II. IMPROVED WHEELCHAIR SEATING

♦ S-1 CUSHION DESIGN FOR ULCER PREVENTION

♦ S-2 ADVANCED MATERIALS AND MECHANISMS

♦ S-3 IMPROVED USER INPUT DEVICES AND CONTROL CONCEPTS

♦ S-4 INTEGRATION OF IMPROVED MOBILITY COMPONENTS

♦ S-5 THE USE OF INTEGRATED CONTROLS BY PERSONS WITH PHYSICAL DISABILITIES
Rationale

The prevention of pressure ulcers through the use of custom contoured foam seat cushions (CCFSCs) is one aspect of seating that can benefit the user through investment in research. The efficacy of using CCFSCs has been shown in clinical trials [Sprigle, et al 1990] and is being established on a larger basis now that CCFSCs are commercially available. Computer-aided design and manufacture (CAD/CAM) technology related to CCFSCs is limited to anatomical measurement, ad-hoc data processing and shape editing techniques, and the automated manufacturing of cushions. The expansion of this technology to systematic data processing techniques requires that the existing gap in scientific knowledge concerning the relationship between support surface shape and interface pressure distribution be filled. The research proposed in this task will work to fill this void in knowledge. The flow chart of Figure 31(a) depicts the current design process. The weaknesses of this procedure is the dependence of the outcome on the clinician’s knowledge and experience, and the trial and error iteration involving repeated cushion manufacturing, both of which add cost to the end product. The improved prescription process is illustrated in Figure 31(b). Generic modification formulas, dependent on parameters like functional ability, tissue tone, age, body weight, and gender, will be used to eliminate the need for extraordinary skill and experience on the part of the therapist and the trial and error process. The proposed work focuses on the needs of populations with specific requirements for specialized and/or custom seating for pressure relief as a prophylaxis for pressure ulcers.

Figure 31(a) - Current custom seating design process (b) Future custom seating design process.
Goals

1. To develop generic seat contour shape modification techniques for persons with SCI and elderly persons.
2. To add to the body of scientific knowledge related to custom seat support surface design.

In Year III, the first year of this project, efforts focused on the analysis and dissemination of previously collected data [Brienza, et al 1996]. During the progression of work in Year III, we identified the need to further investigate the relationship between external forces and soft tissue responses. Understanding this relationship is critical to the design of effective support surfaces. Thus, Year IV work continued the analysis of the pressure and shape data for elderly and spinal cord injury subjects. A third manuscript was published [Brienza and Karg, 1998].

In order to develop the cushion design techniques, the complex shape data had to be reduced. A technique using singular value decomposition was developed to normalize and reduce the shape data. Further analysis of the normalized data can then be accomplished using a factor analysis such as principle component analysis. Initial work has been done to characterize the shapes and determine their relationship with interface pressures on a flat surface.

Year V continued to define the relationship between interface pressure and surface shape from the existing shape libraries. This information will be used to develop design and shape modification techniques. A pilot study will be done to test and refine the technique(s). The ultimate goal will be to develop a method to design contoured cushions from clinically accessible measures such as interface pressures on a flat surface, anatomical dimensions and other characteristics of the user.

Outcome Summary

The interface pressure distributions between flat foam cushions and the buttocks of seated test subjects were compared to custom contoured cushion surface shapes generated with a seated buttock contour gage. Our hypothesis was that pressure measurements could be used to generate a contour equivalent to that obtained with a force deflection contour gage. The study was performed in a university medical center using SCI (12) and elderly (30) test subjects. Interface pressure was measured using a pressure mapping pad. Contour shape was measured using an electronic force deflection contour gage. Pressure and contour information were reduced prior to analysis using singular value decomposition. Polynomial regressions were performed on the values in the first singular vectors of the corresponding pressure and contour decompositions. Relationships best described by cubic polynomials were detected between pressure and contour shape suggesting that interface pressure predicts optimal contour shape. These results will be published in IEEE Transactions on Rehabilitation Engineering 1999.

Recommended Future Research

Our results should be viewed as preliminary and further investigation is necessary to establish appropriate transformation equations for particular subject groups. In particular, we did not find the same relationship between the flat pressure and contour data for both subject groups. We have not determined if the differences between subject groups reflect intrinsic differences in soft tissue properties; or were the result of the use of different thicknesses of foam cushions during the pressure measurement procedure (3” for the elderly and 4” for SCI); or were caused by other factors. Furthermore, the results may be dependent on the measurement techniques employed, including the type of foam used and the spring constantly used in the Electronic Shape Sensor (ESS).

