Seating Fabrication System for Clinical Rehabilitation Settings in Low Income Countries: The Experience of Mexico and Colombia

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Abstract— **The benefits experienced by assistive technology (AT) users include increased independence and comfort, however, only a small percentage of the world population with a disability has access to AT. In low income countries AT is rarely available. Sustainable methods for designing, producing and distributing AT within these are required. This paper describes the design and implementation of a seating fabrication system to be used in clinical rehabilitation settings in urban areas of low income countries. The system was implemented and tested in a collaborative project between Mexico and Colombia. More than 60 seating systems were fabricated. Therapists approved and adopted the system easily. Children and adults with disabilities were provided with a custom made seating system. Numerous additional devices would need to be developed before the AT needs of these countries are met. However, international teamwork between local universities proved to be an effective method to address the AT needs of their communities. This approach could be implemented in other low income countries.**

I. Introduction

Based on the 2010 population estimates and the 2004 disability prevalence estimates [1], including children, over a billion people (or about 15% of the world's population) were estimated to have a disability [2]. This is higher than the previous global estimates (1970s) that suggested a prevalence of 10% [3] and, stressing that 80% of people with disabilities, particularly in the child population, live in low income countries where poverty further limits their access to health services, including rehabilitation [4].

Assistive technology (AT) device means any item, piece of equipment, or product system, whether acquired commercially off the shelf, modified, or customized, that is used to increase, maintain, or improve the functional capabilities of a child with a disability [5]. The benefits experienced by AT users include increased independence and comfort [6,7]; however, only 5 to 15% of the population with a disability has access to AT [8]. This lack of appropriate AT significantly limits active participation of people with disabilities in their social, educational and vocational activities in their communities.

Exceptional rehabilitation organizations with global presence include Disabled Peoples' International [9] and Rehabilitation International [10]. They have been instrumental in establishing public policy regarding people with disabilities in numerous countries. Their focus has been the defense and promotion of human rights and the inclusion of people with disabilities in mainstream activities.

Other organizations, recognizing that personal mobility plays a significant role in the lives of many people with disabilities, have focused exclusively in the provision of wheelchairs to low income countries. Organizations like Wheelchairs for the World [11], Joni and Friends [12], and pioneer organizations like the Wheelchair Foundation [13] have been providing wheelchairs since 1979. On the other hand, as meaningful, helpful, well structured, and funded as these organizations are, their lack of long term involvement with local organizations has rarely resulted in development and sustainability [14]. Their work is perceived mainly as charity.

When considering the reasons for not having commercially available AT in low income countries and specifically in Latin-America, literature comes short of answers. One potential explanation may be that as long as medical insurance, socialized or private, will not pay for these devices, the only technology that will be available are devices received through charity or devices that people can pay out of pocket. This condition represents a major obstacle for procuring AT, particularly if considering that the economic resources of the population with disabilities throughout this region are very limited. Therefore, if AT is needed to improve the lives of people with disabilities in Latin America, it is necessary to develop alternate sustainable methods of designing, producing and distributing AT.

With the purpose of developing and distributing appropriate AT for Latin America, the Rehabilitation Engineering and Technology Center (CITeR® for its name in Spanish) at Universidad Iberoamericana in Mexico City, and its sister organization at Escuela de Ingeniería de Antioquia – Universidad CES in Medellín, Colombia – embarked in the development of several AT projects. A needs assessment study was conducted and, although innumerable AT needs were identified, it was determined that for the great majority of persons with physical disabilities the basic seating and mobility needs were not resolved. Therefore, the purpose of this project was to jointly develop an affordable Seating Fabrication System (SFS) that would allow therapists in Latin America to locally fabricate low cost seating systems. Types

*Research supported by Consejo Nacional de Ciencia y Tecnología de México. Proyecto Salud 2007-C01-69603, Salud 2011-1-161827, Universidad Iberoamericana, División de Investigación. DINV C401010, and Escuela de Ingeniería de Antioquia, Medellín, Colombia.

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of seating systems to be fabricated include planar and contoured. The project included instrumentation to measure pressure exerted by the user on his/her cushion. The customized seating systems would be placed on the existing client's wheelchair.

II. SYSTEM REQUIREMENTS

A. General requirements

SFS would be integrated by the following devices: seating simulator, manual carving machine, and pressure sensing array. General requirements included: SFS would be fabricated and repaired at local shops, be housed at a clinical facility within an urban area; must not require special installations to function and should be operated by anyone with average mechanical skills.

