A New Concept in Prosthetic Interface Design for Hemicorporectomy Amputees Using ROHO Compression Therapy: A Case Study From a CPO's Perspective

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ABSTRACT

The management of a patient who is a hemicorporectomy (translumbar) amputee requires a multifaceted approach in trying to improve the patient's quality of life. In an effort to improve even weight distribution, heat dissipation, comfort, to avoid lower thorax shear forces, and to care for the overall well-being of the patient when prescribing a hemicorporectomy or bilateral hip disarticulation prosthesis, a new interface design is presented here. The new design incorporates a custom 2-inch ROHO low-profile therapeutic cushion (dry floatation) with drainage holes for ventilation, lining an adult polymer (thermoplastic) "bucket-type" prosthesis with an anterior panel for ease in donning and doffing. The prosthesis does not include any prosthetic components such as knees, ankles, or feet. Three patients with a primary diagnosis of hemicorporectomy amputation who were fit with this new design have been followed with positive results. Clinical observations were found to be positive in all cases concerning ease of application in donning and doffing, heat dissipation, improved sitting posture and balance, comfort, even weight distribution, prosthesis function (skin health, usefulness, sounds, and appearance), regular hours of daily use, and mobility (transfers) with wheelchair function. (*J Prosthet Orthot.* 2004;16:104–112.)

Keywords: compression therapy, dry floatation, hemicorporectomy, ROHO low-profile therapeutic cushion

Traditionally, the prosthetic management of a hemicorporectomy (translumbar) patient requires aggressive positioning designing an environment that will prevent severe skin breakdown with the often insensate torso or high-risk amputee. Michaels and Gruman[1] reported that the translumbar amputee requires a multidisciplinary approach from the entire medical and prosthetic management team in an effort to save the patient's life in the face of severe trauma, infection, or cancer.

The majority of patients with this condition receive what has been well established in the literature as the "bucket-type" prosthesis. The main function of this conventional prosthetic design was to prevent excessive pressure on the inferior, weight-bearing aspect of the lower thorax using a built-in suspension system that would compensate for the abnormal shape of the lower thorax and achieve a balanced upright sitting position to compensate for loss of pelvis height.[1,2] The conventional prosthetic design uses semiflexible or rigid thermoplastic/laminates as the outer frame (bucket), and the inner surfaces of the interface are lined with foam padding.[1–6]

An improved sitting prosthesis for the hemicorporectomy or bilateral hip disarticulation amputee was described by Carlson and Wood.[2] They crafted a flexible corset-type, air-permeable fabric interface suspended within a rigid outer frame or shell that promoted heat dissipation, reduced skin shear trauma, and permitted upright weight-bearing, wheelchair function, and mobility. This design was shown to be successful in three of four cases. "The critical part of this design (the flexible fabric socket) uses one of the oldest fabrics (cotton) known to humankind and one of the oldest arts (sewing)" (p. 111).[2] The same authors also proposed a common thought: "We should all be aware that when we confine our creative thinking to what we can design with new materials and new fabrication processes, we overlook some very rich resources" (p. 114).[2]

When designing a prosthesis for a hemicorporectomy patient, prosthetists have encountered inherent problems using conventional techniques that use rigid thermoplastics or laminates. These designs do not take into consideration developing a material that adapts precisely to the contours and anatomy of the patient, provides additional space for daily volumetric fluctuations, decreases friction when there is full function of the upper torso, and provides proper air circulation. The material used in this study has been successfully tested by ROHO as designed by the ROHO Group (Belleville, IL). The body of literature is large and the success of using the ROHO compression therapy is well documented on other patient populations.[7,8]

DRY FLOATATION TECHNOLOGY

Dry floatation is designed on the concept that blood flow is primarily compromised as a function of deformation of the vascular bed. In total immersion, i.e., scuba divers, there is no ischemia (deficiency of blood) with high pressures because there is no deformation of the vascular bed. The immersion depth for dry floatation cushions is adjustable to provide the

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lowest possible pressures applied to the individual being supported. The external pressure magnitudes produced by dry floatation range from 20 to 50 mm Hg for emaciated persons, depending on the mass supported versus the contact area available.