This study revealed relationships between the interface pressure measured between the buttocks and a flat foam seat cushion and the contour measured using a force deflection contour gage. The result indicates that custom contoured seat cushions can be generated using interface pressure measurements without the need for a contour gage. Verification of the relationships is necessary to validate the method.
Publications


References

**Task: S-2 Distortion Measurement and Biomechanical Analysis of In Vivo Load Bearing Soft Tissues**

Investigators: David M. Brienza, Patricia Karg, Jue Wang, Chen-Tse Lin

Collaborator: Ying-Wei Yuan, Qiang Xue

**Rationale**

Pressure ulcers continue to be a common complication and costly clinical problem. Interface pressure distributions between the buttocks and seat support surfaces are used clinically to evaluate the efficacy of seat cushions relative to the risk of pressure ulcer development. Soft tissue deformation, resulting in internal strain, is potentially a superior indicator of pressure ulcer risk, however, limitations of current clinical assessment technology render tissue deformation measurements inaccessible in the clinic.

As an alternative, interface pressure, a parameter that is clinically accessible, is used as an indicator for potentially harmful internal stresses and strains. This task was designed to provide additional support to a research effort (Paralyzed Veterans of America, Spinal Cord Research Foundation, PVA #1503) to develop an ultrasound system that may be used to study in vivo soft tissue response to external loading on the weight-bearing human buttocks during seating, and, therefore, a means to determine how external loading contributes to the risk of pressure ulcer development. Results from the work will also produce valuable information concerning the efficacy of using external pressure as an indicator for harmful internal strain in soft tissues—muscle, skin and fat.

**Goals**

1. Design, develop and evaluate an ultrasonic transducer that will be compatible with the computer controlled seating system (CASS) and useful in evaluating soft tissue response to external loading in vivo
2. Design and evaluate a compound sensor containing pressure, force, and ultrasonic transducers
3. Develop and evaluate of a multi-channel ultrasound system to allow for data collection from and control of the ultrasonic transducers
4. Integrate ultrasound system and force measurement system into the CASS
5. Develop and evaluate software tools necessary for control of new system
6. Perform pilot and clinical evaluations to test system performance and efficacy

**Outcome Summary**

A unique ultrasound-seating system for soft tissue characterization has been developed at the University of Pittsburgh based on the CASS system developed by Brienza et al. [Brienza et al., 1996]. Ultrasonic detection has been combined with the closed-loop, dynamically controlled shape and pressure sensing system. This allows quantification of the complex relationships between shape, tissue deformation and interface pressure under controlled loading conditions. This system contains an 11 by 12 array of sensors for which the height can be computer adjusted to vary loading conditions and surface shape in 3-dimensions. Ultrasonic and force transducers have been integrated into 9 of the support element heads to form a 3 by 3 array so that we can also investigate soft tissue deformation around the ischial tuberosities.

**Sensor Configuration**

Specifications for the sensor to be developed required that external loading and tissue deformation information be measured simultaneously. However, the sensor also had to meet the limitations due to the geometrical structure of the CASS, especially the ultrasonic transducers. One of the first steps of the project was to determine the configuration of the sensor. Initially, two sensor configurations were...
One design allowed the measuring point of the pressure transducer to coincide with that of the ultrasonic transducers. An alternate configuration was chosen and is shown in Figure 32. The chosen configuration consists of a pressure sensor centrally located in the swiveling head of an actuator element, surrounded by four planar ultrasound transducers. This design was chosen over others using custom ultrasonic transducer configurations because of the need to design a less expensive sensor using an established technology with well-defined parameters. The overall size of the sensor is 33.7 mm in diameter by 7.2 mm high. Each ultrasonic transducer has a 5 mm diameter and a height of 7.2 mm. The pressure transducer had previously been evaluated [Brienza et al., 1996]. The sensor can detect pressure from 0 to 10 psi with 0.15% linearity and an ultrasonic echo from 5 to 50 mm depth with an axial resolution exceeding 0.5 mm.

