WET SPINNING OF COLLAGEN MULTIFILAMENT YARNS.

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ABSTRACT

Fiber based scaffolds for tissue engineering applications manufactured through textile technologies feature an anisotropic, highly porous, and controllable macro-, micro-, and nanostructure. For the fabrication of fiber based collagen scaffolds, collagen multifilament yarns are required. The paper summarizes a scalable collagen multifilament yarn production method. Collagen yarn production was realized via wet spinning and a 3D printed spin packs comprised of coaxial nozzles. Mechanical, thermal, structural, and biological characteristics of wet-spun collagen yarns are given.

Key Words: collagen, wet spinning, biomimetic, scaffold, tissue engineering,

1. INTRODUCTION

Collagen has been widely studied for tissue engineering applications. Regarding the preparation of scaffolds for tissue engineering applications collagen has typically been processed into gels, membranes, and sponges [1]. In fewer cases, short fibers [2–7] and endless filaments [8–12] were prepared, which may be fabricated into fiber based scaffolds featuring a high surface-to-volume ratio and a well-defined fiber structure. However, due to the lack of suitable spinning devices and methods, collagen multifilament spinning could not be implemented. In here, a collagen multifilament wet-spinning method, its crosslinking method and the applied 3D printed spin packs are briefly summarized.

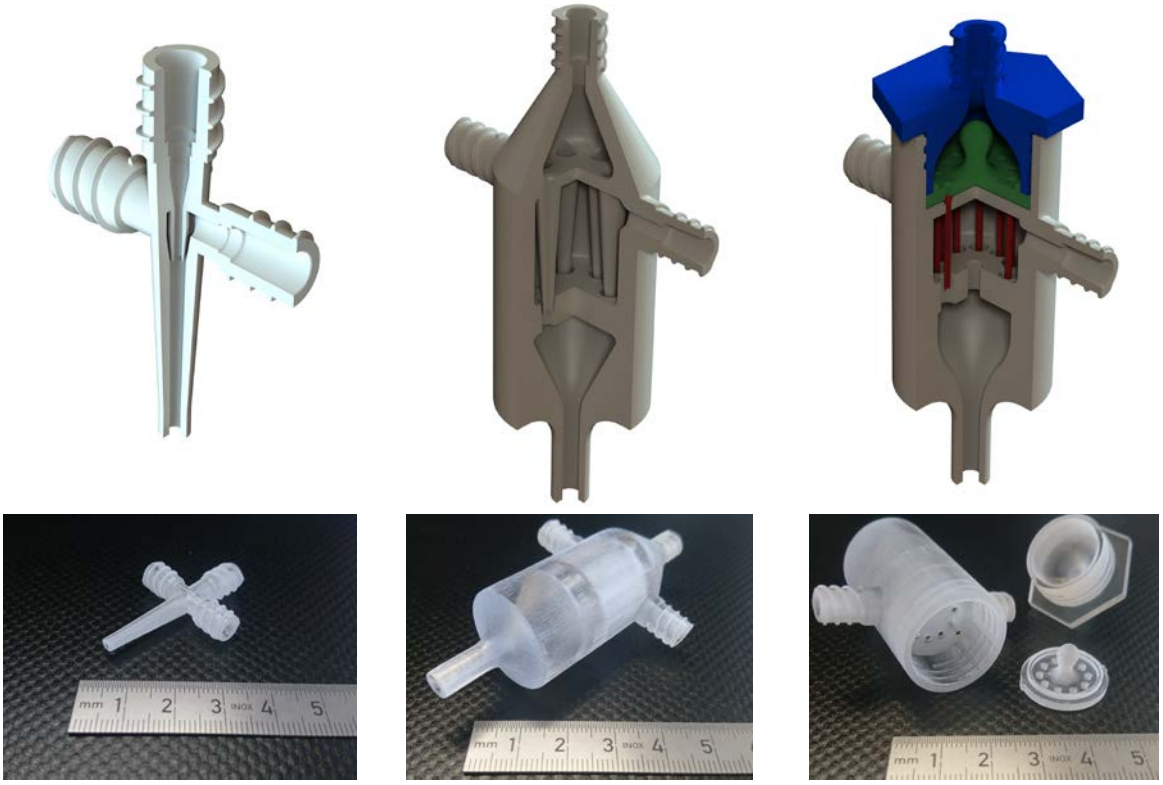
2. METHODS

The spinning dope was prepared by dissolving acid-soluble type I/III collagen from bovine skin (Collagen MDP from GfN Herstellung von Naturextrakten GmbH, Germany) to yield a collagen concentration of 2 wt. %. The coagulation medium was prepared according to the literature [10], had a pH of 7.4 and consisted mainly of polyethylene glycol (10 wt. %) and sodium phosphate.
Collagen multifilament yarns were produced on a laboratory wet spinning line, which consisted of a specially designed spin pack comprised of several internal channels and coaxial nozzles, a long coagulation tube (internal diameter 3.5 mm, length 1.2 m), washing baths, a drying section and a winding unit (production rate 14 m/h). Spin packs were 3D printed (Objet30 Prime from Stratasys).