The custom ROHO low-profile cushions have many benefits and features to provide an advantage for the hemicorporectomy patient. The cushions are made of soft but durable neoprene rubber that is resistant to flames, urine, and metabolic waste. The drainage holes built in the configurations provide increased ventilation for air circulation between the cells. The air cells have a height of 2 inches and are pneumatically interconnected. The dry floatation cushions uniquely address the complex tissue viability problem by not compromising blood flow in a field of external compression forces.

To achieve dry floatation, a highly displaceable surface is completely contacting several body shapes, creating a constant restoring force (buoyancy), low friction, and freedom to slide and move with the skin and body movements. Dry floatation is, therefore, not shape- or weight-sensitive and is not dependent on tissue bulk or muscle tone to be effective. Dry floatation provides a thermodynamically passive support surface that deforms (deformation relief) to make an intimate fit to any shape being supported, promoting vascular dilation and improved flow rates.

Robert H. Graebe, the inventor of the ROHO cushions, demonstrated that local external forces acting on the soft tissues for long periods of time force interstitial fluids to move elsewhere. This passive compression effect minimizes edema and brings the capillaries in closer proximity to the tissue cells. Reducing the interstitial spaces also causes the body contours to change. These contour changes are constantly tracked by dry floatation cushions to maintain an intimate fit.

THE INTERFACE DESIGN GOALS

The fitting goals for the hemicorporectomy and bilateral hip disarticulation population are:

1. Increased weight distribution on the remaining lower thorax assisted by containment of the abdominal tissue to prevent skin necrosis[1,2];
2. Support for an active and insensate part of the anatomy safely within the prosthesis[1,2];
3. Reduced shear trauma to tissues covering the lower thorax[2];
4. Pressure relief in the inferior borders of the scapula, any prominent spinous processes, the distal portion of the spine, and the axilla to allow ease in shoulder flexion and extension during wheelchair ambulation[1,2];
5. Adequate heat dissipation[2];
6. Adequate room for the patient's chest expansion or breathing[1,2];
7. Upright seating for wheelchair function and mobility[1,2];
8. A hinge opening or access panel to make donning and doffing easier[1–6];
9. Proper suspension of the prosthesis using over-the-shoulder suspenders for independent transfers from one surface to another[1,2];
10. Access to holes or "mail slots" for the ostomy stomas allowing the collection bags to remain outside the interface, free of any pressures induced by bearing and self-care[1,2,7,9];
11. Increased base of support to promote sufficient stability at the base of the hemicorporectomy prosthesis[1,2]; and
12. Total contact to reduce the pressure per square centimeter.[5]

CASE REPORT

Three patients with hemicorporectomy amputation participated in this study. All three hemicorporectomy surgeries were performed by the same surgeon. Table 1 summarizes the characteristics of the participants.

The proposed prosthetic design incorporates a custom-fabricated inner liner using an array of dry floatation cushions manufactured by the ROHO Group. For this application, we used three custom 2-inch ROHO low-profile cell configurations with drainage holes lining an adult polymer "bucket-type" prosthesis that included an anterior access panel for ease in donning and doffing (Figures 1 and 2). The rigid outer frame was constructed with 0.25-inch high-density polyethylene. The base of the apparatus is fabricated with a firm-density 0.5-inch Pelite vacuum formed in several layers with tread until a solid base is achieved for upright positioning.

All three configurations Velcro to the rigid outer frame and anterior access panel. The three cushion configurations include drainage holes lined to allow air circulation around

Table 1. Patient characteristics

Patient	Age	Diagnosis Prior to Amputations	Diagnosis After Surgery	Time Since Amputation
1	43	T9 paraplegic for 22 years	Hemicorporectomy	14 months
2	48	T4–T5 paraplegic for 29 years	Hemicorporectomy	4 months
3	57	Tumor for 10 years	Hemicorporectomy	3 months