Ultrasonic Transducer Specifications

The next step was the specification of an appropriate ultrasonic transducer for the sensor. Geometric constraints dictated that the diameter of the ultrasonic transducer had to be less than 5 mm, have a long cable to connect to the existing seating system, and have good acoustic and electric characteristics. For example, the transducer had to provide an acoustic impedance match between the transducer and soft tissue, and an electric impedance match between transducer and emitting/receiving amplifier. The transducer also needed to have high sensitivity, a broad frequency bandwidth, narrow pulse width, good axial resolution and low noise. Among these are two tradeoffs, that between the small size and high sensitivity, and the tradeoff with the compound sensors to also measure force and tilt angle. Force is measured through bonded strain gages mounted on a load-bearing cantilever beam located in the actuator body. Vertical force applied to the sensor head is transmitted by a piston with a conical end that contacts the cantilever beam through a concentrated load at the tip. The head of the sensor is free to tilt and rotate on all support elements on the CASS to allow the sensor head to be normal to the tissue surface at all times. In order to determine normal force, a linear potentiometer was added to calculate the angle of tilt of the head. Figure 33 shows the compound sensor with force and angle sensing capabilities added.

Figure 32 - CASS with close-up of compound sensor.

An analysis of the preliminary data and a review of the literature led us to a tissue model for use in characterizing the buttocks soft tissue. Our’s and other’s data suggests that it is necessary to model buttock soft tissue as a viscoelastic material. The model we chose to use is the quasi-linear viscoelastic (QLV) model defined by Fung [Fung, 1981]. This model required force-deformation data to characterize the tissue. Rather than using the pressure data to approximate the normal force applied to the tissue, we chose to measure it directly. Thus, we expanded the capability of the 9 support elements with the compound sensors to also measure force and tilt angle. Force is measured through bonded strain gages mounted on a load-bearing cantilever beam located in the actuator body. Vertical force applied to the sensor head is transmitted by a piston with a conical end that contacts the cantilever beam through a concentrated load at the tip. The head of the sensor is free to tilt and rotate on all support elements on the CASS to allow the sensor head to be normal to the tissue surface at all times. In order to determine normal force, a linear potentiometer was added to calculate the angle of tilt of the head. Figure 33 shows the compound sensor with force and angle sensing capabilities added.

Figure 33 - Sensor with ultrasound, pressure, force and tilt angle measurement capabilities.

Ultrasonic Transducer Specifications

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between high emitting frequency with a long cable and low noise.

Etalon, Inc manufactured two prototype PZT ultrasonic transducers to our specifications. The pertinent performance measures of the transducers were quantified and the data indicated that the transducers would meet the basic use requirements. However, some parameters did not meet the design requirements; sensitivity, ring down, bandwidth and electrical impedance. These parameters affect the resolution and sensitivity of the system. Since these prototypes did not meet all our specifications, we contacted a second manufacturer, Furuno Diagnostics America, Inc. Furuno had recently commercialized a novel composite ultrasonic transducer using a 1-3 ceramic-polymer structure. We requested that they construct one of these composite transducers to meet our needs. Specifications determined for the ultrasonic transducer included a central frequency of 7.5 MHz, a frequency bandwidth more than 60%, pulse width less than 0.2 µs and sensitivity more than -22 dB. In addition, the coupling materials needed between the sensor and body soft tissue must be compatible with the pressure transducer. The composite transducer was compared with the two conventional PZT transducers. Table 1 summarizes the performance results of the transducers.

Table 1. Sensor performance results

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Composite</th>
<th>PZT 1</th>
<th>PZT 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity (dB)</td>
<td>-22</td>
<td>-31</td>
<td>-35</td>
</tr>
<tr>
<td>Bandwidth (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(-3 dB)</td>
<td>81.7</td>
<td>42.7</td>
<td>34.04</td>
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<tr>
<td>(-6 dB)</td>
<td>98.7</td>
<td>53.3</td>
<td>43.9</td>
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<tr>
<td>Central Frequency (MHz)</td>
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<td>7.157</td>
<td>8.136</td>
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<tr>
<td>Pulse width ( )</td>
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<td>0.295</td>
</tr>
<tr>
<td>Axial Resolution (mm)</td>
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<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>Cable Length (m)</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

The composite ultrasonic transducer, using 1-3 piezocomposite material was shown to have several advantages. Its sensitivity is 9-13 dB higher than the homogeneous PZT ceramic transducers. The bandwidth is wider by 39-47.7% and pulse width is reduced by more than 0.065 ms. The expanded bandwidth improves the near-zone ultrasound properties of the transducer. Thus, it improves the ability to identify soft tissues just beneath the subcutaneous skin layer, for example, connective and adipose tissue. In addition, the axial resolution was improved to 0.3 mm. Although the cable of the composite transducer was 3 m, its performance was much better than that of the conventional PZT transducers with a 2 m cable. The composite transducer has higher sensitivity, signal-to-noise ratio and resolution than the conventional PZT ultrasonic transducers.

