Prosthetics and Orthotics International, 1983, 7, 25-28

Structural matrices for use in rehabilitation

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Abstract

Progress is reported on the development and application of structural matrices in rehabilitation. The development of a stronger and more adjustable matrix than was previously reported is detailed, together with the principles necessary to achieve this. Application of this new matrix to adult seating is described. The emergence of programmable beams and the need for containment matrices are also documented and the advantages of these approaches to a variety of problems in rehabilitation are given.

Introduction

One of the fundamental problems in designing devices for the disabled is that of providing a strong and lightweight yet adjustable structure. This problem is common to the design of a variety of devices ranging from seats to spinal orthoses. A diversity of materials are currently employed to build these structures, such as thermoplastics for spinal body jackets, plaster of Paris for limb fracture management and thermosetting plastics for seating the cerebral palsied child. These materials perform satisfactorily in their various configurations but often the need for adjustability is frustrated. The need for strength is not adequately met by thermoplastics unless the structure can be formed into an integrally strong shape.

The design of a universal structure, or structural matrix, was therefore considered necessary. A matrix in this context is defined as an array of small components that can be linked, shaped and locked to form a strong enclosing or supporting structure. This matrix would have a wide range of rigidities and be adjustable both in stiffness and in shape. The adjustability of the structure was considered to be the most important feature, as this would allow the structure to be used in such diverse applications as seating of the cerebral palsied child, where changes in shape of the seat are needed as the child grows; or in fracture management, where the rigidity of the orthosis should be changed as the fracture heals. Early attempts at a solution to this design problem have been reported (Foort et al. 1978) and since that time considerable progress has been made. The purpose of this report, therefore, is to demonstrate this progress, to illustrate the current clinical applications and to outline the problems remaining.

Progress

The first structural matrix to find useful clinical application was reported as a shapeable matrix for use as a seat for disabled children (Cousins et al. 1979). The latest version of this seat, as shown in Figure 1 (left), is a major advance over

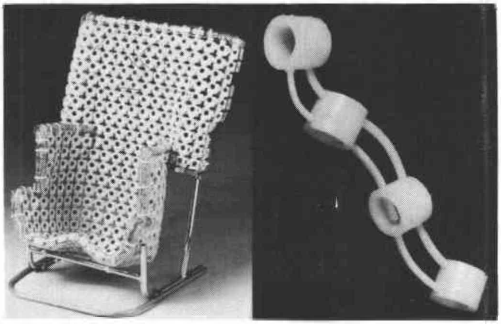

Fig. 1. Left, the shapeable matrix used by Cousins for child seating. Right, prototype of the node and beam structure.

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conventional seating systems as it permits fine adjustment to meet the critical shapes needed to effectively seat and control the cerebral palsied child. The limitations of this system are that, because it is constructed as a matrix of fixed increments, it can only be easily contoured to cylindrical-conical shapes. A second disadvantage is that the locking force of the matrix, that is the tension in the wires, is opposed by the loading forces. These opposing forces act along the neutral axis of the structure, that is along the wires themselves, and so very high friction is needed at the nodes to give a secure lock.

It was felt that the ability of a matrix to form around spherical and complex anatomical shapes was required; and secondly, any loading forces applied to the matrix should aid in locking the matrix. Design efforts continue.

An important improvement was the use of the I-beam principle, where the structural beams are separated as far as possible away from the neutral axis. This is shown in Figure 1 (right), where two rods are separated by nodes. The locking of the rods occurs at the top and bottom of the nodes, that is well away from the neutral axis. Loading of this system puts one beam in tension and the other beam in compression. A strong structure with positive locking was therefore possible. This concept was also very attractive as the nodes could be positioned and locked at any point along the beam, so giving continuous rather than incremental adjustment. The nodes could be inserted and removed to vary the strength of the beam and variability of link length at the nodes gave a structure that could encompass complex shapes.