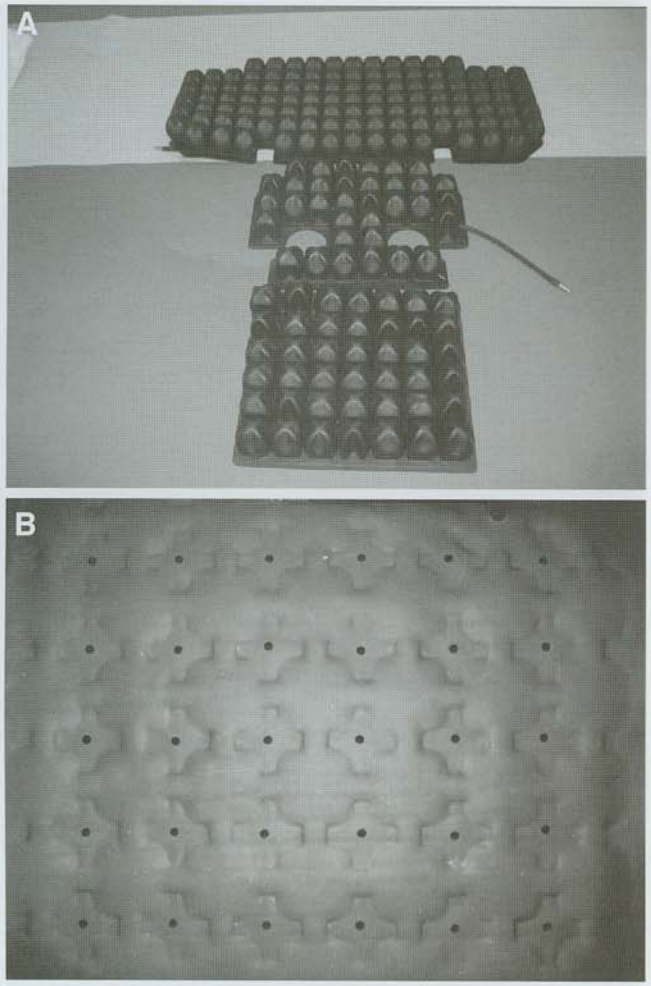

Figure 1. The custom-fabricated hemicorporectomy (translumbar) inner liner uses an array of dry floatation cushions with a cell height of 2 inches, manufactured by the ROHO Group. Note the three sections of the custom ROHO low-profile cell configurations are joined together using Velcro (A). The ROHO low-profile therapeutic cushions were engineered to maximize stability of the user while protecting the insensate skin from the potential risk of skin breakdown. (B) The drainage holes fabricated between each air cell allow air circulation.

Figure 2. A rigid outer frame or "bucket-type" prosthesis that supports the custom-made inner liner. This rigid outer frame is fabricated with ¼-inch high-density polyethylene using a blue jean decal pattern. The base of the apparatus is fabricated with a firm half-inch Pelite vacuum formed in several layers with tread until a solid base is achieved for upright positioning and immediate wheelchair mobility.

the interface promoting increased ventilation (Figure 1B). The rigid outer frame has ventilation holes drilled matching the drainage holes in the low-profile cell configurations to ensure this air exchange (Figure 3). When the hemicorporectomy patient moves his or her upper torso, the bending motions encourage air to enter the ventilation holes and the interstitial cell space, resulting in the dissipation of moisture and heat.

The pattern for the three configurations was developed by fabricating a custom negative mold over a custom-sewn casting garment (Figure 4). The patient's anatomy is carefully marked using an indelible pencil to indicate the pressure-sensitive areas and proper location of the stoma bags (Figure 5). To simulate partial to full weight-bearing, a tilt table is used when applying the plaster to fabricate the negative mold (Figure 6). Once measurements have been recorded and the cast preparation is complete, a two-piece bivalve "clam shell" negative mold can be fabricated (Figure 7), followed by the fabrication of the positive mold (Figure 8). The positive mold is rectified using a combination of orthotic and prosthetic modification techniques (similar to rectifying a thoracolumbosacral orthosis, ensuring proper relief as mentioned in the interface design goals and maintaining the exact anatomic shape).

The design of the rigid outer frame included a void to ensure proper continuity of fit with all three patients involved in this study. This void was created using custom-fabricated high-density Plastazote (Zotefoams Inc., Walton, KY) filler formed to precisely match the shape of the positive mold.

