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CLINICAL REPORT

Clinical Analysis of a CAD/CAM System for Custom Seating: A Comparison with Hand-Sculpting Methods

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Abstract—A CAD/CAM system for manufacturing custom seating inserts was evaluated within a moderately to severely disabled population. Using the Otto Bock Shape System, 25 CAD/CAM seats were manufactured at a remote facility and compared to 9 seats manufactured using hand-sculpting techniques. Clinician and client questionnaires were completed for each seat to assess satisfaction, fitting/manufacturing times, and to collect demographic data. The CAD/CAM method was significantly better ($p<0.05$) than the hand-sculpting method in terms of on-site fabrication time. No significant differences were found for initial fitting time, final fitting time, clinician insert rating, and client satisfaction. These results support the CAD/CAM method as an effective and clinically efficient technique for making custom wheelchair seats.

Key words: *CAD/CAM, seating, wheelchair.*

INTRODUCTION

Computer Aided Design/Computer Aided Manufacture (CAD/CAM) is now being used as a clinical tool for the design and fabrication of custom wheelchair seats. Using a CAD/CAM system, the shape of a patient's back and/or buttocks can be digitized, stored in a computer, and modified to the desired specifications. The saved shape can be sent to a computer-controlled carver to produce a seating insert directly or to carve a model for postproduction. Since this is a new technology, it is important to verify that custom seats produced using CAD/CAM methods are as good as seats produced using manual methods.

Custom-fitted seats have made a substantial contribution toward treating nonambulatory individuals. Some benefits of custom seating are increased head control, increased sitting time, improved reaching/grasping capabilities, easier social interaction, improved sitting posture, and increased functional capability (1,2). Wheelchair cushions should provide "an effective platform from which the user may perform a wide range of tasks" (3). The cushion should also reduce the concentration of pressures over the seated area and, as a result, lessen the incidence of pressure sore formation.

Accurate and reliable definition of the surface contour of a seating insert is essential for the successful fitting of a nonambulatory patient. In some cases, seat dimensions and contour can be defined from physical measurements of the client and the wheelchair. These measurements are used as guidelines when manufacturing a seating insert manually from raw materials, such as foam blocks, wood, or plastic. In cases where substantial spinal deformity exists, the insert is hand-carved to accommodate the client.

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Manual seating insert fabrication requires minimal equipment, uses readily available materials, and provides a simple and quick solution for less complicated situations. Patients with more complex spinal deviations, however, may require a more accurate definition of surface contour. Manual manufacturing techniques rely on the "artisan" skills of a technician to sculpt the required shape. Since linear measurements and clinical notes are the only information available for designing a hand-sculpted insert, additional modifications and multiple fitting sessions may be required to obtain the final shape (i.e., the client must try the insert before changes can be identified). Carving a complex shape by hand also involves many hours of technical time.

One mechanical system for determining seat shape has been developed using a matrix of small, interlocking, metal and plastic cells. To create the shape, the clinician changes the matrix's inter-cell positions until the desired contour is achieved (2,3). A foam cover is placed between the client and the matrix to finish the insert. This technique is mechanically uncomplicated, can be fit to almost any spinal shape, and allows the clinician to modify the shape during the fitting session. Despite these advantages, the matrix method is time consuming, since each cell has to be individually adjusted; it is difficult to fit since changes to one series of cells can change the tissue orientation in another area of the matrix; and it requires regular service to insure that the cells have not moved.

Foam-in-place systems have also been used as a one-step method of obtaining the shape of a seating insert. This method involves positioning the client in a wheelchair, or fitting chair, and placing a bag between the body and the chair. Various chemicals are mixed in the bag to produce a foaming reaction. While the patient is held in position, the foam-filled bag is quickly manipulated to the correct orientation and held until the foam hardens. The resulting hard or soft foam is hand modified and covered to provide the custom insert. This system is an acknowledged means of insert fabrication due to the fast production time, minimal technical requirements, and variety of foam densities. Clinically, the setting time of the foam can be a disadvantage, since minimal time is available for positioning the client. Inadequate chemical mixing facilities in a clinic may also lead to inconsistent results, such as air bubbles in the hardened foam or areas that are not cured. Since foam-in-place chemicals (isocyanates) are also health hazards, these systems are not ideal for most clinical environments.

