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ANNULUS FIBROSUS MODEL IDENTIFICATION ENRICHED BY TRANSVERSE STRAIN MEASUREMENTS

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Key words: Annulus Fibrosus, Intervertebral disc, Hydro-chemo-mechanical interac-
tions, Finite element model, Digital image correlation.

Annulus fibrosus (AF) is the outer tissue of intervertebral disc (IVD). Its peculiar mi-
crostructure and biphasic composition confers to AF a non-linear, viscous, anisotropic
and chemo-sensitive behaviour. Many experimental and numerical studies underlined
the anisotropic and non-linear mechanical behaviours but fail to represent the hysteresis
observed under loading cycles \cite{1}, that would be related to biphasic behaviour and the
chemical sensitivity. On the other hand, characterization rarely relies on volumic behaviour
but it’s relevant when model deals with soft porous media. This work aims to couple a
poro-hyper-elastic model with an osmotic model and transverse strains measurements
highlighting model sensitivity and limits.

An experimental process has been developed to measure simultaneously stress and trans-
verse strains fields ($E_{rr}$, $E_{zz}$) during cyclic tensile tests and chemical test with \textit{in vivo}
conditions \cite{1}. Strain fields were computed from a digital image correlation (DIC) tech-
nique (\textit{Kelkins}, University of Montpellier 2) performed on both transverse planes.AF
tissue was modelled (\textit{LMGC90}, University of Montpellier 2) with an hyper-elastic quasi-
compressible porous material \cite{2} plus an osmotic model to represent the underlying
fibres network embedded in an isotropic, chemo-sensitive and porous matrix.

Experimental results exhibit the classical non-linear stiffening behaviour with hysteresis
under loading cycles \cite{1}. The anisotropic and heterogeneous behaviour clearly appear on
strain fields and is illustrated thanks to averaged values over 300 measurement points in
each direction on Fig.1. Furthermore, the chemical sensitivity appeared simultaneously
in stress and transverse strains data. The 6 mechanical parameters associated with the
theoretical model are identified using a Levenberg-Marquardt algorithm (\textit{Python}). On
stress-strain curves, the hyper-elastic part gives the non-linear shape and the porous
model accounts for the viscous behaviour. Nevertheless, it is noteworthy that due to the
non-uniqueness of solution when transverse strains are not taken into account (Fig.1a),
the model didn’t represent the transverse behaviour \((R = 0.16, \text{correlation coefficient}
\text{averaged over 10 human plus 19 pig samples}),\) even if it fairly translates the stress-strain
measurement \((R_{\text{stress}} = 0.99).\) Adding strain measurements in characterization improves
the model accuracy keeping accurate results in classical stress-strain curves \((R_{\text{stress}} =
0.99)\) and enhances transverse behaviour results \((R = 0.44).\)

Uniaxial tensile test enriched by DIC transverse strain measurements improves the hydro-
chemo-mechanical behaviour characterization of biological tissue. With only 6 parameters,
a fair agreement is obtained on stress/strain and transverse strains curves. On the other
hand, this work reveals model sensitivity and limits regarding transverse strains, local
heterogeneities, chemical behaviour and thus fluid flows characterization within AF. These
results are crucial when dealing with IVD FE model. They will improve the impact of
predictive model translating multiscale interactions like the IVD cells environment.

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gen metabolic transport in the intervertebral disc decreases with degenerative changes.