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Biomechanics of the SB Charité lumbar intervertebral disc endoprosthesis

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Summary. *The SB Charité intervertebral disc prostheses consist of two metal end-plates and an interposed polyethylene slide core. These were subjected to static and dynamic testing in a servohydraulic test rig. When embedded in polypropylene, the prostheses were found to function adequately under a high static load, and under a lighter dynamic load for a long time. When tested in a cadaveric vertebral segment, a large end-plate surface area proved to be of critical importance in preventing collapse of the prosthesis into the vertebral body.*

Résumé. *La prothèse des disques intervertébraux de type "SB Charité" est composée de deux plaques métalliques entre lesquelles est interposé un noyau élastique de polyéthylène. Elle a été soumise à des épreuves biomécaniques comportant des expériences statiques et dynamiques de compression. Les tests faits sur des prothèses encastrées dans du polypropylène ont démontré une fonction satisfaisante après des charges statiques élevées et après des épreuves dynamiques de longue durée. L'examen de prothèses implantées sur des rachis de cadavres a montré l'importance d'une surface étendue des plaques métalliques afin d'éviter leur encastrement à l'intérieur des corps vertébraux.*

Introduction

Fusion of a motion segment in degenerative disc disease increases the stress on adjacent levels and leads to premature wear [8, 9]. Restoration of intervertebral disc function by means of a prosthesis should prevent these secondary changes but, so far, attempts to achieve this have failed.

The theory of prosthetic replacement of the intervertebral disc was formulated by van Steenbrugghe in 1956. In 1972, Ferström [7] reported the results of implanting a steel sphere prosthesis but in only 12% had adequate disc height been maintained after four to seven years. Replacement of the nucleus pulposus with a flexible plastic has also been attempted but with little success [6, 13].

We report the results of biomechanical testing of two SB Charité lumbar intervertebral disc prostheses. The SB I prosthesis has two small circular end-plates each carrying eleven teeth and a slide core without a radio-opaque marker (Fig. 1), whereas the SB II prosthesis has expanded lateral wings to increase the surface area of the end plates, six teeth per end-plate and a radio-opaque

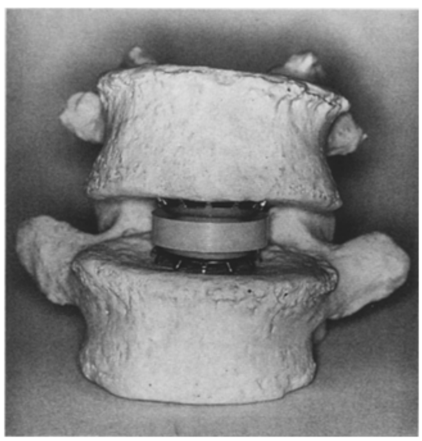

Fig. 1. SB I intervertebral disc prosthesis in the vertebral model

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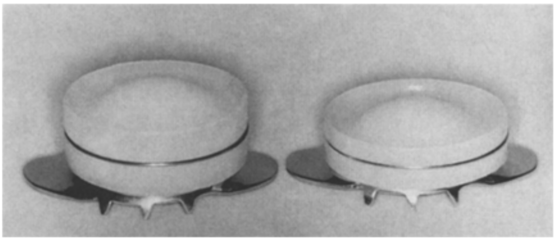

Fig. 2. SB II intervertebral disc prostheses with slide cores of different heights

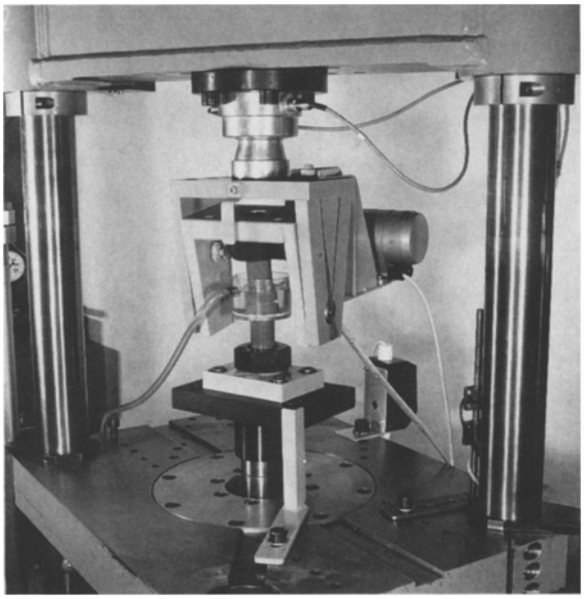

Fig. 3. Servohydraulic rig used for testing the prostheses. (Institute of Lightweight Construction, Dresden, GDR)

marker embedded in the circumference of the slide core (Fig. 2).