A custom seating method similar to foam-in-place is described by Colbert, Doyle, and Webb (4). This system (DESEMO) involves adding epoxy to a latex bag filled with polystyrene beads. After the bag is sealed and kneaded, it is placed in the wheelchair and the patient seated upon it. The seat is then molded to the desired orientation while a vacuum is applied to the bag. The vacuum is required to retain the seat shape until the epoxy cures (approximately 6 hours). The hardened seat is fitted with straps, modified after a 2- to 3-week trial period, and painted. Although this system is useful, the extra equipment requirements, long cure time, and the need for mixing toxic chemicals may contraindicate its use in favor of other systems. The main benefit of this approach over traditional foam-in-place methods is that the initial fitting time is much longer. A client can be left in the bead-bag for a few hours to test whether the seating system is functioning correctly before the resin has cured. While the DESEMO system is not commercially available, other bead-bag and foam systems are currently in use.

Another bead-bag-and-vacuum method of obtaining a custom insert shape uses plaster bandages instead of active chemicals to save the shape (5,6). A latex bag, filled with expanded styrofoam beads, is placed in a wheelchair or fitting chair and the subject positioned on it. The shape of the bag is changed until the final insert contour is reflected in it. Once the preferred contour has been achieved, air is removed from the bag using a vacuum pump. With the air removed, the bag retains its shape, since the beads have "consolidated into a semi-rigid matrix." The shape of the bag is subsequently copied by making a plaster of Paris bandage shell from its surface. The insert is then manufactured by foaming up to the negative cast, either on-site or at a central fabrication center.

This system has the benefits of being easy to apply without requiring dangerous chemicals during the assessment session, providing unlimited initial fitting time, and requiring minimal equipment when a central fabrication facility is used to produce the insert. If insert fabrication is performed on-site, the problems associated with toxic chemical foams and technical time must be considered. While remote central fabrication (i.e., sending the cast to a company with the facilities to manufacture the insert) saves clinical and technical time, some error many be introduced due to cast positioning and alignment. The plaster cast method requires more technical/clinical time and more materials

than both the DESEMO system and manual method, but not as much time as the matrix method.

A custom seat shape can also be defined using computer-aided approaches. Weishaupt discusses a measurement method that involves a series of 91 pressure sensors located in a sling-test seat (7). As the patient sits in the chair, pressure transducer deformation reflects seat deformation. Through proper calibration, the pressure distribution can also be obtained. Although Weishaupt used this system for seat evaluation only, it can also be used to generate a surface map for CAD/CAM systems.

Sprigle, Chung, and Brubaker use a CAD/CAM seating system to investigate the effect of foam densities on cushion function (8). The buttock shape is obtained from a positioning system consisting of 64 linear potentiometers arranged in a 16×16 in (40.64×40.64 cm) grid. Once the patient is seated on the grid, the potentiometer deflections were collected using a computer; the data are expanded to a 33×33 array, reviewed, and the resulting shape carved using a numerically controlled milling machine. The use of CAD/CAM for custom cushion production improves experimental control since the shape is exactly reproduced for each test cushion. Due to the lack of normal pressure exerted by the back, the use of linear potentiometers may not be adequate to obtain the seat back contour.

CAD/CAM should improve current custom seating methods by:

- decreasing the time required for the seat manufacturing process
- providing data files for remote insert fabrication (central fabrication)
- providing a method for determining the patient's shape without the use of potentially hazardous chemicals
- saving the shape data on disk for later retrieval (assess previous clinical interventions, make additional inserts, and so forth)
- improving inter-clinician communication since the data file can be viewed on screen before the seat is fabricated, transferred to another computer, or displayed on a computerized conferencing system
- providing a more efficient platform from which to service remote areas (i.e., mobile clinic)
- improving seating research by providing a more controlled manufacturing approach (testing different materials, testing different clinical interventions, and so forth).

Most of the methods described in this document for custom seat fabrication are presently in use; however, *clinical* CAD/CAM methods are not adequately described in the literature. The possible benefits of an efficient and valid CAD/CAM seating system would suggest the need for further research into this area. This paper describes a clinical evaluation project that examined time requirements, clinician satisfaction, and client satisfaction with a commercially available seating CAD/CAM system.