Multi-channel Data Acquisition and Control System Development

A 36-channel ultrasound system was integrated into CASS. The main computer, a Gateway 2000-64G Pentium Pro PC, sends control instructions using a serial port to a slave computer that controls the positions of the 11 by 12 sensor array using 8 axis step motor controller. The pressure signals from the sensor array are scanned into the main computer with 12 bit resolution by a data acquisition processor (Oregon micro systems, Model-DAP1200E). At the same time, the system triggers the ultrasound transducer to emit an ultrasound wave. The system also receives the ultrasonic echo from the soft tissue interface and sends it to the main computer. A 100 MHz high-speed data acquisition card (CompuScope 250) was used for digitizing the ultrasound echo signals with 8-bit resolution. Two CYDIO-96 digit I/O units are used to select the channel measured or controlled in the motor, pressure, and ultrasonic arrays. The software for motor control was developed using Turbo Pascal 7.0 for Windows 3.1 and other components are implemented in LabView 4.0 for Windows 95. The ultrasound system consists of a synchronizing signal generator, 36 ultrasound transducers, 36 emitting/receiving channels, Multiple analog complexer and pre-amplifier, dynamic compression amplifier, TGC control, a Compsoscope 250-2M high speed data acquisition board, and the Gateway 2000-64G Pentium Pro PC.

The ultrasound system specifications included the following:

- Central frequency: 7.5 MHz
• Detecting range: 5 – 75 mm
• Emitting repeat frequency: 10 KHz
• Field scan repeat frequency: 278 Hz
• Bandwidth: > 75 %
• Axial resolution: 0.3 mm
• Signal Noise Ratio (SNR) > 45 dB
• TGC compensation: 40 dB/80 dB (Option)
• Dynamic compression: 60 dB
• Digit sampling frequency: 25 / 50 / 100 MHz with 8 Bits resolution (option)
• Tracking precision: 0.030 / 0.0150 / 0.0075 mm (option)

System Software

The main program and all data collection software were implemented in LabView 4.0 for Windows 95. The motor control is resident on the slave computer and was developed using Turbo Pascal 7.0 for DOS. The thickness of each layer is obtained by tracking the ultrasound echo signal peaks reflected from the interfaces between different layers. Depending on the echoes that need to be monitored, several tracking windows can be used to measure the thickness of these soft tissue layers during loading/unloading. In the program, two echoes, from the fat-muscle and muscle-bone interfaces, are tracked simultaneously during loading.

In Vitro Testing

The composite ultrasonic transducer was used to scan a pelvis in vitro. The system used is shown in Figure 34. A cadaveric pelvis was submerged in a water tank with the composite transducer mounted onto a computer-controlled, 3-axis positioning mechanism. The transducer scanned the pelvis at 6.35 mm increments. The ultrasound echoes were sent to another computer, which then displayed a two-dimensional projection of the three-dimensional contour. The computer sampled the echoes with a 50 MHz sample frequency. Typical results are shown in Figure 35(a). The points in the figure are from the ultrasound scan. The ischial tuberosities were clearly identified. Figure 35(b) shows a typical echo from the pelvis. The effect from the trigger pulse is less than 1.5 mm.

![Figure 34 - System used to scan pelvis in vitro](image1)

![Figure 35- Scanning of the pelvis (a) 3-D Scatter Plot; (b) Ultrasound Echoes](image2)
Additional in vitro testing was performed on porcine tissue using a compound sensor integrated into the CASS. This testing was performed for the development and fine tuning of the signal analysis software and control algorithm. Figure 36 shows the experimental set up used for this in vitro testing. This software development continued through this evaluation and experimentation phase of the project. Interface pressure and tissue thickness data were successfully collected and repeatability was demonstrated. After some fine-tuning, the system was for in vivo data collection.

In Vivo Testing

In vivo tests began using able-bodied human subjects to finalize the development of the software and to begin to evaluate the in vivo performance of the sensor. The testing was performed with individuals seated on the CASS support surface. In the initial tests, the compound sensor determined by initial ultrasound scans to be directly beneath the ischial tuberosity (IT) was moved sequentially through three phases: indentation, recovery and hold. A typical result is shown in Figure 37. The subject was a 135 lb. female. Interface pressure and ultrasound echoes were scanned into the computer as the sensor moved. The total indentation was 6 mm. Thickness 1 of Figure 37 includes the combination of skin and subcutaneous fatty tissue. Thickness 2 is the deeper muscle layer. The total thickness is the distance from skin surface to bone.

