5º CONGRESSO NACIONAL DE BIOMECÂNICA
R.M. Natal Jorge, J.M.R.S. Tavares, J. Belinha, MPL Parente, PALS Martins (Eds)
Espinho, Portugal, 8 e 9 de Fevereiro, 2013

# A NOVEL METHODOLOGY FOR MEASUREMENT OF THE INTRADISCAL PRESSURE AND HEIGHT DISC VARIATION OF INTERVERTEBRAL DISC UNDER COMPRESSION

***Ângelo Araújo[1]; Nuno Peixinho[1], António Pinho[1] & J.C.P. Claro[1]***

*[1]Departamento de Engenharia Mecânica/CT2M-DSM, Universidade do Minho;*
*angelo14araujo@gmail.com; peixinho@dem.uminho.pt; acmpinho@dem.uminho.pt; jcpclaro@dem.uminho.pt*

**ABSTRACT:** *The intervertebral disc (IVD) is subjected to several types of loading during daily routine events. However, the overloading on this structure induces higher intradiscal pressure (IDP), which could cause severe damage on its structure. This study describes a new approach to monitor IDP and determine the height disc variation by applying external pressure, while a motion segment (assembly composed by vertebra-disc-vertebra) compressed at a physiological load. This methodology includes the use of a pneumatic structure that applies a certain pressure on the hydrostatic system, forcing a fluid to enter into the motion segment, through a screw with a drilled hollow along its entire length with an internal bore. Preliminary results indicates these methodology presents high potential to efficiently pressurize the IVD, providing a useful tool to better understand the response of this structure under pressure.*

**KEYWORDS:** Intervertebral disc, intradiscal pressure, height disc variation

## 1 INTRODUCTION

The structure of the IVD is both complex and inhomogeneous, allowing successful load-bearing movements due to the synergy of all components of disc [1].

This structure is subjected to several ranges of loads during the daily routine. These movements create great oscillations on IDP during the several daily activities. Wilke et al. [1999] [2] found that values of IDP are between 0.50-0.97 MPa at a standing position, while the maximum pressure measured was in the range of 2.30-3.60, in an exercise where a human lifted a mass of 20 kg while bending is back. This change could be explained by the assumption that an increase on compressive load applied to healthy discs is directly proportional to an upturn on nucleus pulposus pressure [3]. Finite element (FE) models of human IVDs indicates that the internal pressure exerted by the nucleus pushes the inner margin of the annulus outwards, during compression [4].

However, some movements such as compression combined with hyperflexion could generate an internal disc pressure that is beyond what IVD could withstand, promoting several injuries [1 & 3].

Previous studies have investigated the internal disc pressure on IVD [1, 2, 3, 5, 6 & 7]. These researches helped to generate valuable data, useful for a pre-clinically evaluation of spinal implants and disc injuries in further biomechanical in vitro experiments. However, it is desirable a method which allows to test not only the IDP but also the behavior of biomaterials inside the disc (with potential to replace it, such as hydrogels), in order to understand its response under pressure.

Therefore, the objective of this study was to develop a new methodology that aims to insert an external fluid into the place of removed nucleus pulposus, with a cartilaginous endplate access, monitoring the IDP during this period. In addition, this new procedure will allow determining the height disc variation under the effect of an external pressure, measuring MS height before and after each test.

## 2 MATERIALS AND METHODS

### 2.1 THE PRESSURE APPARATUS

The apparatus is presented on Figure 1.