To determine the filler thickness, minimum deflation and maximum inflation of the air cells must be calculated. The minimum deflation of the ROHO low-profile air cells is approximately 0.5 inches and the maximum inflation of the air cells is 2 inches. It was discovered through trial and error that the recommended filler thickness ranged between 1 and

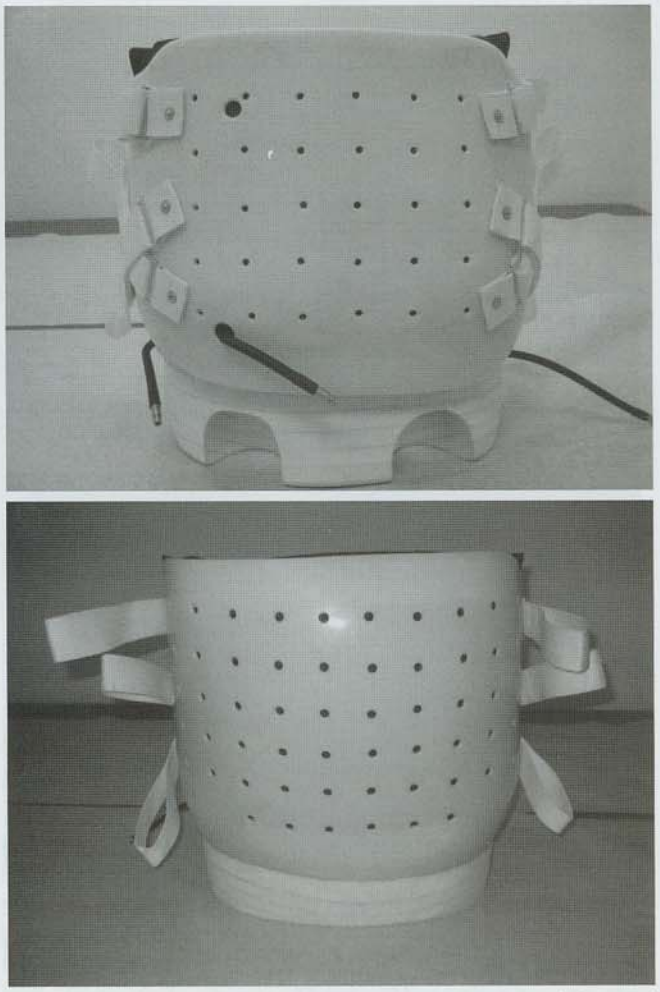

Figure 3. Anterior (top) and posterior (bottom) views of the rigid outer frame showing the ventilation holes drilled to match the drainage holes in the low-profile cell configurations to ensure proper air exchange.

1.25 inches. Once the Plastazote filler has been completed, the 0.25-inch high-density polyethylene is draped or blister-formed over the Plastazote filler and positive mold using a vertical blister form stand and vacuum (Figure 9). The "bucket-type" prosthesis that includes an anterior access panel is then assembled. This finished prosthesis is given to the ROHO Group and is used as their primary pattern for the three custom 2-inch ROHO low-profile cell configurations. The configurations are connected with 2-inch Velcro and secured into the prosthetic bucket, also with 2-inch Velcro.

Before the patient dons the system, he slips on a full-body sock (Knitrite Inc., Kansas City, KS; Figure 10). This custom body sock features a Cool Max (Knitrite, Inc.) fabric, which has been used successfully on transtibial and transfemoral amputees to wick perspiration and moisture away from the skin and has an approximate thickness of a two-ply sock. It is an important first line of protection against skin abrasion and works extremely well to contain or organize any loose tissue because of its diminished friction.