METHODS

CAD/CAM and Manual Manufacturing Systems

All CAD/CAM seats were manufactured using the Otto Bock Shape System (OBSS: Otto Bock Orthopaedic Industry of Canada Ltd., Winnipeg, Manitoba). This system uses the bead-bag-and-vacuum approach to make a temporary seat for the client (5,6) and a magnetic digitizer/micro-computer assembly to record surface contour manually (9). The digitizing unit locates the three-dimensional (3-D) position of a hand-held stylus by creating a magnetic field about the bead bag, determining the strength of the field at the stylus location, and scaling the field strength to x, y, and z distances. The clinician or technician digitizes a series of medial/lateral, parallel lines along the bead bag surface by positioning the stylus on the bag and pressing the mouse button of the computer (**Figure 1**). These data points are used to interpolate a mathematical representation of the insert shape.

Figure 1.
Digitization on the OBSS system.

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The CAD software displays the mathematical surface as a series of 3-D on-screen images. An on-screen shape can be viewed, digitization lines can be removed and redigitized, and seat dimensions can be changed. When the correct insert image is obtained, the shape data file is saved and sent through a modem to a central fabrication facility for manufacturing.

The received data files at central fabrication are transferred to a numerical computer-controlled carver. A negative model of the insert is carved from a block of styrofoam and used to produce the device. By foaming up to the negative model, a variety of foam densities can be used in production.

The minimum OBSS system requirements are a 386-based computer with a math coprocessor, VGA graphics, 4 Mbytes RAM, and 10 Mbytes of hard disk space. A notebook computer is recommended when using OBSS at more than one location. The software is custom made for seating and loaded as a stand-alone DOS application. A magnetic digitizer comes with the OBSS package.

For this study, all clinical work was performed at The Rehabilitation Centre in Ottawa and the Centre de Réadaptation Lucie Bruneau in Montréal. All CAD/CAM inserts were fabricated at Otto Bock Orthopaedic Ltd. in Winnipeg and adjusted and mounted at the clinical facilities. Removable covers were used on all seats to allow for final adjustments on-site.

In addition to the CAD/CAM inserts, baseline data on hand-carved seating inserts were collected from a similar group of clients at The Rehabilitation Centre. This information was used to compare clinician times, fabrication times, insert ratings, and client satisfaction.

Subjects

All subjects involved with this study were recruited through the Special Seating section of the Prosthetics and Orthotics Service at The Rehabilitation Centre and the seating clinic at the Centre de Réadaptation Lucie Bruneau. A disability rating scale, shown in **Table 1,** was used as the subject selection criterion (10). Admittance to the study was initially restricted to people with a disability rating over 3; however, two subjects from the Lucie Bruneau site with a level 2 rating were included since the CAD/CAM approach was considered appropriate for their condition. One seating clinician from each of the centers did all client assessments. Two education sessions were held before data collection began to ensure that the clinicians understood and applied the scale in the same manner.

Table 1.
Disability rating scale.

Rating	Description
1	good head and trunk control symmetrical posturing easily attainable joint ROM within normal limits
2	fair to poor head and trunk control limited ROM in joints symmetrical posturing attainable increased spasticity over level 1
3	moderate deformities (flexible scoliosis, flexible kyphosis) possible flexion contractures foot and ankle deformities 90/90/90 position attainable
4	flexible and fixed deformities pelvic obliquity flexion contractures greater than 120° some difficulty in attaining 90/90/90 posture
5	severe, fixed deformities major limitations of ROM due to contracture extreme difficulty attaining and retaining seating postures

ROM = range of motion.

All subjects were divided into two groups: a group who received a CAD/CAM seating insert and a group who received a conventional insert. The conventional insert group was recruited from the Rehabilitation Centre over a 4-month period before starting the CAD/CAM system evaluation. During this time, all but three subjects who matched the selection criteria were included in the comparison group. The three subjects who were not included had severe (level 5) spinal deformity and were fitted using foam in place (two cases) and casting (one case). After the conventional insert data were collected, a second group of subjects was recruited in the same manner and fitted with CAD/CAM-produced custom contoured seats. Informed consent was obtained from all subjects. Demographic data, including gender, date of birth, disability, and degree of disability, were collected for each client during the first clinic visit.

Data Collection

Clinician and client questionnaires were completed for all seating inserts. One clinician from each center completed the clinician questionnaires for their respective sites, recording information on the prescribed

device, the time required to assess the client, the time lag for seat manufacturing, the custom insert rating, the time required for final fitting, and whether the finished seat was acceptable for dispensing. The initial and final fitting sessions were held on separate days.