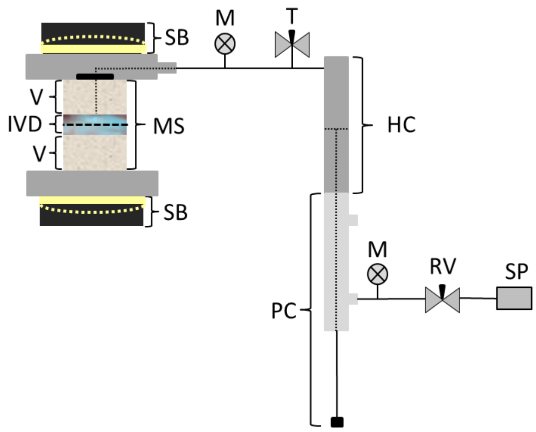


**Figure 1** – Schematic representation of pressure apparatus, containing:
**SP** - Pressurized air source; **RV** - Balancing valve; **M** - Glycerine manometer; **PC** - Pneumatic cylinder; **HC** – Hydraulic cylinder; **T** - Tap; **SB** - Spherical axial bearing; **V** - *Vertebrae*; **MS** - Motion segment; **IVD** - Intervertebral disc.

The novel apparatus could be divided in two compounds: a pneumatic and a hydraulic one. In few words, the pressurizing mechanism could be described as a pneumatic structure that applies a certain pressure on the hydrostatic system, forcing the fluid to enter into the motion segment.

On the pneumatic segment, the pressure will be exerted by the application of external pressurized air source which acts on a pneumatic double-acting mini-cylinder. The pressure will be controlled at the entrance of pneumatic cylinder by a balancing valve. Then, the mini-cylinder pushes an internal piston of a stainless steel hydraulic cylinder, specially designed on the scope of this application. The pressure, applied on the hydraulic cylinder will be transmitted to the fluid poured on hydraulic system by opening the tap. This tap will be opened to allow the entrance of the fluid and closed when there is assured that all hydraulic system is filled with it. During this process, care was taken to prevent the air bobbles formation. When tap is closed, the MS is ready to be pressurized. The pressure on the hydraulic segment is monitored immediately upward the fluid insertion on IVD by a glycerin manometer.

Finally, the fluid could be injected on IVD through a hole on the top of a motion segment.

### 2.2 MOTION SEGMENT COLLECTION AND PRESERVATION

To perform the tests we collected several lumbar spines of young swine, directly from the abattoir. These specimens were sawed immediately after being collected into “motion segments”[8], whose consist on an IVD and its adjoining vertebral body (Figure 2).

Posteriorly, some MS would be submitted to test. The remaining samples were sealed in plastic bags and frozen at -20ºC until the day prior to mechanical testing, to minimize the tissue dehydration.

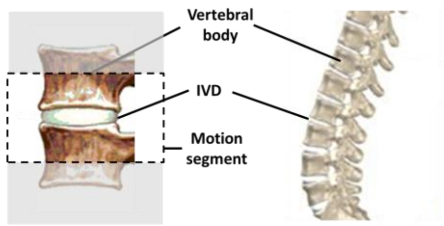


**Figure 2** – The projection of a motion segment. This structure is highlighted by the dashed rectangle. To obtain a motion segment, two vertebrae are cut parallel and transversely, obtaining an assemble vertebra-disc-vertebra.

This procedure would be adopted since dead and frozen storage presents a negligible effect on mechanical properties of the spine [9].

Before start any mechanical test, samples would be hydrated with 12h of PBS (1x).

## 2.3 MOTION SEGMENT ATTACHMENT

The bone is a highly porous, which the easy fluids outflow from its inner region to the outer one. In addition, the vertebral body presents a viscous structure, being extremely hard to tight a screw on it. To prevent these phenomena, a 9 mm diameter and ½ of top vertebrae height hole was drilled on the top part of motion segment, in order to be filled with an epoxy resin. Then, a 4 mm pilot hole was carefully drilled longitudinally through the resin and vertebrae until a sudden change on resistance. This change of resistance indicates the point of contact between the endplate and the nucleus of IVD.

The motion segment will be attached to pressure apparatus by a self-tapping steel screw (Figure 3-B).

