

Title: Improvements to Matrix Seating: Technical and Clinical Developments

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Abstract: Over the past 20 years nearly 30,000 Matrix seating systems have been fitted worldwide. After analysis of manufacturing and clinical issues, improvements to the basic Matrix elements were proposed four years ago at the Royal Hospital for Neuro-disability. A stronger, thinner, and lighter Matrix was developed with preliminary clinical evaluation

started. Static and dynamic structural tests are reported. The static tests include, (1) 250 load-deflection tests of various Matrix clamp designs, and (2) load degradation tests after re-clamping for clinical shape adjustments. The dynamic, accelerated five-year life tests include, (1) fatigue tests over 500,000 cycles (comparisons to the new standard, ISO/DIS 16840-3, are drawn) and (2) 75 Kg and 34 Kg full size manikin tests in a wheelchair test carousel for 16,125 revolutions or 336 Km. Evaluations are limited to 35 patients over a maximum of 36 months with the focus on ease of use and production speed. Application to the manufacture of a custom formable removable wheelchair back is also discussed.

1. Introduction

Over the past 20 years nearly 30,000 Matrix seating systems have been fitted worldwide. This system, using clamps and interconnecting elements with spherical joints, is cold formed and its' shape mechanically locked over an individual's seating cast or during a direct fitting process. The sheet comprising this component matrix can be mechanically unlocked and re-shaped for growth or clinical postural change.

This approach to making a custom seating shell is not without its problems however. As with any structure with many components its' physical integrity must be maintained during its life and it must have adequate strength to maintain its clinically corrective shape (or flexibility to return to the desired shape). In the first instance structural integrity is needed to minimise risk and to safely support the individual and, in the second instance, to not allow loss of corrective shape that can lead to pressure injury and the loss of range of movement. Loss of the corrective shape can occur if the structure is overloaded (beyond its design load) during its' life or, in the longer term, if it creeps and moves under every day cyclic loading. The latter can be tested by an accelerated life test, say 500,000 loading cycles, and the former by static (overload) destruction tests. In a modular structure like Matrix is also important to determine if shape adjustment (the re-clamping of the locking component) affects the load carrying capacity of the structure.

After analysis of manufacturing and clinical issues, improvements to the basic Matrix elements were proposed four years ago at the Royal Hospital for Neuro-disability. The redesigned clamp is substantially stronger than the original allowing fabrication of a seat with a minimum need for the normally structurally important tubular aluminium frame.

This also allowed the manufacture of a Matrix back system that could be fitted as a standard wheelchair back but with the additional benefit of shape customisation. A limited clinical evaluation of these two developments is also discussed.

2. Structural Testing

2.1 Static Tests

Two types of static test have been performed on the Matrix system. One is a static destruction test for single test samples and the other were sequential maximum load limited tests on single units, re-clamped three times during the test.

(1) Static Tests: During its re-development about 250 tests were performed on various design configurations of the new Matrix clamp. These involved various metal and plastic combinations in different physical configurations with various screw head styles torqued to a range of values. Because of the potentially large number of possible test combinations only the most promising combination were tried. Additionally various engineering calculations including finite element analysis was applied to try and model the testing process to reduce the amount of physical testing required.

Table 1 shows a few of the comparative test results. The Matrix sheet is fitted in an 'open weave' condition and can be reinforced (where curvatures allow) by filling in the alternating openings with additional clamps. This process, referred in Table 1 as Close Weave, over doubles the strength of this cold moulded material.

(2) Re-clamped Static Tests: In Figure 1 the changes in load carrying capacity of a single Matrix module (clamp and four four-ball interconnecting units) is shown for three re-clamping actions. Re-clamping represents a change of shape of part of the Matrix shell for clinical purposes. The new Matrix (the upper curve in Figure 1) is initially 2.7 times stronger than the current Matrix. If these values in the upper curve are averaged the new Matrix declines in strength about 1.3% for each re-clamp (although a recovery of strength is seen towards the end of the test). This is in comparison to the current Matrix where a 10.3% average decline in strength with re-clamping is observed. The result of the re-clamping changes improves the current to new Matrix strength ratio to 3.7 to 1.

2.2 Fatigue Tests

Two types of fatigue tests have been performed on the Matrix system. One used a single clamp module loaded cyclically in a testing machine and the other used 75 Kg and 34 Kg manikins in full size Matrix shells (uncovered) in a wheelchair on a test track. Both tests were executed to simulate a five-year life test (accelerated).