B. Seating simulator requirements

Seating simulator would be designed to accommodate children and adults. Therefore, the following parameters needed to be manually adjustable: leg length, back height, seat to back angle, seat to ground angle, and foot rest position. Table I, Section 1, describes the required range of adjustment for these parameters. To copy the shape of the patient a molding material would have to be selected.

C. Manual carving machine requirements

Carving machine would be used to carve readily available polyurethane foam used mostly for upholstering. Seat shape to be carved would correspond to the anatomical shape of the patient. The anatomical shape would be obtained from the seating simulator. The desired characteristics of the carver are described in Table 1, Section 2.

D. Pressure sensor array (PSA) requirements

A PSA is necessary to measure the pressure that the user experiences while seated on his/her seating system [15,16,17]. Pressure measurement is used to assess if there is a proper matching between the patient and the seat he/she is using. PSA requirements are listed on Table I, Section 3.

TABLE I Design Characteristics of Seating Fabrication System

Section 1. Seating simulator	
Leg length	26 to 46 cm
Back height	25 to 56 cm
Seat to back angle	90° to 120 °
Seat to ground angle	0° to 20°
Foot rest position	13 to 60 cm
Section 2. Manual carving machine	
Accommodate commercially available polyurethane foam cushions measuring	50 cm x 50 cm x 15 cm
Foam densities to be carved	From 35 Kg/m^3 (soft foam) to 90 Kg/m^3 (rigid foam)
Should be operated by one person	
Should not require special installations or power requirements	
Section 3. Pressure sensor array	
Individual pressure sensing arrays	4
Display units	mmHg and KPa
Portable and battery operated	
Simple to calibrate and to use	
Sensors should be as thin and flexible as possible in order not to interfere with seating position	

III. RESULTS

A system to fabricate planar and contoured seating systems was implemented. The SFS consisted of a seating simulator, manual carving machine and an electronic pressure sensing device.

Seating simulator characteristics

A seating simulator was designed and built. Structure was made out of two layers of ¾" birch plywood with aluminum reinforcements (Figure 1). Parameters that can be adjusted to accommodate the user include:

Seat length. Can be adjusted from 26 to 46 cm. Seat length is adjusted by manually sliding the seating surface. Once the required length is set, a mechanical lock prevents further movement. This adjustment must be made prior to seating the patient on the simulator.

Back height. Can be adjusted from 25 to 56 cm by removing or adding small back support sections until desired height is achieved. Back support sections run in lateral channels and are "hinged" with fabric, allowing its easy removal or installation. This adjustment can be made while patient is seated on the simulator.

Seat to back angle. This parameter can be adjusted from 90 to 120 degrees at 5 degree increments. Adjustment is made by placing the back support in the appropriate back channel. The system is similar to the mechanism used in the "beach chairs" but requires significantly more movement forward, before it can be disengaged and repositioned at another angle. Safety stops prevent back to fall backwards beyond 20 degrees. This adjustment can be made while patient is seated on the simulator.

Seat to floor angle. Can be infinitely adjusted from 0 to 20 degrees. Adjustment is made by turning a handle attached to a screw mechanism underneath the seating surface. This mechanism also acts as a lock preventing any oscillating movement of the seating system. There are two additional stops at the back and front of the simulator that would prevent the patient to fall in case the handle and screw mechanisms fail.

The foot rest is an independent unit that can be removed allowing manipulation of the patient while seated in the seating simulator. When the appropriate position of the patient is achieved, the foot rest is mounted and adjusted into position. The foot rest is securely locked to the seating simulator structure to prevent further movement.

Two molding materials were selected, fast acting. Polyurethane A/B (Poliformas Plasticas, Mexico City), contained within a PVC plastic bag and Polystyrene pearls (Estiromat, Naucalpan, Mexico) contained within a PVC plastic bag. The mold obtained with the Polyurethane A/B hardens within 3 minutes, while the Polystyrene pearls can be manipulated for approximately 20 minutes prior to hardening. Both molds can be placed on the carving machine.

Figure 1. Seating Simulator shown without molding material

Figure 2. Manual Carver

Manual carving machine characteristics

Manual carving machine was designed and built (Figure 2). Carving is performed by a 3/4" round bit (tungsten grinding bit ball 3/4" 4437A28, *McMaster-Carr*, Santa Fe Springs, California, USA) attached through a flexible shaft to an electrical motor (Foredom, Bethel, Connecticut, USA). Motor speed is controlled by a floor pedal. Motor rotates from 0 to 15,000 RPM. Carver has two adjacent platforms. Right platform is where the mold to be copied is placed. Left platform is where the foam cushion to be carved is placed. A simple adjustment procedure was implemented where seat cushion boundaries, maximum height and maximum cutting depth are adjusted. After these adjustments, operator closes the protection doors and begins manual movement of the carving tool. Starting from one end and covering the entire surface at a predetermined depth is how the seat is carved. After first pass the cutting tool height is readjusted (to obtain a deeper cut) and the process is repeated. This process is repeated until the entire shape has been copied into the foam cushion. Experience demonstrated that an operator of average mechanical skills can fabricate one contoured cushion in approximately 40 minutes, after a short training session.