The results in Figure 37 demonstrated that the system is capable of performing multiple parameter measurements simultaneously. The system also demonstrated good tracking capability, allowing measurement of the changes in tissue thickness as the tissue was compressed or during recovery. It also demonstrated the ability to measure multiple tissue layers simultaneously. In this data, we observed that the muscle tissue had a larger percent deformation than the first layer of tissue (first layer decreased 3.3%, the muscle layer decreased 19.2%). This indicates that the muscle layer over the IT deforms more than the skin and fat under uniaxial loading.

After the integration of the force and tilt angle measurement capabilities, additional in vivo testing occurred, as well as data analysis. A 140 lb male subject was positioned on the CASS seating support surface, with special care taken to locate the ischial tuberosity (IT) directly above the 3 x 3 array of sensor probes equipped with ultrasound capabilities. The sensing probe directly beneath the IT was lowered away from the tissue until a zero pressure state was obtained. To conduct the stress-relaxation experiment, the probe was raised at a constant indentation rate (0.25 mm/sec), loading the tissue, to a maximum upward probe travel of 10 mm. The probe was held at its maximum indentation position for 50 sec, then lowered away at the same constant rate to the initial
starting position. During the entire load hold-recovery cycle, continuous force and bulk tissue thickness measures were collected. Time of flight of the ultrasound wave was used to determine tissue deformation-time history.

Force time history data was used to characterize soft tissue relaxation response according to the reduced relaxation function, $G(t)$, of the QLV model [Fung, 1981]. Relaxation parameters were approximated through curve fitting to experimental data. The force-time history data (Figure 38(a) from the load-indentation experiment was used to approximate relaxation parameters. A comparison of the $G(t)$ calculated from the QLV model vs. experimentally derived $G(t)$ is shown in Figure 38(b). The QLV reduced relaxation function appears to adequately model experimental results.

Examples of data from additional pilot testing are presented in Figures 39 and 40. Figure 39 shows the force-time and deformation-time history and Figure 40 shows a force-deformation curve for a second male subject. These results demonstrate that our system can be used to measure the biomechanical properties of buttock soft tissue in vivo and in situ.

![Figure 39 - Force-time and deformation-time histories](image)

![Figure 40 - Force-deformation curve](image)

The developed system can simultaneously measure interface pressure, applied force, and tissue deformation in multiple soft tissue layers. In vitro analysis and in vivo evaluations of the ultrasound system developed and integrated into the CASS show that the system has the ability to investigate and quantify the complex relationship between the biomechanical parameters of buttock soft tissue. The in vitro and in vivo testing demonstrated the dynamic measurement capabilities of the CASS and ultrasound system. The thickness of the soft tissue layers can be measured using an automatic tracking of the ultrasound echoes.
The in vivo pilot testing also showed that acquiring and maintaining the ultrasound echoes was challenging and took time and proper positioning of the subject. The challenge was maintaining the ultrasound echoes during the dynamic load cycle. There are several variables affecting this, such as subject posture, loading range, test site on the buttocks, tissue deformation and the change in angle of the sensor head. We found that we needed to learn more from pilot tests before going forward with clinical trials.

In addition to the tissue thickness data, additional data on the mechanical response of tissue to external loading can be obtained using this system. This information can be used to investigate the biomechanical properties of the tissue and allow more accurate tissue characterization using existing tissue models.

**Recommended Future Research**

Given the development and refinement of the new above technology, clinical trials with various populations should follow. These studies should investigate the biomechanical properties of the buttock soft tissue and allow more accurate tissue characterization using existing tissue models. A project has been funded by the Department of Education to continue with the work begun by this project. The project will determine the relationships between the deformation of soft tissue and externally applied load to determine differentiating intrinsic soft tissue characteristics for spinal cord injured subjects with and without past pressure ulcer pathology. If successful at identifying differentiating characteristics, the project will result in the development of a tissue characterization based risk assessment tool for individuals with spinal cord injuries. An understanding of soft tissue biomechanics for stratified patient populations will also lead to improved clinical practice guidelines for the prevention of pressure ulcers through improved support surface design criteria.

