COMPARATIVE STUDY OF THE FATIGUE BEHAVIOUR OF ARTIFICIAL KNEE LIGAMENTS ACCORDING THEIR STRUCTURE

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INTRODUCTION:

While the first artificial ligament was implanted in 1906 (Hertz – 1906), and in spite of many researches, the replacement of natural ligament by a prosthetic substitute, with acceptable reliability, remains a real problem. Surgeons and Bio-engineers have to take up a true challenge to design an efficient substitute, as the natural structure, while known, remains to complex to be duplicated.

Thus, some synthesis materials are commonly used (polyethylene terephthalate, polytetrafluorethylene, polyethylene, polyester, polypropylene, carbon fibers), with knitted or yarnd filaments. Their technical performances must be checked by clinical application results or by tests on walk-simulation device, comparatively with those of natural ligaments, particularly in their ability to withstand mechanical ageing.

A clinical approach by Beaupré and al. (1991) on artificial knee ligaments implanted in Canada or in France over 3 months to 3 years shows that failures occur mainly by breakage (66%), while synovias (12%), excessive extension (18%) or defective implantation (10%) remain minority cases. This study points out clearly the importance of mechanical aspect of failures. Main ruptures are observed in tibial or femoral tunnels or at their emergence, where wearing and fatigue mechanisms are crucial.

A knee ligament have to endure 3 basic stresses: traction, flexion and torsion, to which can be added concomitant wearing against tibial and femoral tunnels or between filaments themselves.

An experimental approach of fatigue and fretting degradation must be performed to know the reliability of artificial knee ligaments. The best technical solution will be those leading to a minimum movement at the emergence from bone tunnel and a limited friction between filaments.

These remarks lead to the designing of “free filaments” LARS ligaments. Their structure is dual as the intra-articular region is made of pre-twisted (right or left), longitudinal and parallel unknitted filaments while the ends of ligaments are knitted (inside and at the emergence from bone tunnels).
The originality of this structure lies in its ability to endure flexion and torsion, thanks to the pre-twisted filaments in the intra-articular part, with a limited wearing at the end of bone tunnels. Moreover, fretting between fibres frequently observed on traditional knitted ligaments (between longitudinal and transverse filaments) could be decreased or cancelled.

A comparative study of fatigue behaviour of traditional knitted ligaments and ‘free filament’ LARS ligaments is carried out to check these points.

**TEST PROGRAM:**

In order to stick as much as possible on in-vivo conditions, the fatigue test includes the 3 previously mentioned stresses: traction (constant to 20 daN), torsion (±15° around the neutral position of the ligament) and flexion (0° - 30°).

Two poly-acetal cylinders, drilled at the same diameter as in practical surgery conditions, are used to simulate bone tunnels.

The intra-articular zone is set to 30 mm by positioning the upper and lower poly-acetal cylinders.

Physiological serum is sprayed continuously on the ligament during the test in order to maintain its humidity.
Our fatigue equipment can test 2 samples simultaneously in the same conditions.

Movements are applied at a frequency of 3Hz, giving a light acceleration of walk rhythm without any risk of local heating.

Four types of ligaments are tested: LARS PC 80 and AC 100 ligaments and 2 wholly knitted ligaments.
RESULTS:

The fatigue behaviour of knee ligaments is quite dependent on their structure (with or without free filaments), as much for the lifetime as for their degradation modes. As mentioned in the following boards, ligaments with free filaments lead to a better fatigue behaviour if we compare to traditional knitted ligaments. Abrasion at the emergence from bone tunnels and degradation in the intra-articular zones by fretting between filaments occur later in the lifetime. After 10 millions of cycles, in spite of some ravelling is observed on intra-articular filaments coming from fretting mechanism between fibres at the junction between the knitted and the unknitted parts, and local squeezing at the end of bone tunnel, the mechanical integrity of LARS ligaments is not altered. Comparatively, traditional ligaments show important ravelling and fibre failures after 5 millions cycles; these degradations increase drastically after 8 and 10 millions cycles.

Knitted ligaments:

<table>
<thead>
<tr>
<th>Cycles (millions)</th>
<th>End of bone tunnels</th>
<th>Intra-articular zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Fibres squeezing without breakage</td>
<td>No degradation</td>
</tr>
<tr>
<td>5</td>
<td>Important squeezing with breakage</td>
<td>No degradation</td>
</tr>
<tr>
<td>8</td>
<td>Fibres failure by abrasion</td>
<td>Ravelling</td>
</tr>
<tr>
<td>10</td>
<td>Important reduction of section</td>
<td>Important ravelling</td>
</tr>
</tbody>
</table>

LARS ligaments:

<table>
<thead>
<tr>
<th>Cycles (millions)</th>
<th>End of bone tunnels</th>
<th>Intra-articular zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>No degradation</td>
<td>No degradation</td>
</tr>
<tr>
<td>5</td>
<td>Light fibres squeezing</td>
<td>No degradation</td>
</tr>
<tr>
<td>8</td>
<td>Fibres squeezing with some fibres failures</td>
<td>Tendency to ravelling</td>
</tr>
<tr>
<td>10</td>
<td>Fibres squeezing with some breakage</td>
<td>Light ravelling</td>
</tr>
</tbody>
</table>
"FREE FILAMENTS" LARS LIGAMENTS

Limit of the knitted zone (10 millions cycles)

Intra - articular zone (10 millions cycles)

Emergence from bone tunnels (10 millions cycles)
KNITTED LIGAMENTS

End of bone tunnels (10 millions cycles)

Evolutions of the residual traction resistance, measured after 10 millions cycles, show a great degradation of knitted ligaments and a better behaviour of LARS ligaments. While knitted ligaments residual strength decreases of about 30 to 40%, this variation reaches only 10 to 15% on free filaments ligaments.

CONCLUSION:

Tests performed over combined traction, torsion and flexion show the improved fatigue behaviour of free filaments ligaments. This global result is imputed to the limitation of ligaments mobility at the emergence of bone tunnels, leading thus to a decrease abrasion. The pre-twisted free filaments provide a large possibility to endure intra-articular movements without induced movements on the knitted parts of the ligament, whereas on wholly knitted ligaments these movements are completely transferred to the length of ligament, leading to early degradation. Moreover, free filaments are less sensible to breakage by fretting between fibres in the intra-articular zone as only longitudinal filaments are in contact. In traditional ligaments, shearing between longitudinal and transverse fibres leads to the bad results observed after 10 millions cycles.

No doubt that free filaments ligaments offer new possibilities in the development of artificial ligaments as a better reliability is obtained.