Biomechanical evaluation of a corporectomy in porcine lumbar specimens using flexible polymer belts.

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Abstract. This paper presents the experimental results of a biomechanical evaluation in lumbar porcine specimens (L2-L4), instrumented with flexible polymer belts, under fatigue and tensile loading. The clinical effect called facetary arthrosis is evaluated. An experimental analysis was carried on 3 lumbar porcine specimens. In two of them, polyamide belts are fixed on the interspinous ligament from L2 to L4. Specimens are taken from pigs which are 6 months old. For the present work, the stiffness reduction of the spine and the biomechanical behaviour of the belts in conjunction with the interspinous ligament are evaluated. The purpose is to determine the failure conditions for the elements of the specimen (vertebral disk, supra and intraspinous ligament and vertebral body). Under static loading, which is the base line case, the elements of the specimen failed as a typical healthy structure. While in the fatigue combined with static loading, the element failed in different order. Additionally, the stiffness changed in accordance with the fatigue loading conditions. Because of the simplicity of this alternative technique, a high level of the structural integrity is preserved, as no holes are made on the spinous process in order to insert the fixation screws. Furthermore, there is a cost reduction.

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1. Introduction

One of the most important topics in human health relates to the spine. Lumbar vertebrae diseases are the main causes of back pain. There are several factors which contribute to this, and can be classified on 6 levels: (1) **Idiopathic back pain**, associated to bad postural hygiene, obesity, pregnancy and an excessive endeavour; (2) **Traumatic back pain**, which can be associated with muscular tears, vertebral fractures, vertebral luxations, column sprains, rupture of vertebral disks, traffic accidents, vertebral nipping and working accidents. Fractured vertebrae or lesions can cause bone displacement and as a consequences different injures of the spinal cord and nerves, and hence paralysis, can be developed; (3) **Emotional disrupters and tension**, as depression, economic problems, personal disorders (schedules, diets) and lack of physical activity; (4) **Stress and back pain**, excessive physical work, constipation, working tension, insomnia, anorexia and weight loss; (5) **Degenerative back pain**, caused by excessive use and wear, arthritis and espondiloarthritis, *Disk degeneracy*: disk protusion, disk hernia, *nervous degeneracy*: Sciatica, Radiculopathies, *Arthritis*: Facetary and vertebral arthrosis. And lastly, (6) **other causes**, *congenital ones*: hypercifosis, scoliosis, the sacralisation of the fifth lumbar, the lumbarisation of the sacrum, hyperlordosis, rectifications, spondilolisis. *Espondiololistesis*: Anterolistesis, retrolistesis, spinal estenosis, bifid spine, infections, circulatory, post-surgical fibrosis, osteoporosis and tumours. [1]

Regarding this paper, Hyperlordosis is being considered, which in some cases, can also overload the facetary joint, and eventually, this can be affected by a facetary syndrome. This syndrome can also cause pain in the lower back and is referred as a pain in the legs.

![Figure 1. Lumbar vertebrae anatomy, showing main ligaments [2]](image-url)

Figure 1 shows the lumbar vertebrae anatomy of a human spine. The lumbar spine is a unique bony and ligamentous structure. It can withstand excessive loads while, simultaneously, neurologic functions are protected, providing flexibility and stability. This intricate interplay provides efficient motion and constant mobility among the different anatomic components of the lumbar spine.
The five vertebral bodies and intervertebral disks of the lumbar spine withstand significant physiological loads. The intervertebral segment of the lumbar spine consists of three characteristic articulations, the disk-vertebral body and two posterior apophyseal (facet) joints, which can resist high loads and stresses. The vertebral bodies are cylindrical masses of cancellous bone with a cortical shell. The disks consist of the annulus fibrous, the nucleus pulposus, and the cartilaginous and bony end plates of the vertebral bodies. In accordance to the figure 2, this complex bony anatomy serves as a load-bearing structure, a passive restraint to torsional strain and excessive tensioning of annulus fibrous, and as a means of protection against disk injury.

In order to establish the involved factors in the analysis of the mechanical effect, it is necessary to define the facetary arthritis as the degeneration of the cartilage that separates the joint formed by two superposed vertebral laminae [4]. Facetary arthritis is caused by normal wear of the cartilage in the facet joint. In young people, this cartilage is thick and cushions the burden borne by the joint, but it gets thinner through the time. It is normal to find a certain degree of thinning after 30 years.

