Prosthetics and Orthotics International, 1995, 19, 120–123

Technical note

Design and manufacture of a high performance water-ski seating system for use by an individual with bilateral trans-femoral amputations

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Abstract
A high performance seating unit has been produced for a water-skier with bilateral trans-femoral amputations. The system, in which the user sits whilst skiing, has helped the client to further her sporting career and enabled her to compete successfully at the highest levels of disabled water-skiing competition.

Introduction

The Clinical Engineering Group at Withington Hospital was asked to produce a high performance seating unit to fit onto a standard Kan-Ski water-ski (designed for use by paraplegics) for use by an individual with bilateral trans-femoral amputations. The client involved is a highly successful, competitive disabled water-skier (current UK and World Disabled water skiing champion), who was experiencing difficulties with the equipment which she was using. She felt the technique which she had adopted in order to use this equipment was both unsafe and inefficient and that if she was to remain competitve at a high level, then alternative equipment configurations would have to be sought.

Before the authors became involved in the project, the client had tried various equipment combinations, the latest being the commercially available Kan-Ski water-ski and seating system. The Kan-Ski is a high performance carbon fibre water-ski with dedicated aluminium frame seating system, designed for use by paraplegic water skiers. The seating system can be used by individuals with high level lesions as it offers a high degree of lateral support around the thorax. Unfortunately, this system proved to be unsatisfactory for this client as the seat could not be used as was intended by the manufacturer. She had to sit directly on the board, effectively trapping herself in the framework. As well as being quite unsafe, this seating position required a lot of upper body strength to manoeuvre the board, due to the proximity of the skier's centre of gravity to water level.

The task was to design and construct a completely new seating system that would easily interface with the preferred performance water-ski (the Kan-Ski) and allow complete safety combined with high level performance.

Design requirements

The first stage of the design process was to specify fully what was actually required by the client and to establish what parameters and restrictions the project would be subject to. A design specification was drawn up and issued to all parties concerned with the project for comments and queries. The specification included:

- geometry: client physical measurements, required seat height above water, dimensions of fixation lugs on Kan-Ski, strapping requirements etc.;
- forces: estimations of the forces experienced by the system when being towed around a

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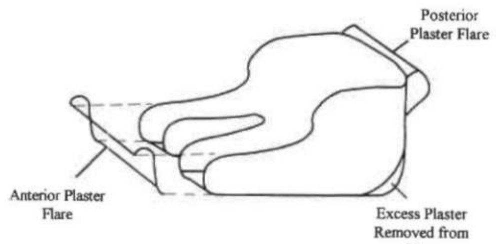

Fig. 1. Rectified seat mould

slalom course at speeds up to 58 km/h;
- materials: corrosion and safety implications (methods of failure);
- safety: getting out of the seat in an emergency;
- maintenance and cost factors.

Viewing the specification, it became apparent that the problem would be best approached by splitting it into two separate parts; i) a custom built seat (manufactured using standard orthotic techniques); ii) some means of supporting the seat and fixing it to the ski.

Production of dedicated seating unit

The client was cast in a "dry suit", which she normally wore when water-skiing (the suit was protected from the plaster used during the casting procedure by a polymer film wrap). During casting, she was seated on a casting couch, with her stumps lying on the head board, her body being tilted to a position which she deemed most comfortable for water skiing. The stumps and weight bearing aspects of the gluteal region, were then cast using pre-measured slabs of six-ply, 200mm thick plaster. This was followed by casting of the pelvic region and the region immediately proximal to it, with a wrap cast from 200mm thick rolls of plaster. Concave profiles were then moulded by hand over each iliac crest. The cast was then removed from the patient, sealed and filled to produce a positive mould.

Rectification of the cast involved removing a maximum of 25mm of plaster at the weight-bearing/non-weight-bearing border of the gluteal region, as well as building up the region of the cast accommodating the stumps, so that the seat was the same length as its supporting frame. Flares were then added to the front and back of the seat, enabling it to locate firmly with the cross members of the supporting frame (Fig. 1).

The seat was made by moulding 3mm low density expanded polyethylene foam to the positive cast, and vacuum moulding polyethylene-polypropylene copolymer over it. This was then trimmed to shape and all sharp/rough edges removed.