(1) Fatigue Test: An average Matrix custom fitted seat is about 12 modules wide by about 23 modules long (a module is a clamp with attached interconnecting spherical units) and is strategically reinforced by a tubular framework (original system) or cladding made of metal strips bolted to the modules (new system) and, in both cases, the supporting wheelchair base. The fatigue test however was performed on an un-reinforced single Matrix module. The main difficulty in this test, due to a paucity of published information, is determining the load to apply to the test sample to reflect the clinical loading that might be

expected in service. One reference [1], a postural support device draft testing standard (the Standard, ISO/DIS 16840-3), suggests a repetitive static load, in Newtons, of 10 times the user's mass in Kilograms, applied initially for 100,000 cycles. The load is then increased in 25% increments up to 200%, 100,000 cycles for each load increment until failure occurs (nine failure modes are defined in the Standard; one is five millimetres of permanent displacement). A note in the draft Standard, page 27, assumes that the user is loading the seat twenty times per hour over a 14-hour day (280 loading cycles).

Figure 2 shows the result of a 500,000 cycles dynamic fatigue test (0.5 Hz, 100N to 300N cycle) in a hydraulic testing machine (made by Zwick) on a single Matrix module, [2]. (The Matrix fatigue test was completed many years before the Standard [1], was drafted.) About 84% of the movement (creep) that occurs in the first 100,000 cycles occurred in the first 10,000 cycles. At an estimated 300 cycles/day this is just over one month's use. Joint movement settles down after 10,000 and at 300,000 cycles, about 2.78 years, deflection has progressed another 22% or about 0.05 mm. The clinical implication of this is that if the Matrix fit is acceptable in the first month of use, very little shape change will occur after that.

When the size of the loading pads proposed in the draft Standard are taken into consideration (a minimum length of 100mm which will spread the load over at least two Matrix modules) only a slight increase in the applied loading for the 500,000 cycle test would give the same conditions as the Standard. The Standard's loading protocol, that is increasing loading and cycles to failure, is different however, but will establish the fatigue limit of the support device.

(2) Carousel Test: This test completed on the current Matrix a number of years ago, [1], used 75 and 34 Kg manikins on two wheelchairs pushed around a seven meter diameter test track. The track was lined with small diameter wires for part of its circumference, larger rods and staggered smooth bumps to apply a high and medium vibration frequency and frame twisting to the wheelchair and its seat. Additionally, about every 22 revolutions of the track, a 15 cm ramp and drop appeared to simulate the wheelchair being bumped down a curb. The Matrix system successfully finished the test (16,125 revolutions) without visible damage.

Table 2 summarises the test results. These include the static tilt tests of the Matrix shell/Wheelchair combination and the statistics of the five-year life tests.

3. Clinical Evaluation

3.1 'Frameless' Matrix

In summary the new Matrix has these features (compared to current matrix):

- About 4 mm thinner than current Matrix
- About 2.7 times stronger in bending than current Matrix
- About 3.7 times stronger after three re-clamping actions than current Matrix
- About 20% lighter (reduced framing) than current Matrix
- Reduced components to handle: 3 vs 6 component in a clamp
- Improved production speed (less framing)

- Larger flat surfaces for improved support surface area
- Potential 3D shaping with less tailoring required
- Potential flexible elements for dynamic features

New Matrix evaluation has involved 35 patients. The majority of fittings are within the last six months although some go back nearly three years. Ten of the fittings were with pre-production components, the last 25 with the production components that have a slightly larger range of movement at the ball and socket joint and with components that clip together more easily. All of these fittings were not part of a 'clinical trial' but rather a comparative evaluation of its ease of use of and overall production time. Although there is no clinical conclusion to draw from these, other than the clinicians were as happy with the results as with the previous system, overall production times have decreased by 30 to 40%.

The first subjects' Matrix shell has shown no movement (in use over 36 months) as measured across the diagonal corners of the shell. However we have no way currently to measure the quality of fit between the Matrix shell and the patient or how this changes over time. The development of a hand held digital depth gauge is underway.

3.2 Matrix Back

Because the new system is stronger backs can be made without the tubular framework. This allows a direct fitting approach to be followed and allows subsequent adjustments to be made efficiently. Three patients were tried using a removable new Matrix back centrally mounted on a track system, with front to back adjustment arms, to brackets on the wheelchair back upright tubes. They were evaluated for use with the system using loan

equipment first and then followed up with a definitive fitting. Fitting typically took about 30 minutes from start to finish. It is too early to report on the clinical effectiveness of this approach.