According to Riew et. al [5], nearly 84% of people will experience back pain at some point in their lives. In a patient with reduced mobility, 16% of axial loading is supported by the vertebral column and is transferred to the facet joints. However, in extension, 47% can be loaded when the space between vertebral disks is limited or there is degenerative arthritis. In this way, the facet does not allow excessive movement in vertebral disks [6].

On the other hand, the most important consideration within medical treatment of the vertebral column is to preserve the human natural movement. One of the main injuries which affects it is the facetary arthritis and the replacement of the vertebral disk. It produces tensile forces on the vertebral surgery and the medical term is known as: arthrodesis.

In figure 4, the pain zone is located on the inferior side of the vertebral disk, as a consequence of the excessive movement and contact between facet joints, affected by arthritis and tensile loading. Mechanical pain occurs when damaged disks and joints, which connect the vertebrae, become inflamed from excessive motion of the vertebrae. This type of pain is commonly felt in the lower back and may radiate into the buttocks and upper thighs. In order to get more knowledge of the problem, a biomechanical study is required.

Medical treatments involve the use of alternative surgical techniques. This work is focused on the evaluation of the space reduction caused by facetary arthritis testing lumbar porcine specimens instrumented with polyamid collars. This reduces the space between facet joints and contributes to
the vertebral fusion. The affected lumbar zone is stabilised, and, at the same time, the use of external
distracters is avoided and no holes are made on the facet joints. Corporectomy is associated to the
surgical technique used by medics in order to fix polymer belts between vertebral body and ligament.s.
[9]

Figure 3. Facet joint movement, affecting the lumbar zone [5]

Figure 4. Facet joint movement, affecting the lumbar zone [7]

2. Materials and Methods

2.1 Testing conditions.

Three porcine lumbar specimens, which are six months old, were considered. In all cases muscles
were removed and the interspinous and supraspinous ligaments were not affected. For the first
specimen any collar was used. However, two polyamide 6/6 collars, fixed on L3-L4 and L4-L5
interspinous ligaments, were used on the other specimens. This constrains the movement for the
spinous process. In figures 5 and 6 is shown the testing arrangement.

Figure 5. Lateral view. a) Intact porcine specimen, b) Instrumented porcine specimens with polyamide
6/6 collars.
Figure 6. Posterior view. a) Intact porcine specimen, b) Instrumented porcine specimens with polyamide 6/6 collars.

Figure 7. Polyamide 6/6 collar used within the experimental testing. (Units in mm)

2.2 Analysed specimens

The loading conditions are shown in Table1. The first case is the base line analysis, because an intact specimen without any collar was tested under tensile loading. Its purpose is to evaluate the influence of the collar on the damage process. A maximum tensile load of 3000 N was applied. Regarding the other two specimens, which were not subjected to a preliminary fatigue analysis, it was carried on a preliminary fatigue analysis. In first instance, after applying a tension load, high cycle fatigue load was applied. By contrast, the third specimen was subjected to low cycle fatigue load. The failure conditions of the vertebral bodies are developed under these loads. All the tests were performed on an INSTRON 8501 universal testing machine, and the mechanical properties of the porcine specimens and polyamide 6/6 collar are shown on table 2.
Table 1. Loading conditions

| Condition | Loading condition |
|-----------|-------------------|
| Specimen 1 (figure 6-a) | Intact - removed muscle | Tensile static loading (up to 3000 N) - 1 mm/sec. |
| Specimen 2 (figure 6-b) | Instrumented with two Polyamide 6/6 collars | Tensile static loading - 1100 N. High cycle fatigue load - 1,000,000 cycles. Variable fatigue load from 1200 to 2000 N. Average load = 1600 N, amplitude = 400 N |
| Specimen 3 (figure 6-b) | Instrumented with two Polyamide 6/6 collars | Tensile static loading - 1100 N. Low cycle fatigue load - 100,000 cycles. Variable fatigue load from 1200 to 2800 N. Inverse positive relationship fatigue R = 0.42, average stress = 2000 N, amplitude = 800 N |