One questionnaire was completed for each seating system. An acceptable insert manufacturing time (central fabrication time) was considered to be 2 weeks. All other items were compared between the CAD/CAM and manual modification groups. Clinician insert ratings were based on the modification scale shown in **Table 2.**

A client questionnaire was administered by mail 3 months after the device was dispensed, to obtain information on insert design, durability, comfort, appropriateness, and general comments. These questions were included as part of a quality assurance questionnaire circulated in either English or French versions to all patients seen at the centers.

Data Analysis

All questionnaire data were analyzed using descriptive statistics. The patient and clinician responses were compared by gender, age, disability, and level of disability. A Mann-Whitney U test was used to compare the clinician and client questionnaire results between the CAD/CAM and conventional groups. The on-site manufacturing and fitting time associated with the CAD/CAM approach were compared to conventional on-site manufacturing and fitting times using t-tests ($p<0.05$). If the CAD/CAM and conventionally produced seats were at least equal in function, the many benefits of the CAD/CAM approach would support continued use of the CAD/CAM system for custom seating.

RESULTS

Subjects

Clinician feedback was available for 25 CAD/CAM inserts and 9 conventional inserts. Patient satisfaction questionnaires were received from 16 (64 percent) of the CAD/CAM subjects and 8 (89 percent) of the conventional subjects.

For the CAD/CAM group, the average age was 37.3 years (SD=20.1 years); 56 percent were male and 44 percent female. Fifty-six percent of the patients had cerebral palsy and all suffered from scoliosis or kyphoscoliosis. On a scale of 1 to 5, most of the client disability ratings were above 4 (48 percent rated as level 5, 40 percent as level 4, and 12 percent as level 2 or 3).

Table 2.
Clinical rating scale.

Rating	Description
1	Insert was redone
2	Excessive modifications required (modifications to 25-50% of surface)
3	Intermediate modifications required (modifications to 10-25% of surface)
4	Minor modifications required (modifications to under 10% of surface)
5	No modifications required

The conventional group had an average age of 39 years (SD=27.6 years); 56 percent were male and 44 percent female. Forty-four percent of the patients had cerebral palsy and all suffered from scoliosis or kyphoscoliosis. On a scale of 1 to 5, the seating disability ratings for these subjects were all above 3 (33 percent rated as level 3, 56 percent as level 4, and 11 percent as level 5).

Clinical

Approximately half the CAD/CAM subjects received a seat and back while 48 percent received only a back. Fifty-six percent of the subjects with conventional inserts received a seat and back, 22 percent received only a seat, and 22 percent received only a back. All the conventional inserts were hand carved.

Two CAD/CAM devices were unacceptable on the first attempt and one was redigitized and sent back to the central fabrication facility. Five seats required manual modifications before dispensing. All other seats were acceptable on the first attempt.

Custom-contoured seats were mounted in either AMS, Quickie, or Invacare 3000 wheelchairs[1]. Custom fabricated plastic mounting shells, Otto Bock System (drop hooking interface kit, back and seat frames, and connecting hoods), and a combination of an Otto Bock frame and a custom made mounting clip were used to mount the inserts. The clinical and technical staff considered the mounting process uncomplicated.

The time required to produce the seats and/or seat backs using the CAD/CAM system is shown on **Table 3.** Total time is divided into four segments:

Initial Fitting: The time required to create the CAD/CAM insert shape in the bead bag. For conventional

[1]AMS: American Medical Systems, Kingston, ON, Canada K7M 4H5; Quickie: Quickie Design, Fresno, CA 93727-1328; Invacare: Invacare Corporation, Elyria, OH 44306-2125.

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Table 3.
Time required for CAD/CAM and conventional seat fabrication (average and standard deviation (SD) for all subjects).

	Measure	Units	Average	SD
CAD/CAM	Initial fitting time	hours	1.1	0.5
	Central Fabrication time	days	39.1	17.4
	On-site Fabrication time	hours	2.5	2.5
	Final fitting time	hours	1.0	0.6
Conventional	Initial fitting time	hours	1.2	0.8
	On-site Fabrication time	hours	15.0	3.6
	Final fitting time	hours	1.2	0.6

inserts, this referred to the client contact time before fabrication starts.

Central Fabrication: The number of days between sending the CAD file and receiving the insert. This is not applicable to conventional inserts.