Experimental method and results

Static and dynamic studies were carried out using a servohydraulic test rig (Fig. 3).

Static testing

The steel end plates of the prosthesis were embedded in polypropylene and the whole implant subjected to increasing loads.

Results

Hysteresis was observed in the polyethylene (Chirulen) slide core in response to loads up to 4.2kN (Fig. 4); loads between 6kN and 8kN produced incipient irreversible deformation due to cold flow, behaviour typical of elastic plastics. When the load was increased to 10.5kN (Fig. 5), the height of the slide core was reduced by about 10%. Macroscopic change in the endplates was not observed even in response to loads of 19.5kN but the slide core bulged visibly (Fig. 6).

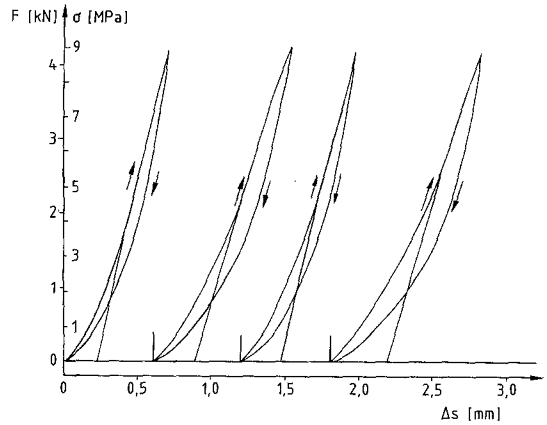

Fig. 4. Hysteresis loops showing the deformation of four intervertebral disc prostheses in response to loads of up to 4.2kN

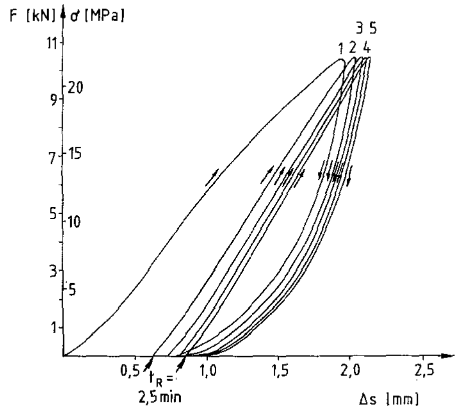

Fig. 5. Hysteresis loops showing the deformation of one disc prosthesis in response to five cycles of loading up to 10.5kN. (t_R resting time)

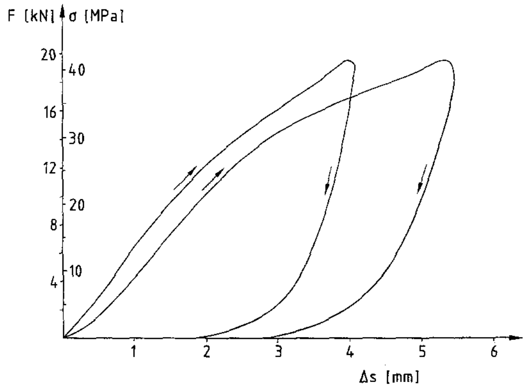

Fig. 6. Hysteresis loops showing the deformation of one disc prosthesis exposed to two load cycles up to 19.5kN

Dynamic testing

Dynamic behaviour was tested in a rig which rocked the prosthesis through ± 10° about the neutral position at a rate of 5–10 cycles per second. Load increments were not synchronised with this movement, so peak loading occurred at

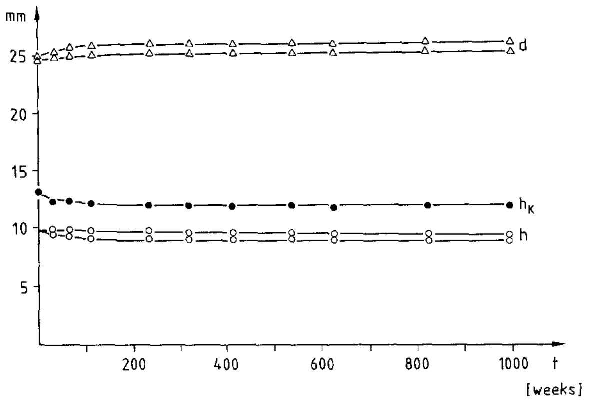

Fig. 7. Irreversible deformation of the polyethylene slide core with time. The x-axis is calibrated in "equivalent weeks". (*d* diameter of slide core, h_k central height of slide core, *h* peripheral height of slide core)