**Publications**

Bertocci GE, Brienza DM, Karg PE, Wang J. In vivo test protocol to determine soft buttock tissue relaxation properties Accepted for publication *ASME 1999 Summer Bioengineering Conference Proceedings*, Big Sky, Montana, June 16-20, 1999


**References**

Rationale

Spinal deformity of individuals with spinal cord injury, and other disabilities such as cerebral palsy, muscular dystrophy or brain injury, can lead to loss of sitting stability, loss of upper body function, decrease in respiratory capacity, increased risk of pressure ulcers, and increased pain and discomfort [Hobson, et al. 1992], [Hobson, 1992]. Increasing numbers of prescribers and suppliers of seating and mobility devices are attempting to address these problems. Unsupported claims are often made that specialized seating inserts and cushions can reduce or inhibit the onset of spinal and/or pelvic deformity of individuals using wheeled mobility devices (WMD). More importantly, service providers and WMD users do not have a quantitative method of assessing either the current status or the past history of spinal/pelvic alignment while seated in their WMD. Serial x-rays taken at 3-6 month intervals are thought to expose clients to unacceptably high levels of radiation exposure, especially if follow-up is extended over a number of years. Determination of pelvic/spinal alignment is recognized as one of the most important variables in special seating. It is important to be able to take the measurements while the client is in the WMD, as the contribution of the seating support to the spinal/pelvic alignment is often the desired determinant.

Many non-invasive techniques have been applied to detect and measure scoliosis and kyphosis of the spine. Most of these techniques were developed to detect idiopathic scoliosis through screening of school age children. Among the more qualitative methods developed are the Scoliometer [Amendt et al, 1990] Back Contour Device Moir [Burwell et al 1983], topography [Daruwall, 1985] and thermography [Cooke, 1980]. The more quantitative techniques have been surface topography [Pekelsky et al], light beam scanning (ISIS) [Turner-Smith, et al 1986], and ultrasonic digitization [Letts et al 1988]. All of these techniques have been compared to the “gold standard” of orthopedic radiographic spinal measurement, the Cobb method. Some techniques correlate better than others with the conclusion by several investigators that the frequency of radiographs can be reduced, but not eliminated from spinal monitoring, especially for scoliotic curves that have progressed beyond a 30° Cobb angle. Good correlation between spinous process mapping and the Cobb measurements was demonstrated by [Letts et al. 1988], for curves over 30°. Furthermore, they were able to demonstrate that an acceptable correction factor can be achieved for curves under a 30° Cobb angle.

The major limitation of these techniques is that they require direct exposure of the spine to the measurement instrumentation, preferably in the erect standing position. Radiographs require medical approval, are costly, and run the risk of excessive exposure. A literature review was unable to identify any technique or instrument that could measure and record spinal/pelvic alignment of a person seated in their WMD.

Figure 41. Schematic of radio frequency method of determining spinal pelvic position of a subject seated in his/her personal wheelchair.
Goals

To research and develop a quantitative method, including reasonably priced instrumentation, to monitor changes in spinal/pelvic alignment of a wheelchair seated person at risk of increased deformity.

Outcome Summary

This task was transitioned into the technology transfer phase at the end of Year II (7/31/95). No further RERC funds were expended on this task. A partnership was formed with ARTSCO, Inc. (Pittsburgh, PA) to continue the prototype development of the measurement tools. An NIH/NCMRR SBIR technology transfer grant was awarded to ARTSCO to further the development this technology. In addition, a technical report entitled, Spinal/Pelvic Alignment Monitoring of Wheelchair Users, which details the research findings, has been prepared and is available from the RERC upon request.

Phase I research began in October 1997. Under the support of the NIH/SBIR, ARTSCO collaborated with the Antenna Lab at the Virginia Tech University to design small flexible patch antennas that could be placed on landmarks of the spine. Prototype antennas were completed in February 1998. While Virginia Tech was developing the antennas, ARTSCO developed the supporting electronics system to test the feasibility of measuring spinal alignment through radio frequency signals. A signal generator capable of producing a 900MHz sine wave and a vector voltmeter capable of measuring small phase differences were purchased. The laboratory was set up with three receiving antennas, and one transmitting antenna. A special calibration jig was developed by ARTSCO to move the transmitting antenna in 1mm increments in each dimension (X, Y, Z). Electronic switches and a computer software program were written to measure the phase difference between each pair of receiving antennas. Upon acquiring the prototype antennas from Virginia Tech, testing of the system began at the ARTSCO facility.