On-Site Fabrication: The time required to digitize, modify and mount a CAD/CAM insert (i.e., all tasks performed by the on-site technicians/clinicians). For conventional inserts, this referred to the clinician and technician time required to make the insert.

Final Fitting: The time required to fit and dispense a completed insert.

Figure 2 shows central fabrication times for the CAD/CAM group. These data were sorted by the date on which the seat and mounting hardware (if required) were received from the manufacturing facility. One extreme case was not representative of the regular central fabrication process and was removed from the data set (110 day time lag). The average time lag for central fabrication was over the initial estimate of 14 days. Fabrication times using the CAD/CAM system were significantly faster than the manual modification group ($p<0.01$). The statistical power was 0.32 for the initial fitting t-test, 0.97 for final fitting, and 1.0 for fabrication. It should be noted that CAD/CAM fabrication times were for shape digitization and technical work on site (i.e., they did not include the time lag for central fabrication).

Clinician insert ratings (**Table 2**) for the CAD/CAM inserts were high, since 72 percent of the seats were rated at, or above, 4 on a scale of 5 (40 percent rated 4 out of 5, 32 percent rated 5 out of 5). Two of the CAD/CAM inserts were rated as 1. Most of the clients were satisfied with their custom seat. The manually produced seats had a lower clinician insert rating (56 percent rated 4 and 11 percent rated 5) than the

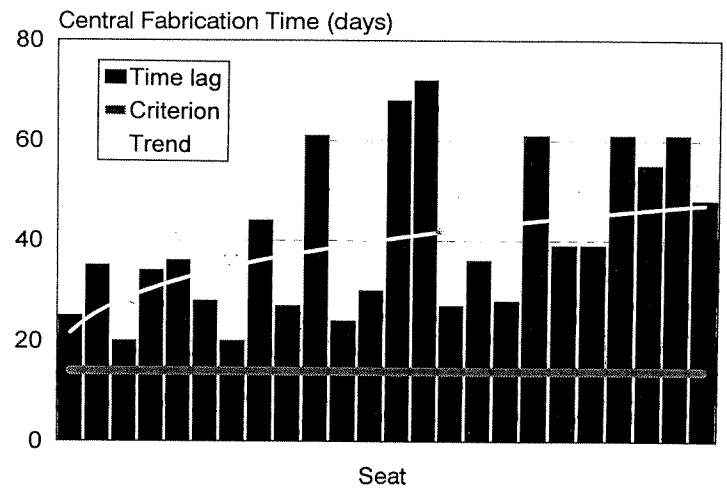

Figure 2.
Time lag, power regression curve (trend), and criterion time for the central fabrication process.

CAD/CAM seats; however, no manually produced seats were rated as 1. The clinician and client results are displayed in **Figures 3** and **4.** No significant differences ($p<0.05$) were found between the CAD/CAM and conventional groups in terms of the seat comfort, appropriateness, design, durability, and clinician satisfaction.

DISCUSSION

Custom wheelchair seating CAD/CAM systems are no longer exclusive to the laboratory. This technology is being used worldwide to serve the disabled community. While conventional seating produces desirable results, the combination of computer-aided techniques and clinical knowledge provides many benefits over traditional methods.

The questionnaire results from this study supported the use of CAD/CAM for custom wheelchair seating. Since no significant differences were found between client satisfaction ratings for CAD/CAM produced inserts and conventionally produced inserts, the CAD/CAM method can be considered as good as conventional methods. Clinician satisfaction results were higher for the CAD/CAM method; however, no significant difference was found between the CAD/CAM and manual fabrication groups. Since there was no statistical difference between the clinician and client perception of seat comfort and function, the benefits of using a CAD/CAM system (e.g., data saved to disk, on-screen

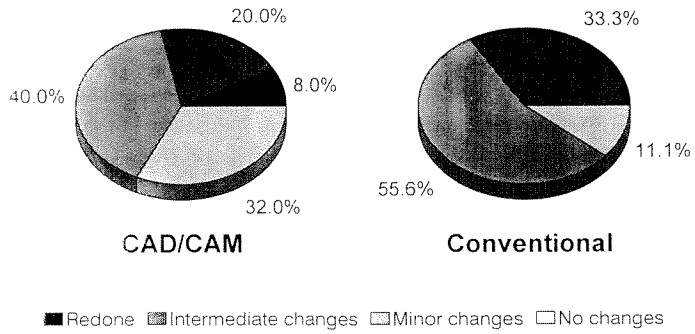

Figure 3.
Clinician satisfaction as a percentage of the total number of responses for CAD/CAM and conventional seating inserts (item definitions are in **Table 2**).

graphics of final shape, central fabrication, and so forth) would support continued use of the computerized approach.

