Lumbar Interbody Threaded Prostheses

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Introduction

Two types of intradiscal prostheses are presented and discussed. They have been developed for two basic but opposite clinical-biomechanical reasons: (1) restoration or maintenance of discal height and mobility, viz., a prosthetic nucleus and (2) interbody fusion. Although at diametric ends of the mechanical spectrum, i.e., flexible vs. rigid, both utilize a technique of threading (or tapping) holes bored or cut into the intradiscal or interbody space. The threaded external construction provides instant mechanical holding strength against expulsion of the prostheses and more than doubles the area of the interface contact, as compared with equivalent, smooth-surfaced devices. The flexible prosthetic nuclei require shallow threading of the vertebral end plates and no direct attachment to the bone, whereas the fusion devices must have deep penetration into bleeding spongiosa for ultimate ingrowth of vertebral bone.

The threaded outer shell of the flexible nuclei are woven of filaments, somewhat resembling segments of an aortic prosthesis; each has an internal, semipermeable membranous sac filled with hyaluronic acid and a thixotropic agent. Although inserted in a partly collapsed, relatively dehydrated, initial condition, the strongly hygroscopic hyaluronic acid within the capsular prosthesis swells rather rapidly, locks the matching threads of the device within the tapped recipient bed, and then continues to swell such that disc height and flexibility return. The formerly slack, partly degenerated annulus then tightens. The cyclic loading function, important to discal metabolism and caused by fluctuations in applied pressure (from body weight and muscle pull) balanced against swelling pressure of the nuclear gel, causes metabolites to leave and enter the disc. With primary functions thus restored, hopefully the annulus will heal. The viscosity altering thixotropic agent permits the contained fluid to translocate during bending, but take a set when immobile in order to imitate the normal rheology of the disc nucleus.

The rigid, threaded, titanium cage fusion devices have multiple perforations (60%–70%) around surfaces that penetrate well into the
threaded spongiosa. When packed with autologous, cancellous bone chips, a bony bridge grows across the cages and through the chips to unite the opposing vertebral bodies [35].

Anatomy and Biomechanics of the Normal Intervertebral Disc

Intervertebral discs, mechanical cushions of the axial skeleton, are unique structures comprising two principal types of tissue; an outer, multilayered ligamentous band; the anulus, built rather like a laminated automobile tire; and an inner, softer, partially movable, relatively amorphous, fibrocartilaginous nucleus. Each lumbar disc normally measures about 10–15 mm in height at rest but diminishes in height by 10%–25% on prolonged weight-bearing. The circumferential margin of the anular band is about 15 mm thick [19]. The contact surface area and size of the vertebral bodies vary linearly with the load carried; thus the average lowest lumbar discs have an area of about 20–28 cm², becoming smaller with each higher disc [9]. The average size at the lumbosacral junction is about 3.5 × 5.5 cm. The fibers of the outer anulus, principally of type I collagen, are laid down in relatively discrete multiple layers; the fibers attach to the vertebral bodies at an angle of about 30°–40° in both directions, that is, right- and left-handed [37]. This design resists torsion, as half of these angulated fibers will tighten with vertebral rotation in either direction.

The discs comprise about 20% of the total length of the axial spine. The controlled motions between vertebral segments of the skeleton are determined and limited by flexibility of the discs, intervertebral ligaments, and by the facet joints. Although flexion-extension reaches about 12° per lumbar segment, lateral bending is about 5° and rotation is limited to about 1.5° [20, 32]. Greater freedom of rotation is potentially more destructive to the segmental structures and especially to emerging nerves [32, 43, 46].

As the vertebral column is bent and the end plates become out of parallel, compression or tension occurs on opposite sides of the anulus. This wedging motion is aided by a limited translocation of the semifluid internal nucleus away from the narrowed side [19, 45]. This translocation effects a shift in the center of motion between the vertebrae. The complex intervertebral motions demand both nuclear fluidity and anular flexibility and are important to anular integrity, as wedge bending is needed to reduce fiber stretch on the tension side [46].

The contained nucleus, acting rather like the fluid center of a golf ball, is strongly hygroscopic due to the mucopolysaccharide content. By imbibing water, this vaguely encapsulated, semifluid gel serves to keep the anulus tight (as does the air inside a tire); the gel also exhibits pressure-related swelling, viz., the nuclear fluid volume, which is reduced with gravity and muscular pull