During the fitting sessions, further trimming was undertaken and a region between the stumps was marked out and a high density expanded polyethylene foam "pommel" fitted therein. This incompressible pommel allowed a more intimate fit between stups and seating system and thus added to the feedback that the client received when using the system on a water-ski.

Straps made from neoprene and nylon webbing were attached to the frame to hold the client firmly in the seat. These straps were placed over each stump, crossing over through a hole in the seat immediately behind the pommel and attaching to the diagonally opposite side strut of the frame. The client was held within the seat by these straps using a Velcro fastening. This fastening could be rapidly removed if the occupant so required, hence allowing an expedient escape from the seat in emergencies.

Production of supporting framework

The final frame design basically consisted of two portal frames at the front and rear supported by cross-bracing members onto which the seat would attach (Fig. 2).

It was assumed the frame would be subjected to a maximum force of 3 times occupant body weight in a vertical direction and shearing force of 2 times occupant body weight in a horizontal

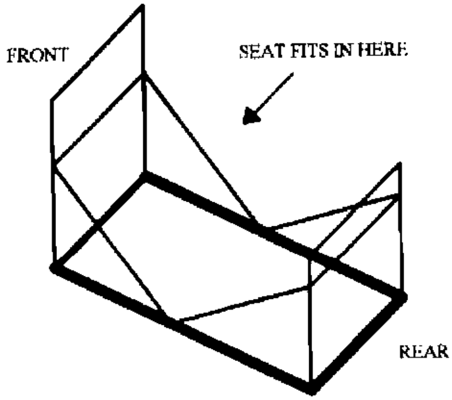

Fig. 2. Seating system framework

Fig. 3. Completed water-ski seating unit

(front to rear) direction. These estimations of the forces were calculated for the seating system when being used on a slalom course only, and not for jumping or trick skiing (a condition stipulated in the specification).

1 inch diameter 16 gauge BS1474 HE30TF aluminium alloy tubing was chosen for the main frame members as it has a high strength to weight ratio and good corrosion resistance properties. The tubing framework was welded onto a rectangular base (constructed of the same alloy but in flat bar form) which had a series of 10 vertical holes drilled into it down each side. The frame could then be placed over the lugs provided on the Kan-Ski and fixed down using wing nuts. The series of holes allowed the skier to adjust the frame to the most suitable position.

A comparison of proof stress against maximum estimated stress in the frame members was used to calculate factors of safety for the frame members. The lowest factor of safety was 4.5 for the vertical members of the rear portal frame. This was deemed acceptable as in the worst case of maximum loading scenario, the structure would show visible signs of deformation before actual failure occurred.

The hollow members of the frame were filled with polyurethane foam. This ensured improved flotation but more importantly ensured that water would not collect inside the frame, thus reducing the chances of corrosion.

Outcome

After manufacture, the 2 components of the seating system were brought together during a fitting session with the client (Fig. 3). The system was tested for fit and comfort and the overall construction and form was discussed further, allowing both designer and client to anticipate any problems that may occur during use. When all concerned were satisfied with the system, the first prototype was issued for use.

The system was first used by the client during a training week in the USA. During this week the client regularly used the system and by the end of the week was using it at full speed on the slalom course. Some problems were experienced by the client when cracks appeared in the polyethylene-polypropylene seat and it eventually broke at the attachment point to the frame. This mode of failure had been anticipated by the design team and no injuries were sustained by the client. The client was able to reattach the seat to the frame using Nylon webbing.

On return to the UK, the client reported her experiences to the team and the whole seating system was inspected to assess any damage. Apart from the seat, the system showed no other signs of failure.

A new seat was made using a slightly thicker (4mm) polyethylene-polypropylene copolymer and new straps attached. A slight reduction in the height of the rear portal frame was also made to allow a more functional seating position.

Conclusion

A high performance water-ski seating system which allows the client to compete at the highest levels has been produced and has been in continual use by the client since April 1994.

No further problems have been experienced and the user is again competing successfully.

This successfully completed project has been achieved through collaboration and co-operation between the Clinical Engineering Group at Withington Hospital and the School of Prosthetics and Orthotics at Salford.

Acknowledgement

The authors would like to thank Mr. Stefan Jedut at Salford and Mr. Robert Williams at Withington Hospital for their assistance with this project.