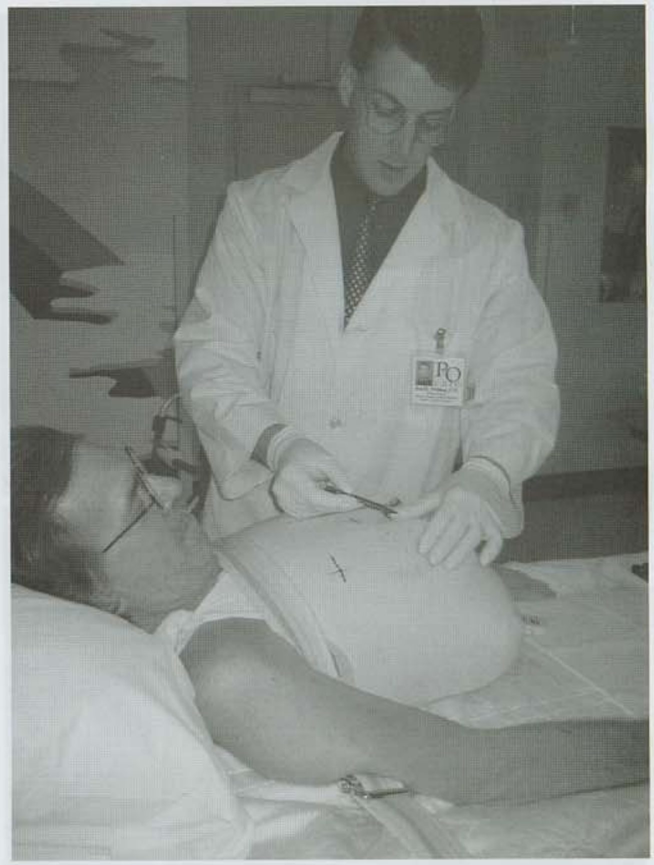

Figure 4. Preparation before fabricating a custom negative mold.

The patient can easily don and doff the prosthesis in the supine position with use of the fully adjustable anterior access panel. By using a torso lift, the patient is able to slide into the posterior aspect of the interface (Figure 11).[10] The adjustability of the anterior access panel accommodates minor volume fluctuation. Once the Velcro straps are properly adjusted (Figure 12), the cells can be inflated. It is important that the proximal trimlines are free from impinging the axilla. The patient must also be able to sit fully erect with hands flat on the table and elbows slightly flexed (Figure 13). This will ensure easier transfers and comfortable mobility.

The patient's urinary and defecation collection bags or urine drainage tubes are easily accessed or threaded through the cushions and base of support (Figure 14). It is important to ensure the accuracy in properly locating the stoma sites so that the collection bags will drain properly and prevent herniation of the soft tissue.

The alignment of the hemicorporectomy prosthesis is angled approximately 5° to 7° of extension with respect to vertical or relative to being perpendicular to the floor (Figure 15). This alignment is directly proportional to the circular base of support attached under the rigid outer frame. The alignment is also dependent on the amount of stability achieved on a flat surface or in the patient's wheelchair. The alignment angulation is easily changed by removing or adding firm-density Pelite (Knitrite, Inc.) in a wedge-shaped pattern.

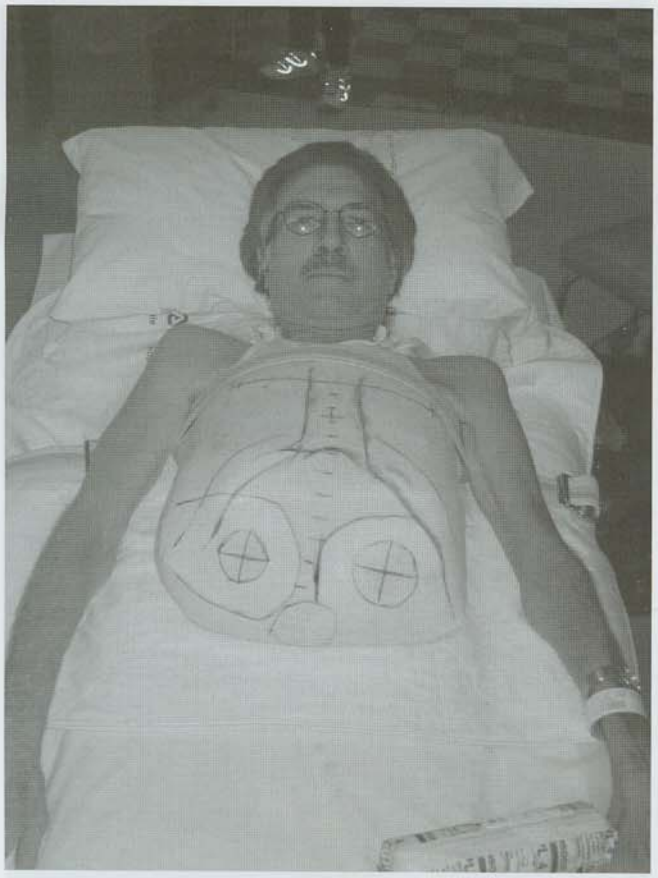

Figure 5. Pressure-tolerant and pressure-sensitive areas are marked before the plaster wraps are applied.