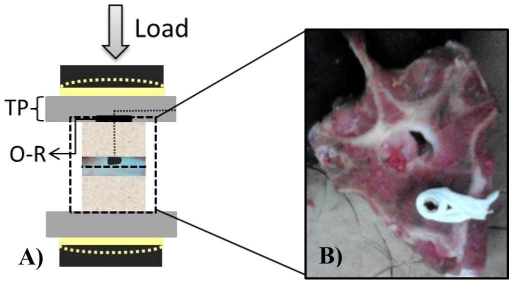


**Figure 3 –** The *motion segment* attachment.
A) The motion segment is placed between two plates on Instron® 8872, being subjected to compression strength. The top plate is drilled, allowing the fluid passage from pressure apparatus to the hollowed screw. The O-ring (O-R) would prevent the leakage on system.
B) The bottom part of pierced screw is drilled on the top of motion segment, with Teflon to obtain a better adhesion.

This screw presents two threads. The objective is to strengthen the tight between the screw and the vertebral bone. Its total length is 20 mm: 10 mm × Ø 7 mm presenting a thread typical of a drywall screw, in order to drill on vertebra and 10 mm × Ø 5 mm to attach to stainless steel top plate. This self-tapping screw also presents a drilled hollow along its entire length with an internal bore of Ø1,5 mm, allowing the fluid passage.

The screw would be tight through the pilot hole until reach the contact point between cartilaginous endplate and the IVD. In addition, an O-Ring was placed on the stainless steel top plate (around the self-tapping screw) in order to prevent the fluid leakage.

## 2.4 EXPERIMENTAL PROCEDURE

This assemble will be placed on an *Instron® 8872*, to be subjected to an axial compression load of 500 N, for 15 min (Figure 3-A), the same procedure presented by Heuer et al. (2007) [6].

Before specimens were loaded, the samples would be correctly aligned using a transversal dashed line in middle plan of the disc. Every sample is placed at same position during the test, using an axis system.

After these procedures, MS is pressurized and during this period, the values IDP are registered on glycerin manometer. In addition, the values of load and disc displacement will be recorded by the *Instron® 8872* software, the *BlueHill®*. Also the MS height is measured immediately before and after the test. The area of each IVD will be measured after each test, by a transversal cut on disc structure. Thus, using the recorded data of load and displacement, a curve of stress *vs* strain will be traced.

## 3 PRELIMINARY TESTS AND SYSTEM VALIDATION

This study is focused on the description of a new methodology to monitor both IDP and height disc variation by applying external pressure. Preliminary tests were taken with tap water. These tests were performed to assess the functionality of pressurizing system and, in addition, to validate it. On the three initial tests, the water introduction was made on the bottom part. The system revealed leakage on the contact zone between (visible on Figure 4). However, immediately before leakage occurs, the glycerin manometer had revealed a maximum of pressurization of 5 Bar. This pressure dropped until zero during the water outflow after pressurizing the IVD. The leakage on the system indicated that this methodology needs some improvements to inject low viscosity fluids, such as water, on IVD. Low viscosity fluids could leak from vertebral body basis, since this is a highly porous structure. Since the time of pressurization was not enough, there was no variation on height of motion segment. Next validation procedures will use fluids with higher viscosity and the contact surface between the bottom or top plate and vertebra will be isolated.

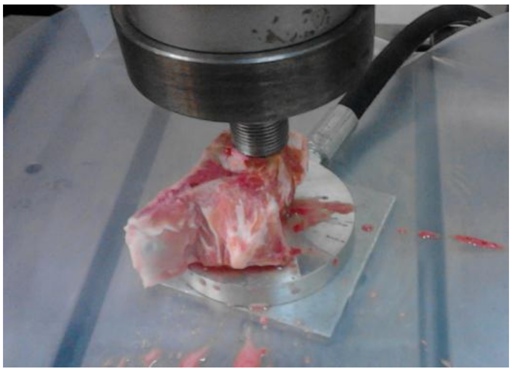

**Figure 4 –** The image showed a pressure test of IVD, using tap water. It is visible the leakage that occurred on contact surface between. **Note**: On these pilot tests, and due to experimental limitations, the fluid insertion was made through the bottom and not from top (as indicated on Figure 3).