Table 2. Mechanical properties of the porcine specimens and polyamide 6/6 collar.

| Description | Mechanical properties |
|-------------|-----------------------|
| Polyamide 6/6 collar | Maximum tensile strength 227 N 20000 hrs at 85 ºC |
| Legrand colring polyamide 6/6, catalogue 320 43.[8] | |
| Cancellous bone | Porcine specimen | Young’s Modulus 466 MPa [9] Poisson’s Ratio - 0.2 |
| Cortical bone | Porcine specimen | Young’s modulus 12 GPa Poisson’s ratio - 0.2 [10] |

Cast plaster, was used to fix the specimens on the clamps. In all the tests, the structural integrity among the clamps and the specimens was maintained.

Figure 8. Specimen loading conditions. a) Instrumented specimens, b) Aluminium clamps.
3. Results

Main results of the three porcine specimens are summarized in table 3, in accordance with the loading conditions of table 1.

**Table 3. Experimental results**

| Specimen | Condition                                      | No. Cycles reported on the testing | Failure load                                                                 |
|----------|------------------------------------------------|-----------------------------------|-----------------------------------------------------------------------------|
| 1        | Intact - removed muscle – figure 6-a.         | N/A                               | - Vertebral disk was broken at 1287 N<br>- Intraspinous ligament was broken at 2686 N<br>- Cortical bone (Vertebral body) was broken at 3000 N (separar cada elementos y sus no de ciclos) |
| 2        | Instrumented with two Polyamide 6/6 Collars   | 867496                            | - Vertebral disk was broken at 1215 N<br>- Intraspinous ligament was broken at 1834 N<br>- Cortical bone (Vertebral body) was broken at 1986 N<br>- The collar was unbroken. |
| 3        | Instrumented with two Polyamide 6/6 Collars   | 26895                             | - Vertebral disk was broken at 1386 N<br>- Intraspinous ligament was broken at 2386 N<br>- Cortical bone (Vertebral body) was broken at 2750 N<br>- Collar was broken at 2580 N. |

All the tests were stopped when the ligaments were broken. In particular, the collar was unbroken in the second test. On the other side, when the fatigue load was increased, the number of cycles diminished considerably and the collar was broken after the ligaments and vertebral bodies failed.

![Mechanical Stiffness behaviour](image)

**Figure 9.** Mechanical Stiffness behaviour for the tested specimens.
4. Discussion

In accordance with the results shown on the Table 3 and figure 9, several aspects of the mechanical behaviour for the instrumented porcine specimens can be discussed:

The stiffness of the intact specimen is the base line for the rest of instrumented specimens on the mechanical testing. The influence of the high and low cycle fatigue loading on each test show different mechanical effects over the specimens. The results show that the stiffness is reduced as the number of fatigue cycles increases. At this respect, it can be said that the accumulated damage can be evaluated as a function of the stiffness reduction. In this way, figure 9 may give a glance of the damage introduced by fatigue loading.

Regarding the high loading conditions and low cycle fatigue, the cortical bone of the vertebral body was broken at a lower load than in the static test in which no belts were used. Nevertheless, the behaviour of the vertebral disk is similar to that experienced in static conditions.

On the other hand, as the number of fatigue cycles is reduces, the stiffness of the instrumented vertebral body increases. In this case, the polyamide collar was broken after the supraspinous and intraspinous ligaments were damaged.

5. Conclusions

Facetary arthrosis was defined as a complex syndrome which degenerate the integrity of the structure of each vertebrae [11]. The alternative surgical technique using polyamide collars referred in this work contributes to reduce this disease. In general terms, the polyamide collar contributed to reduce the space between damaged lumbar vertebrae. However, the resultant arrangement has a complex geometry. Accordingly, the mechanical behaviour was evaluated considering the relation between the applied load and the clamps displacement.

In all the cases, the applied loads were in the range in which failure of the vertebral components is expected. The collar was broken when static load was combined with high stress fatigue loading. According to these results, it is expected that under normal loading conditions, the integrity of this arrangement is maintained.

One point of concern relates to the damage introduced as the number of fatigue cycles is increased. This has to be analyzed in more detail in future work, as well as the effects of torsion and bending.

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