Pressure sensing array characteristics

Pressure measuring has become a common clinical practice to assess if the seat surface fits the patient properly. Most commercially available pressure measuring devices require a computer to display the information. Information presented includes a complete view of the surface of the patient that is in contact with the seat. However, most clinicians center their attention in those areas known to be prone to develop pressure ulcers like the ischial tuberosities or coccyx. For this reason, the designed pressure measuring device was made to have four independent sensing mats (each 6 cm in diameter) and their control box (Figure 3). Within the control box is the display that numerically shows the pressure values. Each sensing mat has four sensors. This configuration, although of lesser surface area than commercially available devices, has proven to be clinically adequate to assess seat patient interfaces.

The pressure information is displayed in the control box with selectable units (KPa or mmHg) to choose from. Information displayed shows the average pressure sensed in each sensing mat. Calibration is a simple procedure where specific certified weights from 80 to 500 grams are placed in a pre-designated sequence on top of each sensing mat. The calibration protocol is guided by instructions appearing on the display. The calibration procedure takes approximately 15 minutes.

Clinical evaluation of the SFS

The entire system has been used to fabricate more than 60 seating systems for children and adults with disabilities. Resulting product, mounted on the client wheelchair is shown in figure 4. With the use of the seating system, children adopt proper posture, facilitating other activities and preventing secondary disabilities. Twenty five of the seating systems were fabricated and installed in their own base (not wheelchairs) for school use. The remaining 35 seating systems were installed on clients' wheelchairs. Clinical evaluation for adults consists of obtaining pressure readings every three months and recording seat cushion performance. After seat performance diminishes, the foam cushion is replaced. These pressure readings are performed in addition to conventional clinical follow-ups. Children on the other side, use the system until they outgrow the seating system and require a new one.

Adults report extended hours of use without signs of pressure ulcers. Therapists have expressed their enthusiasm with the system because it is simple to learn and use.

The SFS was designed to be transferred to multiple clinical sites within the CITeR® Network. Until now, three locations are using the system, two are located in Mexico City and the third site is in Medellin, Colombia. However, the process is underway to transfer the system to three additional locations in Mexico, one in Ecuador and one in Peru.

IV. DISCUSSION

Providing assistive technology and specifically seating systems to people with disabilities in Latin America will have a significant impact on their lives, allowing them to participate in social, academic and vocational activities.

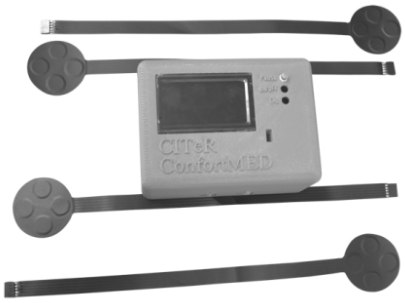

Figure 3. Pressure sensing array

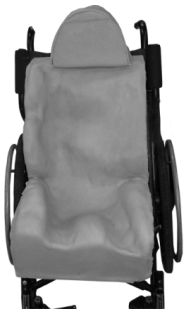

Figure 4. Customized foam seat, fabricated with SFS

Therapists and technicians are presently exploring the viability of a micro enterprise dedicated to fabricate customized seating systems. If economically viable, SFS would result in local development and sustainability. With proper training, the SFS could be duplicated in other low income countries. Cost of the fabricated devices is significantly lesser than imported ones. However, affordability remains a major issue for acquiring assistive technology in Latin American and low income countries. Long term studies, regarding the impact of AT on the population with disabilities are needed in order to demonstrate the benefits that these devices bring to the people. Also, studies are required to assess the economic savings that AT can generate by reducing the long term cost of medical attention. Seating systems are only one of the originally identified needs; therefore, a significant number of devices would need to be developed appropriately before the assistive technology needs of these countries are met. Alternate mechanisms to deliver these technology services to the population outside the urban areas still need to be developed. Nonetheless, the work presented here exemplifies that university based AT centers, working in concert, can design and implement quality and affordable AT devices. These devices will serve the AT needs of people with disabilities in their own communities.

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