## 4 CONCLUDING REMARKS

This new methodology would allow defining the mechanical response of IVD, under different values of IDP, at a set compression. In addition it would measure the variation of IVD height, at different pressure conditions.

The future results provided by this new methodology could be important to understand and compare the influence of nucleus pulposus on the IVD loads response.

Moreover, the possibility of introduce fluids with higher viscosities than water (with a necessary apparatus adaptation), could be useful for analysis of the effect of the insertion of different material, such as hydrogel, as NP substitute.

This new pressure apparatus has still the potential to provide new insights about the mechanisms of IVD failure, namely about the values about what is the pressure it support, and, if associated with a microstructural analysis, to assess the information about possible critical points on annulus fibrosus.

Since it is an on-going procedure, it is possible to optimize it. In future improvements, it is planned to adapt a video recording system, which would provide a better comprehension about the phenomenon that occur on disc when it is pressurized, such as the IVD swelling and hypothetical disc rupture.

Finally, the optimization of the methodology presents a great interest, since it would give the values which a NP substitutes could expand once inside the IVD.

## ACKNOWLEDGEMENTS

This work was performed within the project “NP Mimetic – Biomimetic Nano-Fibre Based Nucleus Pulposus Regeneration for the Treatment off Degenerative Disc Disease”, funded by the European Commission under FP7 (grant NMP-2009-SMALL-3-CP-FP 246351).

## REFERENCES

[1] H. Schechtman, P.A. Robertson, & N.D. Broom, “Failure strength of the bovine caudal disc under internal hydrostatic pressure”, Journal of Biomechanics, 39, 8, 1401–1409, 2006.

[2] H. J. Wilke, P. Neef, M. Caimi, T. Hoogland, & L. E. Claes, "New in vivo measurements of pressures in the intervertebral disc in daily life", Spine, 24, 8, 755–762, 1999.

[3] A. Nachemson, G. Elfstrom, "Intravital dynamic pressure measurements in lumbar discs. A study of common movements, maneuvers and exercises", Scand J Rehabil Med Suppl, 1, 1–40, 1970.

[4] A. Castro, W. Wilson, J. M. Huyghe, K. Ito, J. L. Alves, "A Poroelastic approach for an open source finite element model of the intervertebral disc", Proceedings of CMBBE2012 Symposium, 2012.

[5] J. Pospiech, D. Stolke, H. J. Wilke, & L. E. Claes, Intradiscal pressure recordings in the cervical spine. Neurosurgery, 44, 2, 379–384, 1999.

[6] F. Heuer, H. Schmitt, L. Claes, & H. J. Wilke, "Creep associated changes in intervertebral disc bulging obtained with a laser scanning device", Clinical Biomechanics, 22, 7, 737–744, 2007.

[7] C. R. Dennison, P. M. Wild, P. W. G. Byrnes, A. Saari, E. Itshayek, D.C. Wilson, Q.A. Zhu, M.F.S. Dvorak, P.A. Cripton & D.R. Wilson, "Ex vivo measurement of lumbar intervertebral disc pressure using fiber-Bragg gratings", Journal of Biomechanics 41, 221–225, 2008.

[8] N. H. Campbell-Kyureghyan, S. V. Yalla, M. Voor, D. Burnett, "Effect of orientation on measured failure strengths of thoracic and lumbar spine segments", Journal of the Mechanical Behavior of Biomedical Materials, 4, 549-557

[9] M. A. Adams, D. S. McNally, P. Dolan, ""Stress" distributions inside intervertebral discs – The effects of age and degeneration", The Journal of Bone & Joint Surgery, 78-B, 965-72, 1996.