Figure 6. An electronic tilt is used during the impression technique to simulate partial to full weight-bearing.

The hemicorporectomy prosthesis is independent of the wheelchair and is self-suspending during transfers. It is suspended by off-the-shelf carpenter suspenders converted to over-the-shoulder suspenders (Figure 16). By incorporating the proper suspension, the hemicorporectomy patient has the

Figure 7. The completed bivalve negative mold. After completing the anterior panel, the patient is positioned prone and partially upright so the posterior panel of the negative mold can be fabricated, resulting in a bivalve "clam shell" impression of the hemicorporectomy amputee.

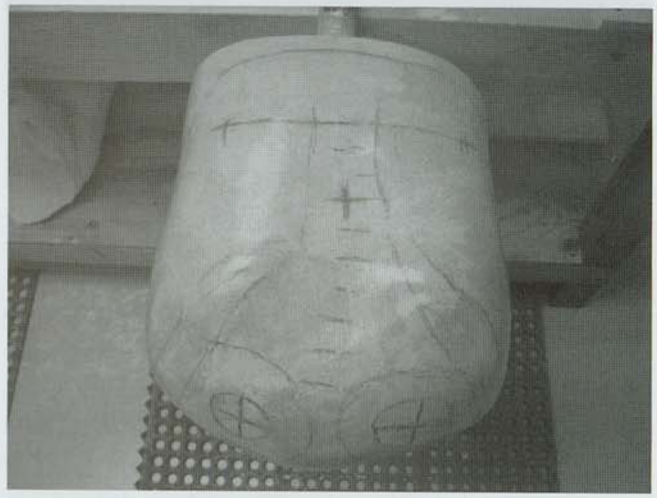

Figure 8. The rectified positive mold indicating the exact location of the pressure-sensitive areas as well as the stomas. Note the positive mold is a combination of standard plaster and vermiculite.

ability to transfer to any given surface for increased independence and to a wheelchair for immediate mobility.

The Xsensor Pressure Mapping System (Crown Therapeutic, Belleville, IL; Figure 17) was used to measure weight distribution. We also used visual observations to monitor the skin and to ensure the absence of abnormal pressure.

Patient Evaluation

Interviews with the three participants were conducted (two by telephone and one in person) after prosthesis use for periods ranging from 1 month to more than 1 year. The interviewer read from a fully written, prepared script and recorded the answers verbatim from the respondents. The Prosthetic Evaluation Questionnaire[11] measured the follow-

Figure 9. Once the positive mold has been rectified, a high-density Plastazote filler is formed directly on a plaster model and then the rigid outer frame is blister-formed using ¼-inch high-density polyethylene.

Figure 10. The custom body sock is the first item the patient dons. Note how there are two custom-sewn holes to allow extra protection around the stoma site, as well as full access for drainage.

ing: ease of application in donning and doffing, heat dissipation, improved sitting posture and balance, comfort, even weight distribution, prosthesis function (skin health, usefulness, sounds, and appearance), regular hours of daily use, and mobility with wheelchair function. Scoring was accomplished using a linear analog scale, with poor responses rated at 0 and excellent responses rated at 100.

Prosthesis function scores were the highest (skin health, 100, with no skin breakdown from wearing the prosthesis; usefulness, 97.6; sounds, 97.3; appearance, 82.3). Mobility (transfers) with wheelchair function was equally high (transfers, 97; wheelchair function, 90). Ease in application in donning and doffing and even weight distribution scores were the same at 88.3. Comfort level scored 86.7, whereas heat dissipation scores were the lowest at 80. Improved sitting posture and balance score was 92.5 and overall well-being and satisfaction of the patients averaged 99.5. The overall wearing time ranged from 5 to 10 hours on a regular daily basis.