While there were no statistical differences for client and clinician satisfaction, differences were shown in the descriptive data (**Figure 4**). The hand-carved inserts were generally perceived as more comfortable. This result was based on five CAD/CAM inserts having a comfort rating of fair while all manual inserts were rated as good. Upon reviewing clinician comments for the five fair inserts, in two cases the clinician had to make additional insert modifications and in one the clinician considered the foam too hard. These factors are directly related to client comfort. Since the cases with fair ratings were some of the first inserts produced (i.e., within the first five cases from each center), the lower perceived comfort can be related to clinical inexperience with the CAD/CAM system and foam density selection. The methods used to modify a central fabrication insert may also contribute to insert comfort. If an area on the CAD/CAM insert has to be built up, the difference in foam densities may be unsettling to the client.

Generally, the same CAD/CAM seats that were rated fair for comfort were rated fair for design and appropriateness. This result could have occurred because a client considered a fairly comfortable seat to be only a fair design and/or because additional modifications to these seats implied a design problem. In one case, problems adjusting a pelvic belt could be the main reason for the fair design rating. These seating inserts were within the first five cases: the necessity of including at least five clinical trials as part of the training process should be considered when implementing a seating CAD/CAM system.

It was not surprising that the CAD/CAM inserts were generally considered more durable, since central fabrication inserts were of a uniform density and had a latex covering sealed to the foam. These qualities gave the inserts both a functional and visual perception of durability, especially since the client could see the base insert when the removable cover was off. None of the seating inserts have been returned or required replacement because of wear.

Most CAD/CAM inserts did not require additional modifications when received from the central fabrication facility. Of the seats that required modifications, the majority were manufactured at the beginning of the study and their deficiencies could be attributed to the problems of learning how to interact with a two-dimensional CAD image of a 3-D shape, refining the bead bag molding and client assessment process to improve digitization, and needed improvements of the early CAD software. Recent versions of the OBSS provide 3-D views and on-screen measurement capabilities that help the clinician discover digitizing errors before the shape is transmitted to the central fabrication facility. Editing options for the insert's trim line and cutting plane were also added over the course of this project. While these features were not required during the study, it is anticipated that they will be very useful in the future.

Two CAD/CAM inserts required reassessment and resubmission to the fabrication facility. These inserts were redone since the insert dimensions did not match the chair and substantial changes to the shape were required before fitting. Since there was a discrepancy between the disk file and the insert shape, the cause of these problems could have been modem communication errors, file labelling errors at the fabrication site, or digitization errors. As metal can disrupt the magnetic field of the digitizer, it is important to set up the computer system in an open area and check the initial calibration to ensure accurate results. The clinician's experience with interpreting a 3-D image can also affect the final product. Initially, clinicians with little CAD experience can have difficulty translating a flat-screen wireframe and/or shaded representation into a mental image of the 3-D shape. This difficulty may cause the clinician to miss some digitizing errors when evaluating an on-screen CAD shape.

The time required to make a CAD data file was well within expected limits, considering that this time included a full patient fitting using a vacuum bag. At the start of the study, it was anticipated that the

