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Intervertebral discs from spinal nondeformity and deformity patients have different mechanical and matrix properties

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Abstract

BACKGROUND CONTEXT: It is well-established that disc mechanical properties degrade with degeneration. However, prior studies utilized cadaveric tissues from donors with undefined back pain history. Disc degeneration may present with pain at the affected motion segment, or it may be present in the absence of back pain. The mechanical properties and matrix quantity of discs removed and diagnosed for degeneration with patient chronic pain may be distinct from those with other diagnoses, such as spinal deformity.

PURPOSE: To test the hypothesis that discs from nondeformity segments have inferior mechanical properties than deformity discs owing to differences in matrix quality.

STUDY DESIGN/SETTING: In vitro study comparing the mechanical and matrix properties of discs from surgery patients with spinal nondeformity and deformity.

METHODS: We analyzed nucleus and annulus samples (8–11 specimens per group) from surgical discectomy patients as part of a fusion or disc replacement procedure. Tissues were divided into two cohorts: nondeformity and deformity. Dynamic indentation tests were used to determine energy dissipation, indentation modulus, and viscoelasticity. Tissue hydration at a physiologic pressure was assessed by equilibrium dialysis. Proteoglycan, collagen, and collagen cross-link content were quantified. Matrix structure was assessed by histology.

RESULTS: We observed that energy dissipation was significantly higher in the nondeformity nucleus than in the deformity nucleus. Equilibrium dialysis experiments showed that annulus swelling was significantly lower in the nondeformity group. Consistent with this, we observed that the nondeformity annulus had lower proteoglycan and higher collagen contents.

CONCLUSIONS: Our data suggest that discs from nondeformity discs have subtle differences in mechanical properties compared with deformity discs. These differences were partially explained by matrix biochemical composition for the annulus, but not for the nucleus. The results of this study suggest that compromised matrix quality and diminished mechanical properties are features that potentially accompany discs of patients undergoing segmental fusion or disc replacement for disc degeneration and chronic back pain. These features have previously been implicated in pain via instability or reduced motion segment stiffness.

Keywords: Back pain; Intervertebral disc degeneration; Indentation testing; Equilibrium dialysis; Proteoglycan; Collagen

FDA device/drug status: Not applicable.

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Introduction

Discogenic back pain is a challenging clinical problem to both diagnose and treat. Although the etiology is uncertain in most patients, it has sometimes been linked with deficits in tissue structure [1]. The healthy intervertebral disc consists of an outer annulus fibrosus (AF) that surrounds the inner nucleus pulposus (NP). The annulus consists of concentric lamellar collagenous rings. The nucleus comprises a proteoglycan-rich matrix that osmotically swells to generate hydrostatic pressure that resists spinal compression. Disc degeneration includes changes in matrix composition leading to deterioration of tissue mechanical properties, such as nuclear depressurization, which can degrade overall spinal biomechanical behavior. Mechanical insufficiency, along with infiltration and sensitization of pain transmitting neurons (nociceptors), may be responsible for discogenic pain [2]. Thus, recent biologic therapies aim to stimulate matrix synthesis in attempt to reestablish mechanical properties [3].

Differences in mechanical properties of degenerated compared with normal intervertebral discs may therefore provide clues to help direct therapies for symptomatic disc degeneration. We know that degeneration decreases nuclear energy dissipation [4], swelling pressure, and compressive modulus relative to normal nucleus [5]. Additionally, the degenerated annulus has a higher compressive stiffness that correlates with tissue dehydration [6]. Consequently, degenerated discs have a breakdown in matrix function, resulting in compromised biomechanical behavior.

However, not all degenerated discs are painful; many asymptomatic individuals have MRI evidence of disc degeneration [7,8]. This suggests that subtle features may be related to pain that are not reliably quantified with standard diagnostic tests. Clinically, patients with back pain may present with disc degeneration and a painful motion segment. Although the precise source of the pain is difficult to identify, the intervertebral disc may be contributory. Histologic data indicate that painful degenerated discs have disordered annulus lamellar structure, innervation, and vascular granulation tissue [1,9,10]. These qualitative observations have not been supported by quantitative analyses to assess their biomechancial significance. One overarching research goal is to quantify and understand these features that may be responsible for disc pain. However, the current study lacks the clinical diagnostics necessary to investigate the painful disc. Instead, this study focuses on degenerated discs from chronic back pain patients without deformity compared with a deformity control group. Using in vitro testing, we hypothesized that discs from nondeformity and deformity patients have differing mechanical and biochemical properties.

Materials and methods

Patient and group selection

Patients in the study were placed into one of two groups: Nondeformity and deformity. The nondeformity cohort consisted of back pain patients with radiographic evidence of disc degeneration and clinically assessed chronic back pain. Back pain is multifactorial, and identification of a source of pain is complex and often nonspecific. Thus, the source of their pain remains undefined in this study; however, in the surgeon's assessment the affected motion segment was contributing to the patient's pain. Our second cohort—deformity—consisted of patients with olisthesis, rotational subluxation, obliquity, or scoliosis. Patients were categorized according to the surgeon's assessment based on clinical presentation, radiographic findings, and discography.

Clinical presentation

Clinical presentation included pain evaluation using a visual analog scale (VAS; included for 19/20 patients), and assessment of pain patterns associated with sitting, bending over, and morning hours. These data were collected by standard patient intake questionnaires at the initial visit and preoperatively, just before or during the clinic visit.

The VAS consisted of a 10-cm line with 0 on the left indicating ''no pain'' and 10 on the right indicating ''worst possible pain.'' Patients were instructed to mark the level of back pain/discomfort, with 0 being none and 10 being unbearable. No further instructions were provided regarding the timing of pain. They were asked to specify the duration of symptoms (including pain) in a separate question. For all patients except two, VAS scores were taken within 1 month of surgery.

Radiographic findings

Radiographic findings were used to evaluate degeneration and included plain films with qualitatively reduced height compared with adjacent discs; T2-weighted MRI image demonstrating reduced nucleus signal and degeneration grade >3 using the Pfirrmann scale; and endplate Modic changes. All patients were evaluated with plain films. We obtained MRIs for all nondeformity patients and six of the nine deformity patients; disc height and Pfirrmann grade [11] were recorded when MRI was available. Disc height was measured from the center of the inferior endplate to center of the superior endplate.

Discography

We conducted discography in 8 out of 11 nondeformity discs, using a low-pressure injection technique ($\leq$50 psi above opening pressure) for pain provocation [12]. Provocative discograms are rated by the quality and severity of pain provoked by injection of contrast medium into the intradiscal space. A positive disc was defined when concordant pain was provoked ($\geq$7/10 VAS) before achieving the pressure limit, a grade 3 annular tear was present, and there was a negative control disc ($\leq$6/10 VAS). Patients with a positive disc and degeneration were placed in the nondeformity cohort.

Tissue collection and preparation

Patient diagnosis and resulting categorization was conducted by the treating clinician and entered into tissue