DISCUSSION

The first patient was our prototype, and significant improvements were made to the second and third hemicorporectomy

Figure 11. By using a torso lift, the patient can easily slide into the posterior aspect of the interface in the supine position.

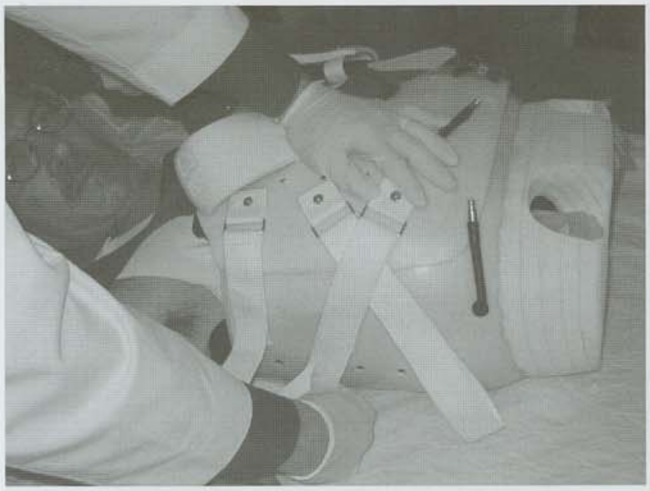

Figure 12. The Velcro straps are positioned to prevent migration of the anterior access panel and feature hand loops for ease in securing the straps.

Figure 13. The upright fitting parameters for a hemicorporectomy amputee. Note that the patients are able to sit in an upright position with hands flat on the table and elbows slightly flexed. This will allow the patient to suspend his entire weight as well as his prosthesis during transfers.

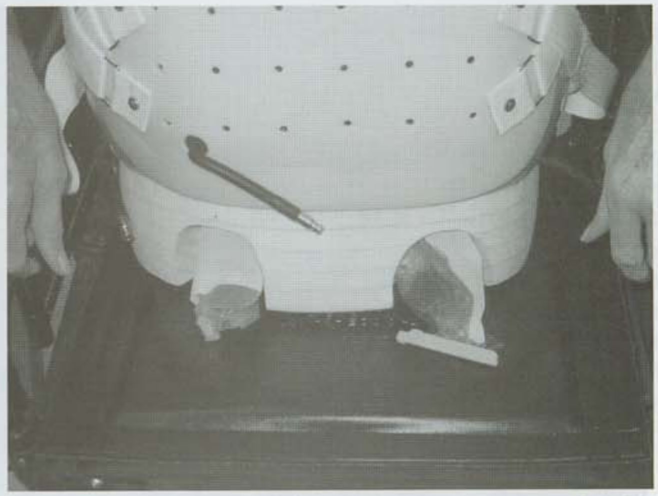

Figure 14. The urinary and defecation drainage avenues are threaded through the cushions and support base.

Figure 15. The alignment of the hemicorporectomy prosthesis is angled in approximately 5° to 7° of extension from vertical or relative to being perpendicular to the floor. The alignment angulation was easily changed by removing or adding firm-density Pelite in a wedge-shaped pattern.

prostheses as our method evolved, resulting in our percentage scores being higher for the second and third patients. The first patient was interviewed 16 months after he received his pros-

Figure 16. The patients have regained their independence and mobility for the first time since they received their prostheses. (A) and (B) show how the hemicorporectomy prosthesis is suspended by off-the-shelf carpenter suspenders converted to over-the-shoulder suspenders. By incorporating the proper suspension, the hemicorporectomy patient has the ability to transfer to any given surface for increased independence and wheelchair mobility.

thesis and reported his wearing time at 5 to 8 hours per day. His weekly activities included mowing his own yard with a zero turning radius, hand-controlled riding lawn mower. He would also go fishing and hunting on an all-terrain vehicle with his nephew. He reported that his future plans include obtaining his driver's license and having hand controls installed in his van.

The second patient was interviewed 12 months after he received his prosthesis, and his wearing time was 9 to 10 hours on a daily basis. His activities of daily living included living in complete independence at home, driving his van that included hand controls and a ramp, grocery shopping, taking his dog for a 1- to 2-hour walk in the morning, and

Figure 17. The Xsensor Pressure Mapping System. This unique method and clinical tool is used to assist in measuring interface pressures that occur between patients and their contact surfaces. The measuring device is a soft, pliable mapping pad that conforms to the surface and user.

photography. This patient drove to see the third patient before and after the third patient's hemicorporectomy surgery. He has also taken several road trips. His future plans include maintaining his independent and active lifestyle.