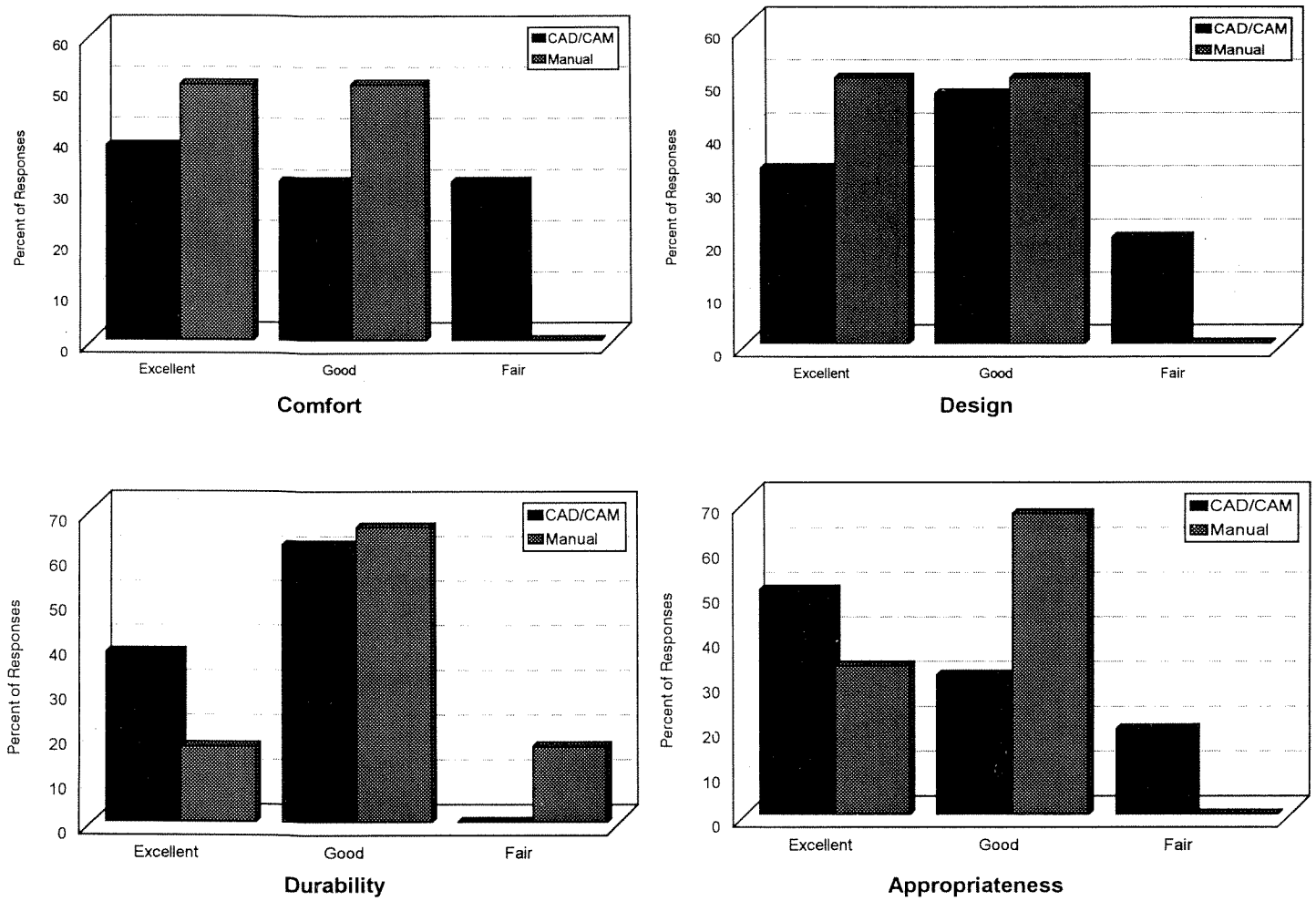

Figure 4.
Client satisfaction ratings for CAD/CAM and manually manufactured seats as a percent of the total number of responses.

CAD/CAM and manual fabrication fitting times would be similar. A benefit of the bead bag approach over hand sculpting was that by pre-molding the bead bag to an approximation of the seat shape before the client was transferred to the fitting chair, fewer people were required to hold him/her in position during initial fitting and he/she did not have to be physically moved as often as with some conventional methods. These benefits are directly related to the bead-bag fitting process alone. Hand sculpting has the advantage of not requiring specialized equipment to obtain shape measurements.

Since a central fabrication center was used to produce the CAD/CAM insert, it was not unexpected that the manually produced seats required significantly more technical time to be fabricated and mounted. While the technical fabrication component was very satisfactory, the time lag for central fabrication was well over our criterion of 14 days. In addition, the linear trend for fabrication increased during the study. The seat/mounting hardware delivery process may have been influenced by the transfer of manufacturing facilities from Canada to the United States during the final stages of this project. To provide optimal service to the client, fabrication facilities should aspire to a delivery period of from 5 to 10 working days. Current prosthetic CAD/CAM fabrication times vary from 24 to 48 hours. Since the insert shape is stored digitally, the implementation of a more efficient computer-controlled manufacturing processes should not influence current clinical CAD/CAM methods.

