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Biaxial stretching of poly(L-lactide) tubes for improvement of mechanical properties

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INTRODUCTION
Poly(L-lactide) (PLLA) is a semi-crystalline bioabsorbable polymer, which has been widely investigated for medical devices despite its inferior stiffness and strength compared with conventional materials such as metal alloys1. Due to the semi-crystallinity behaviour of the polymer, strain-induced crystallinity is expected to improve such mechanical properties by orientation of the crystals as seen in biaxial films2,3. The objective was to investigate improvement of mechanical properties and the changes in crystallinity, crystal size and orientation in simultaneous biaxial strained PLLA tubes.

EXPERIMENTAL METHODS
PLLA (2003D) was extruded into tubes (OD 3.4mm). The tubes were heated to 74°C and longitudinally strained while applying internal pressure, initiating a tube expansion in the heated zone, resulting in a simultaneous biaxial strain.

The degree of strain in each direction is noted as the ratio between the longitudinal and radial strain (LxR). Mechanical testing was conducted to evaluate material properties and the effect of orientation. Orientation and crystal size was determined by X-ray diffraction (XRD), while total crystallinity (Xc) was determined by differential scanning calorimetry (DSC).

RESULTS AND DISCUSSION
Tensile testing of specimens in the circumferential direction show the typical strain hardening behaviour of a semi crystalline polymer, but this is not seen for specimens tested in the longitudinal direction. The elastic moduli (Fig.1) in the circumferential direction were superior to the modulus in the longitudinal direction at all times, due to the higher degree of strain in the given direction. Also the modulus is improved with degree of total area expansion, whereas the LxR ratio does not determine the properties. The yield stress is less affected by the total area expansion (Tarea).

Xc does not increase with the degree of Tarea or LxR ratio, and the improved stiffness of the tubes is therefore not explained by neither crystal orientation nor an increase in strain-induced crystal formation.

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Fig 2: Intensity plot obtained from XRD of tubes with a different L/R ratio.

CONCLUSION
By biaxial stretching PLLA tubes improvement of stiffness and strength was obtained in both directions. Longitudinal stretching leads to crystal orientation in that given direction. Crystal orientation gained from this strain is reduced by degree of radial strain and altering the crystal alignment longitudinally. Xc does not increase with degree of radial strain and the improved properties are therefore not related to the crystal orientation nor a higher degree of crystallinity, but possibly stretching of the amorphous regions.

REFERENCES
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