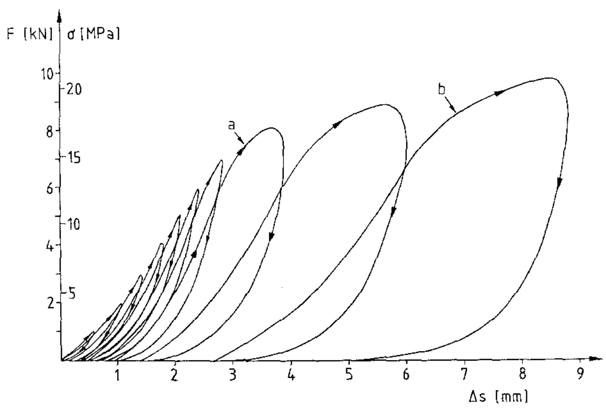

Fig. 8. Hysteresis loops resulting from static loading of the SB I prosthesis in a lumbar vertebral model (*a* start of implant migration, *b* collapse of vertebra)

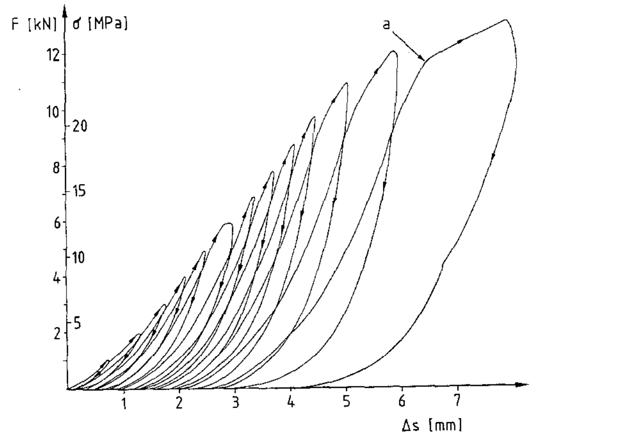

Fig. 9. Hysteresis loops resulting from static testing of the SB II prosthesis in a lumbar vertebral model (*a* collapse of vertebra)

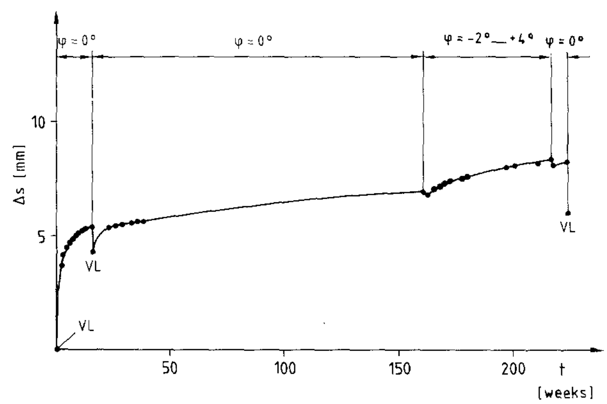

Fig. 10. Dynamic strength of the SB II prosthesis in the lumbar vertebral model over 220 equivalent weeks (*VL* preload, φ deflection due to movement)

unspecified points in the cycle. Testing was carried out over 2×10^7 cycles, which is roughly equivalent to 20 years use. A 0.7kN preload was applied with one weekly maximum load of 8.0kN and several increments of intermediate magnitude.

Results

The slide cores deformed by about 10% mostly within the first two "years" (Fig. 7). Slight track marks were observed on the terminal plates and slide core, and were attributed to the artificially repetitive movement.

Cadaveric testing

The two types of prosthesis (SB I and SB II) were tested in 13 cadaveric lumbar segments from donors aged between 27 and 62 years. Both models were subjected to increasing static load until the prosthesis collapsed into the adjacent vertebra.

Dynamic testing of the SB II model in the cadaveric vertebral segment was carried out once a week using 6.0kN as a maximum load, with 0.7kN preload. Intermediate loads were applied over the course of 3000 cycles.

Results

Considerable migration of the SB I model occurred in response to loads between 4.5 and 8.5kN (Fig. 8), and the SB II model reacted similarly to loads of between 10.7 and 11.6kN (Fig. 9).

In dynamic tests the SB II prosthesis functioned properly for the equivalent of 220 weeks (Fig. 10).

Discussion

Before using this prosthesis clinically it was clearly essential to test its biomechanical properties: in vitro testing appeared to be more appropriate than attempting in vivo testing in a quadruped. Low friction materials of proven success in joint replacement were used in its manufacture [1]. No macroscopic wear was found and little would be expected because of the relatively slight movement of lumbar intervertebral segments [2, 5, 11, 12]. To improve the corrosion characteristics and stability of the prosthesis, the end-plates are now made of a chromium/cobalt/molybdenum alloy [15].

The relatively low loadbearing capacity of lumbar vertebral bodies is well established [3, 4, 10]. It is therefore essential to ensure the largest possible area of contact for the end-plates so that the load may be evenly distributed, although the manner of load transmission will differ from normal. In the clinical situation we expect the vertebral bodies to remodel in accordance with Wolff's law [16].

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