The clinical/technical time for production of a high contour seating insert was greatly reduced by using the CAD/CAM system (average difference of 16.3 hours between CAD/CAM and conventional methods). This time savings can be used to spend more time with each client or to work on other seating systems. While time savings are beneficial to the seating clinician, the time delays for central fabrication did not produce service benefits for the client. An improvement in this fabrication time was the primary concern of the clinicians involved with this study.

While CAD/CAM is an effective approach, the hand-carved method can produce a seating insert for less cost than most central fabrication options. Provided that the seating technician has the skill to produce an acceptable product, a hand-carved insert can be produced with minimal equipment and raw materials. The cost effectiveness of using CAD/CAM versus manual fabrication will rely on the local economics (i.e., cost per device, cost of materials, and so forth), number of referrals, and clinical/technical skill. If hand-carved inserts take an average of 12.5 hours more to produce, this time could be used to make two or three simple seating inserts. Depending on the local economics and a continuous workload, this added productivity could offset the increased cost of CAD/CAM fabrication. In contrast, a facility with technical expertise but little work could financially benefit by letting the seating clinicians and technicians spend the additional time to fabricate and fit a hand-sculpted insert. At The Rehabilitation Centre, OBSS is only used for complex seating cases, since it is more economical and faster to make a simple seating insert using manual methods. Also of note is that patient funding for CAD/CAM inserts in our province has been cut to approximately 50 percent of the funding for traditionally produced, complex seating inserts. This may be in recognition of the increased efficiency of the CAD/CAM process.

A summary session with the participating clinicians and technicians provided valuable qualitative insight into clinical application of the OBSS CAD/CAM system. The CAD/CAM bead bag method was effective since this approach did not introduce time constraints on the therapists during the initial fitting process. Therapists at The Rehabilitation Centre often observed what they affectionately term the sleep test during fitting: if a client falls asleep or visibly relaxes while sitting in the molded bead bag, the seat could be considered comfortable. This test was very useful for clients who have difficulty communicating.

Digitizing the bead bag with a stylus provided a good representation of the shape without having to eliminate wrinkles in the bead bag. One digitizing improvement would be the inclusion of a button on the digitizing stylus to replace the current method of clicking the left mouse button of the computer. The CAD software could be improved by adding more shape editing tools and improving the graphical representation of the seating insert.

Use of a central fabrication facility provided a better quality foam cushion than is often available in a clinical manufacturing environment (fewer air bubbles, more consistent density, and so forth). This approach also eliminated the use of toxic, foaming chemicals in the clinic. The stored insert shape was useful for solving discrepancies during fabrication, since the clinician can see the image on screen while talking to the remote technician. Also, the clinician did not have to worry that his only client mold has been sent through the mail/courier to the manufacturing facility. A potential for alignment problems when a plaster cast is used for central fabrication was also reduced. The CAD/CAM system was very portable and ideal for clinics outside the regular seating area.

The following potential uses for seating CAD/CAM system were described by the participating clinicians and technicians (these items were not applied during this study):

1. Second insert can be fabricated at a reduced cost (i.e., no clinical time) for use in another chair or as a replacement once the old seat has worn out.
2. The CAD system can be used as a fitting tool in simple cases where the seating insert will be manually carved from foam. By using the bead bag during the fitting process the clinician will have a better idea as to the appropriateness of the seating design. After digitizing the bags, a record of the complete shape is stored on disk. Measurements for fabricating the final seat can be taken directly off the screen, thereby reducing the chance of missing important measurements during the initial assessment session. This technique can also be of benefit in cases where the clinical and technical staffs are at different locations (i.e., remote site and fabrication center).
3. The digitized seat shape can be used with a computerized video conference system to share clinical information between clinics.

4. Once a better file storage/retrieval/analysis method has been developed, the CAD/CAM system should provide the clinician with a superior client record.

CONCLUSION

CAD/CAM is an effective and clinically efficient means of producing a custom seating insert. The major benefits of this technique over hand-carved seating inserts are a reduced initial fitting time, reduced technical time during fabrication, and a reduced clinical and technical time for seat fabrication. Areas of improvement for seating CAD/CAM include reducing the time required for central fabrication, adding more shape editing tools to the CAD software, and improving the seating insert's graphical representation. Further research involving CAD/CAM comparisons with other seating insert fabrication methods is recommended.

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