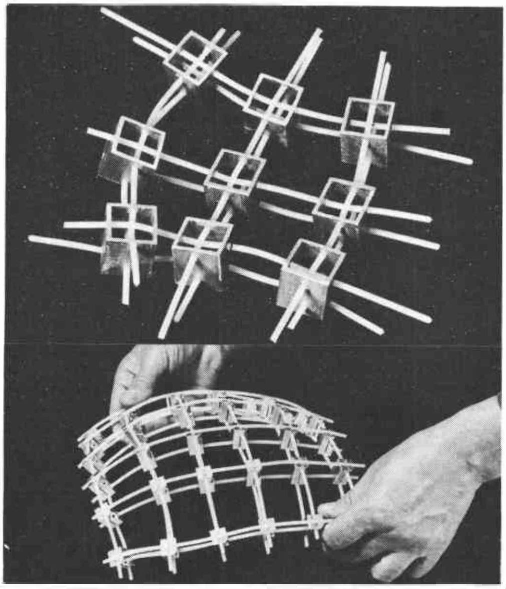

Fig. 2. Early node and beam matrices.

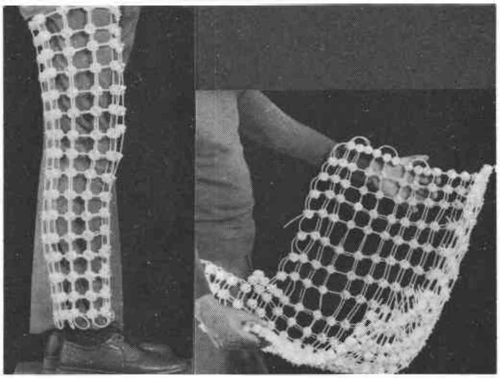

Fig. 3. The node and beam matrix, left, encasing the lower limb and, right, as a seat.

This design process resulted in a structure that overcame the strength and adjustability problems of the first matrix; this new structure has been named Node-and-Beam. Examples are given in Figure 2 of different early versions of this approach and full-scale models of a lower limb support (Fig. 3, left) a seat (Fig. 3, right) and a spinal orthosis (Fig. 4) are shown to demonstrate the versatility of the structure.

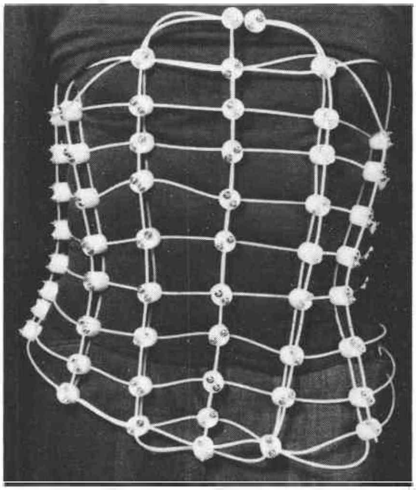

Fig. 4. The node and beam matrix as a spinal orthosis.

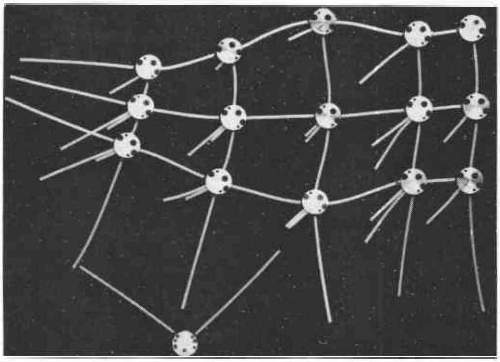

Fig. 5. A single layer of node and beam that "swallows" its neighbour.

However, speedy and secure locking of the beams at the nodes remained a major design problem. Simplification of the locking procedure was achieved through the use of a single screw that gripped all four beams as they crossed at a node. An example of this is shown in Figure 4. This system still necessitated the unlocking of many nodes to achieve a change in the shape of the structure as the beams were continuous. It was felt that the use of short beams, reaching from node to node, would give greater local adjustability of the matrix. This was first modelled as a system where the node "swallowed" the beams of the next node, as shown in Figure 5. This arrangement did give greater adjustability and was incorporated into the original I-beam design to increase its strength. Incremental lock points set along the beam aid in the locking. The resulting structure is illustrated in Figure 6. A clip-on surfacing element was added and the structure is currently being put to clinical use as a seat for the severely disabled adult.

Discussion

Parallel developments of matrices for use in seating have been taking place at a sister unit, the Bioengineering Centre of University College London. The latest seat design emerging from this centre has been reported by Cousins (1981), who was an original member of the MERU team engaged in formulating the shapeable matrix concept in 1975. It is expected that many new applications will emerge from the concept of structural matrices and certain directions for improvement are already apparent.

