use. For the purpose of prototyping, most components would be fabricated from aluminum, since it is fairly durable, affordable, lightweight, and easy to cut or otherwise form or manipulate. The materials for the final marketed device would be high durability plastic, such as polypropylene, which would also make the device lighter and more cost effective to produce. These plastic parts would likely be produced by an injection molding process. Components that could be bought and integrated into the device, such as bearings, pedals, springs, resistance unit, slides or rails, etc. would be purchased and incorporated into the prototype in order to properly demonstrate the functionality of the overall design of the device within the time frame given. While the original prototyped model, discussed and shown in the following section, cost roughly $200 to construct, if the device were to be carried into the manufacturing phase, projected market cost of the device would be around $100 ± 15%. This price range is based off of similar products on the market and the manufacturing methods previously discussed.[6]

As seen in figures 2 and 3, a functional prototype was designed and constructed to give a definitive representation of the device's size, usage, and functionality. Special crank arms were designed to give the unit the ability to have the pedals on the same plane and axis for when the user wishes to perform leg presses. This is accomplished via shafts cut out of the crank arms, in which the axle and pedals can be adjusted to the proper position needed for the desired exercise; for switching from cycling/lunges to leg press, the user loosens the bolts of both pedals and one of the axle bolts, then spins the loosened crank arm 180˚ in phase and slides both pedals toward the axle and re-tighten the bolts. A magnetic resistance unit was used to create cycling resistance, and a locking gas spring was used to create resistance for the leg press portion of the device. Steel drawer slides were used as a means of support between the two sections of the device, as well as to guide the device as the user performed leg press/lunges. An acrylic key was fabricated that could be inserted beneath the locking mechanism on the spring in order for the patient to switch easily between cycling and leg press/lunges. An aluminum structure and polycarbonate enclosure was constructed to house and provide support for all of the internal components.

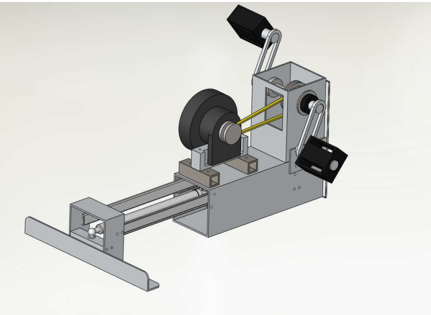

Figure 1.3. *D rendering of prototype model.*

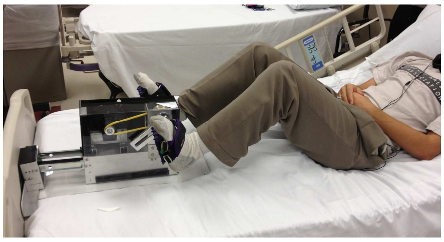

Figure 2. *Photograph of device being demoed on actual hospital bed.*

The prototype also has a Wi-Fi-capable microcontroller to collect usage data from the device. The data collection was accomplished via the use of a reed switch for the cycling portion, and a gyroscope/accelerometer sensor for the leg press portion. An LED module was incorporated in order to show data collection was occurring, shining red when the device was on but not in use, green when the microcontroller was collecting cycling RPM data, and blue when the device was collecting distance/repetition data during leg presses or lunges. This data would be exported wirelessly to an external app running on a tablet or smartphone to give the user detailed, useful feedback as well as make the device more stimulating and interactive. The possibility of incorporating this data into some sort of game to further encourage the patients to use the device is something the team wishes to explore further. The data could also be sent to a different app for the doctors and nurses in order to keep track of patients' progress and use of the device for the keeping of medical records.

5. Future Improvements

The next steps in improving this device would be to work on the display and data exporting discussed in the previous section. This would be accomplished by creating an application to run on a tablet device that will display feedback information and allow for further interaction between the user and the device. For additional fun, mini-games would be used to motivate the user to work harder, longer, and more often. These games could also be turned into a multiplayer platform game, so that users of the device could compete with one another, further encouraging use of the device and thus increasing the health and wellbeing of the patient. Another improvement of the device would be moving the gas compression spring to be even with the cycle axle, removing the opportunity for a moment to be created, increasing structural integrity.

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