The third patient was interviewed 1 month after he received his prosthesis, and his wearing time was 8 to 9 hours on a regular daily basis. This patient increased the comfort level and increased heat dissipation by reinflating his cells every 4 to 5 hours. His activities of daily living included weight lifting to improve his upper body strength, independent transfers in which he was able to lift his entire weight with the prosthesis, and regular Veterans Administration outings. This patient's future plans mirror those of the other two.

It is important to note these patients have endured severe hardships and face significant health complications. Before being fit with their prostheses, the patients spent between 5 and 14 months healing from the hemicorporectomy surgery. When these patients finally received their prosthesis and were able to sit up for the first time and regain their mobility, a sense of renewal and hope was observed. J. Bradley Aust, who performed the first successful translumbar amputation in 1961, said it best: "Freed of the nonfunctioning lower half, the patient is released from the dead weight holding him down, relieved of his chronic infection and/or cancer, and experiences a new mobility, sense of well-being, and renewed enthusiasm for life."[1,3]

CONCLUSION

Like with any prosthetic fitting, the primary factor to a successful rehabilitation of a hemicorporectomy amputee is if the patients possess a high degree of determination, motivation, and compliance. These patients will succeed regardless of the difficulties involved. All three patients in this study were highly motivated. After these three patients were fit with a hemicorporectomy prosthesis that included the three custom 2-inch ROHO low-profile cell configurations with drainage holes lining an adult polymer "bucket-type" prosthesis with an anterior panel for ease in donning and doffing, they succeeded in regaining their mobility and independence. The cushions were highly effective in ease of application in donning and doffing, heat dissipation, improved sitting posture and balance, comfort, even weight distribution, prosthesis function (skin health, usefulness, sounds, and appearance), 5 to 10 hours of daily use, and mobility (transfers) with wheelchair function. Based on the information collected thus far, the new design has met with positive results.

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REFERENCES

1. Michaels J, Gruman G. *Atlas of Limb: Surgical, Prosthetic, and Rehabilitation Principles,* 2nd ed. St. Louis: American Academy of Orthopedic Surgeons; 1981:563–567.
2. Carlson MJ, Wood SL. A flexible, air-permeable socket prosthesis for bilateral hip disarticulation and hemicorporectomy amputees. *J Prosthet Orthot* 1998;10:110–115.
3. Aust JB, Page CP. Hemicorporectomy. *J Surg Oncol* 1985;30: 226–230.
4. Ockenfels PA. Management and construction procedure of bilateral split-bucket type hip disarticulation prosthesis. *Orthot Prosthet* 1968;22:29–36.
5. Terz JJ, Schaffner MJ, Goodkin R, et al. Translumbar amputation. *Cancer* 1990;65:2668–2675.
6. Wagman LD, Terz JJ. Translumbar amputation (hemicorporectomy). In: Bowker JH, Michael JW, eds. *Atlas of Limb Prosthetics.* St. Louis: Mosby-Year Book Inc; 1992:553–562.
7. DeLateur BJ, Frieden FH, Gertler M, et al. Rehabilitation of the patient after hemicorporectomy. *Arch Phys Med Rehabil* 1969; 50:259–263.
8. Jacobs MA. Comparison of capillary blood flow using a regular hospital bed mattress, ROHO mattress, and Mediscus bed. *Rehabil Nurs* 1989;14:270–271.
9. Miller TR, MacKenzie AR. The most radical procedure. *Inter Clin Info Bull* 1966;5:22–23.
10. Porter-Romatowski TL, Johnson D. Hemicorporectomy: A case study from a physical therapy perspective. *Arch Phys Med Rehabil* 1998;79:464–468.
11. Hart DL, PhD, PT. Orthotics and Prosthetics National Office Outcomes Tool (OPOT): Initial reliability and validity assessment for lower extremity prosthetics. *J Prosthet Orthot* 1999; 11:101–111.