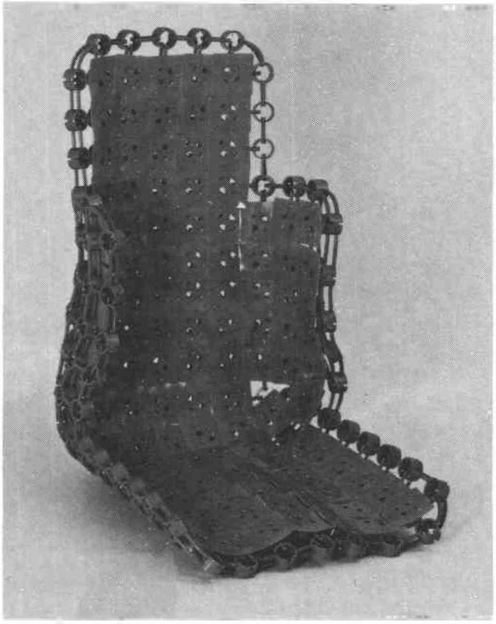

Fig. 6. The latest node and beam matrix assembled as a seat.

There is a need, for example, for node and beam systems of different sizes to accommodate differing problems. The structure illustrated in Figure 6, currently being applied to adult seating, represents one of the most demanding applications of a structural matrix in rehabilitation. Smaller and more adjustable versions are needed for children and for orthoses to be worn on the body. One of our early objectives was to develop a replacement for plaster of Paris for many orthotic applications. It is possible however, that the structural and containment functions will have to be separated to achieve a finely tuneable matrix. This will mean the development of a distinct containment matrix that is compatible with the supporting structural matrix. Containment matrices will find application in non-weightbearing situations such as upper extremity orthoses, or in conjunction with structural matrices for more demanding applications.

Further refinements will include the use of different surfacing elements under different loading conditions; and the use of insertable modules for various functions such as load measurement, surface mobility feedback and attachment of additional structures. Examples of the latter would be the interfacing of the halo apparatus with a body jacket and the addition of hinges to femoral fracture orthoses.

The development of structural matrices has led to the introduction of programmable beams (Dewar, 1979) that can be shaped, or programmed. An example of a common programmable beam is that of the laminated wood beam used in architecture. This structure can be shaped to position and then bonded to the fixed shape. Beams constructed in such a manner will find ready application as side irons for lower limb orthoses or as strengthening members for spinal orthoses. Adjustable programmable beams have been developed by the MERU team and these present exciting opportunities for a diversity of applications. A time lapse photograph of a programmable beam in motion is shown in Figure 7. These beams consist of nodes spaced along flexible plastic rods. Pushing or pulling the ends of the rods will shape the beam. Hinging through various degrees of freedom can be obtained by crossing over the rods, and selective mobility can be achieved by locking the beams at intermediate nodes. Application of mobile programmable beams will be found as feeder/manipulator arms and as joysticks for wheelchair control.

It is felt that the use of adjustable structural matrices and rigid, flexible or mobile beams in rehabilitation will have the effect of reducing costs and speeding provision time of orthoses and other devices. This will be possible because the matrix approach takes advantage of mass-production techniques for producing the standard components. These can then be assembled with no special tools or facilities. The frequency of patient visits may be reduced, as changes to the shape and strength of the orthosis can be made while the patient waits. The comfort of the patient will be increased by the provision of lightweight and cool structures that conform and respond to their needs.

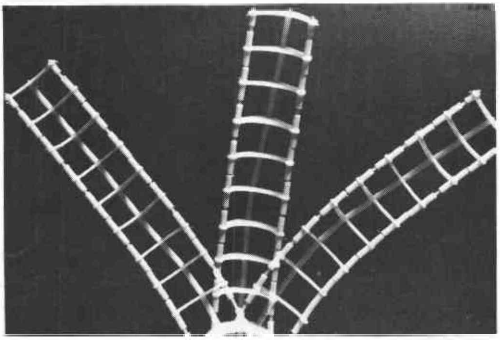

Fig. 7. Time lapse photograph of a programmable beam in motion.

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