To date, testing conducted at the ARTSCO laboratory has not succeeded in demonstrating the ability to calibrate the actual movement of the transmitting antenna to the movement measured through the RF phase difference technique. The most likely cause of the error is unwanted signal reflections from objects, walls, ceilings and floors in the laboratory. Research is continuing at the ARTSCO lab to determine the cause of errors and remedy the situation.

Recommended Future Research

At this time research should focus on determining the cause of the inability to calibrate. Testing the system in a chamber that absorbs all RF signals would eliminate unwanted reflections, and therefore test the theory postulated above. At this time ARTSCO is attempting to arrange a test with a center that has this type of chamber. Once calibration is achieved, human tests should be initiated. An X-ray should first be taken with the antennas in place on the spine to determine if the antennas are indeed over the bony landmarks of interest. Secondly tests should be undertaken to determine whether the measurements made of the antenna locations match the actual locations of the antennas on the spine.

Publications


References


Daruwalla US, Balasubramaniam P. (1985) Moiré topography in scoliosis - Its accuracy in detecting the site


**Task: S-4 The Effects of Positioning on Individuals with C5-C7 Quadriplegia**

Investigators: Michael Boninger, Tracy Saur, Elaine Trefler, Douglas Hobson

**Rationale**

Persons with high level spinal injury have been observed to develop postural deformities of their spines and pelvis after prolonged use of wheelchairs. This task addresses the questions as to whether the deformity progresses over time, causes pain, and whether it adversely effects pulmonary function and life satisfaction.

**Goals**

1. Determine the relationship of posture (kyphosis & scoliosis) between individuals with new onset of C5-C7 spinal cord injury versus long term onset of cervical spinal cord injury.
2. Determine the correlation of posture with pulmonary function, pain, and life satisfaction.

**Methods Summary**

**Recruitment**

Subjects were recruited through searching the patient database at a freestanding rehabilitation hospital. In order to qualify for the study individuals had to have a traumatic spinal cord injury (SCI) resulting in tetraplegia and use a wheelchair as their primary means of mobility. Two distinct groups were recruited: individuals 1 to 3 years post injury — relatively new tetraplegia (NT) and individuals 10 to 20 years post injury — relatively old tetraplegia (OT). The control subjects (C) were recruited after the testing on individuals with tetraplegia was completed. A deliberate attempt was made to recruit individuals matched with the tetraplegia groups for age, sex, height and weight.

**Posture Assessment**

All subjects were seated in a wheelchair specially modified to allow unobstructed A-P and lateral radiographs to be taken. Each radiograph was read by a single investigator who was blinded to the group assignment of subjects. Scoliosis was measured using the Cobb technique (Weissman, et al. 1986). Kyphosis was measured using the technique described by Fon et al. 1980. The control group was included to allow comparison in radiographic measures between individuals with and without paralysis.

**Questionnaires**

As part of each subject’s evaluation a series of standardized questionnaires was completed. These questionnaires were reviewed with the subjects individually to insure adequate completion. In addition to the standardized questionnaires listed below, subjects were asked questions related to back and neck pain, decubitis formation and upper extremity pain. Each subject was given the Center for Epidemiological Studies - Depression Scale (CES-D), (Radloff, 1977), the Life Satisfaction Index Assessment (LSIA) (Neugarten et al. 1961), and the Craig Handicap Assessment and Reporting Technique (CHART) (Whiteneck et al, 1992). In addition to asking yes and no questions related to back and arm pain, each subject was given the McGill Pain Questionnaire (MPQ).

**Outcomes Summary**

**Characteristics**

A total of 10 subjects were recruited into each group. Using an independent sample t-test, no significant differences were found with regards to age, height, and weight between the NT and OT groups. In addition, no significant differences with respect to age, height and weight were found between the combined NT and OT group and C group. The Mann-Whitney U test found no differences in injury level between OT and NT. As expected, a significant difference was seen between the NT and OT group with respect to years out from injury.
Posture, Aging, and Pain

No differences were found between the NT and OT groups in either measures of kyphosis or scoliosis. The C group was found to have significantly less scoliosis and kyphosis than the combined NT and OT groups. The results are summarized in Table 2. Nine of the 20 subjects with tetraplegia reported back pain and 10 of the 20 subjects reported upper extremity pain. No significant differences were seen in kyphosis and scoliosis in those reporting pain and those not reporting pain. No significant relationship was found between pain and radiographic measures.