4. Conclusion

A new, thinner, stronger and lighter Matrix system has been developed. A range of structural tests has been applied to the new design in addition to a limited 35 patient evaluation. The comparative static and dynamic mechanical tests show improvement over the current design. Given the functional similarities between the current and new Matrix designs these improvements should have a general, positive effect on the clinical outcome.

5. Acknowledgements

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6. References

- [1] ISO/DIS 16840-3: Wheelchair Seating – Part 3: Postural Support Devices – Test Methods for Static, Impact and Repeated Load Strength. Prepared by Technical Committee ISO/TC 173, Technical system and aids for disabled or handicapped persons, Subcommittee, SC1, Wheelchairs.
- [2] S. J. Cousins, The Design of Segmented Structural Surfaces, Ph.D. Dissertation, University College London, January 1988.

Table 1: Comparison of Structural Tests

	Load (N)	Close Weave (N)	x3 Re-clamp (N)
Current	592	1196	410
New	1589	3528	1526
Ratio, New/Current	2.7 to 1	2.95 to 1	3.7 to 1

Table 2: Matrix Wheelchair Tilt Tests and Five-Year Life Tests

	Tilt Tests			Distance (Km)	Dynamic Tests		Curb Drops (15 cm)
	Rear (Degrees)	Front (Degrees)	Side (Degrees)		Cycles (1 rev.)	Time (Hrs)	
Manikin							
34 (Kg)	18 (16)	25 (16)	21 (16)	336	16,125	69	747
75 (Kg)	13 (12)	20 (12)	21 (12)	336	16,125	69	747

[Tilt Test angles are in brackets for the respective test limits.]

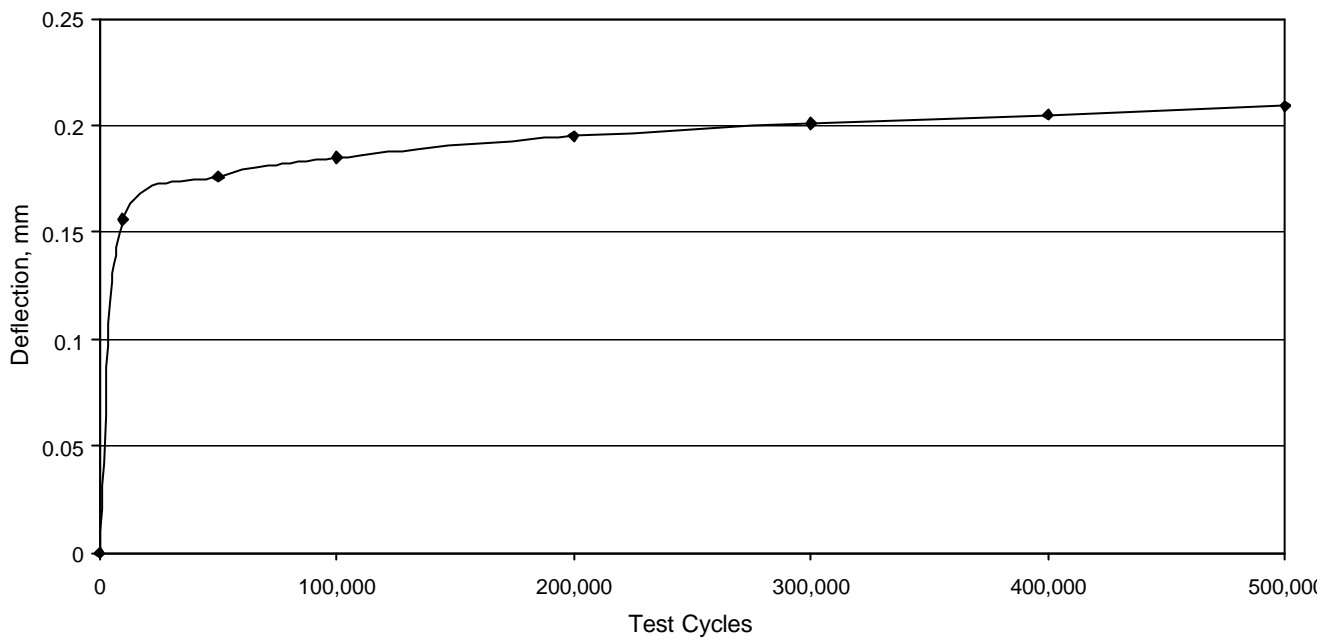
Figure 2: Matrix Fatigue Deflection Test

Figure 1: Matrix Re-clamping Tests