Discussion

This is the first reported study to radiographically measure kyphosis and scoliosis in a group of individuals with tetraplegia. Not surprisingly, individuals with tetraplegia were found to have a greater degree of seated kyphosis and scoliosis than a control group without paralysis. This study did not find a greater degree of spinal curvature in individuals further out from an SCI. This contradicts what has generally been accepted by professionals involved in seating and positioning. One possible explanation for this finding is that our subjects were not far enough out from their initial SCI to develop progressive spinal deformity. An important finding of this study is that individuals who were only two to three years out from an SCI had significant spinal deformity. It may be that a kyphotic and scoliotic posture are assumed early and then are not progressive. If this is the case, early interventions will be needed to prevent problems later.

This study found no association between spinal deformity and pain, perceived function or depression. Only one previous study has addressed the association between pain and spinal deformity. This study by Gertzbein did find an association between pain and kyphosis in individuals with a spinal fracture at the thoracic and lumbar levels, but it was not statistically significant. It is important to note that our subject population was relatively young and all less than 20 years out from SCI. In addition, all of the subjects were recruited from an outpatient SCI follow-up clinic. If the population had included individuals who were more than 20 years out from injury, or who did not receive specialized routine care, the results may have been different.

Recommended Future Research

Larger longitudinal studies are needed to determine if pain does become a problem in individuals with significant kyphosis and scoliosis as they age, and to more definitively examine the progression of kyphosis and scoliosis with aging.

Publications


References


Rationale

Statistics show that traumatic brain injuries incurred each year number around two million. Outcomes can vary from death or prolonged coma to only mild deficits that have minimal impact on the patient and this family. The likelihood or extent of the impairment is difficult to predict soon after the injury. However, it is during this time that clinicians and seating specialists are expected to make a recommendation regarding the equipment for seating and mobility.

There are few guidelines that assist clinicians to determine when the best time is to provide seating intervention and how aggressive to make the intervention considering the likelihood of improvement. There is no information about the natural history of recovery as it relates to wheelchair seating intervention. As well, there are no measures of outcomes related to seating intervention for this population.

Goals

To provide clinical guidelines for seating and mobility intervention for persons with closed head injuries (CHI) over the natural history of the condition for a two-year post injury period.

Methods Summary

An instrument was developed to measure the complexity of seating and mobility intervention. It measured the correlation between recovery and the seating technology needs of an individual who has suffered a CHI. A draft of the tool was used to establish both content validity and interrater reliability. The instrument proved very complex and interrater reliability was not acceptable. The tool was redesigned and the process repeated until the tool could be administered successfully by any one of three therapists assigned to the project.

Items for documentation included

- make and model of wheelchair and seating system (this included a system to indicate the complexity of each component of the system so measures over time would indicate improved motor skill as indicated by less complex seating and mobility scores),
- functional skills,
- sitting posture while in their wheelchair,
- physical motor status (tone, strength, structure, reflexes),
- anthropometrics, and
- comfort/satisfaction survey (subject and clinician).

Outcomes Summary

A seating technology assessment tool (STAT) was developed in collaboration with a physical and occupational therapist from the RERC staff and the UPMC Rehabilitation Hospital. It records the types and numbers of seating system components that an individual required to maintain an upright posture while sitting against gravity. It uses an ordinal rating system in which the components were ranked from the most to the least amount of support provided. The STAT is divided into technology and subject related data. The subject data includes information gathered regarding the individual’s posture, reflex and functional information skills. The technology data is broken down into those relating to the seat and back components. Preliminary validation was performed with two physical therapists and one occupational therapist. The revised tool was administered initially to three subjects and follow up was done with one of the subjects that remained a wheelchair user. The two other subjects improved in function and became ambulatory.
Problem Encounters

Final data collection took place over a nine-month period, which was insufficient to establish a relationship between natural recovery and seating technology. Critical time was missed during the acute recovery phase, as clients were not recruited until they entered the rehabilitation phase of their recovery. As well, several specific items such as degree of tilt of the chair had to be added to the data collection tool, as they were specifically indicative of how well and how long a client could sit upright, which in turn was an indication of the return of sitting tolerance.

Recommended Future Research

Further refinement and validation of the tool needs to be performed. The tool should then be used with a larger sample of subjects as part of a clinical outcome study.

Publications

Documentation in the form of a case study is in process and will be submitted for publication.