Filament formation was achieved as follows. The spinning dope was flowing through the core and the coagulation medium through the sheath of each nozzle within the spin pack. Driven by the coagulation medium flow, filaments from each nozzle were drawn into the coagulation tube, wherein complete coagulation was achieved by collagen self-assembly within 5 min. Subsequently the yarn was washed, dried, optionally cross-linked in-line and finally wound on a spool. Crosslinking was achieved by employing glutaraldehyde or by a combination of riboflavin and UV radiation.

In here, the spin pack design of the wet spinning line as well as mechanical (tensile tests), structural (scanning electron microscopy), and cytotoxic (cell culture) properties of the collagen yarns are briefly summarized.

3. RESULTS

A facile wet spinning method was developed to prepare collagen multifilament yarns. Wet spun collagen yarns were comprised of 1 to 10 filaments, depending on the applied spin pack and its nozzle count. The single filament fineness was 5 tex and the diameter 80 µm. The tensile strength of the yarns was 12 cN/tex. For decreasing swelling ratio in water and increasing its stability under wet conditions, yarns were cross-linked by glutaraldehyde or by riboflavin and UV radiation.



a **b** **c**

Figure 1 Cross-sectional models and photographs of a monofilament coaxial nozzle applied for monofilament spinning (a), a multifilament single-piece spin pack applied for multifilament spinning (b) and a multifilament multi-piece spin pack with inserted metal nozzles applied for advanced multifilament spinning (c). Spin packs were 3D printed.

The spin pack concept was developed starting with a monofilament coaxial nozzle, which was fed by two distinct pumps supplying the spinning dope (center inlet) and coagulation medium (two side inlets), only capable of producing a single filament (Figure 1 a). Based on this concept, a multifilament spin pack was developed, enabling the production of multifilament yarns. It was comprised of several coaxial nozzles, two storage chambers ensuring a homogeneous distribution of pressure of the two liquids and a filament collecting chamber immediately before the tube entrance (Figure 1 b). As the applied 3D printing technology is limited to the generation of relatively large nozzle diameters (1 mm) the spin pack was refined in such a way that smaller nozzle inserts can be applied after 3D printing. Therefor the single-

piece multifilament spin pack was changed into a multi piece design comprised of several metal nozzle inserts featuring small diameter (< 0.8 mm), a fixation plate and a screw cap (Figure 1 c).

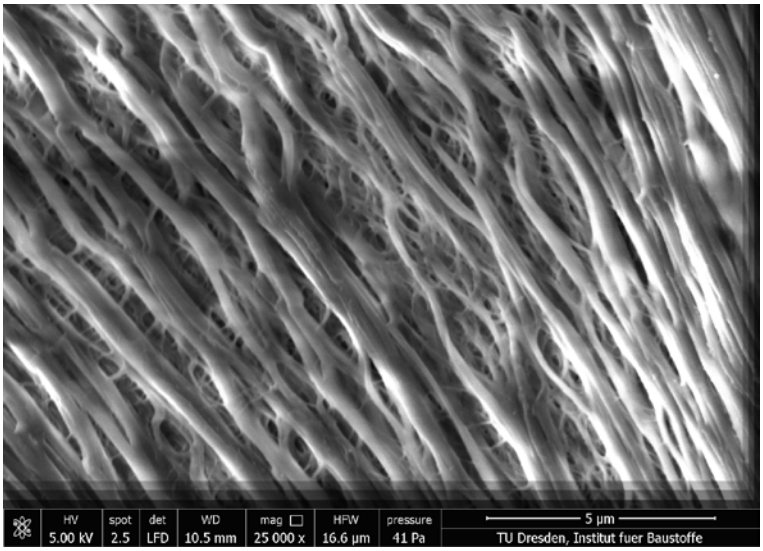
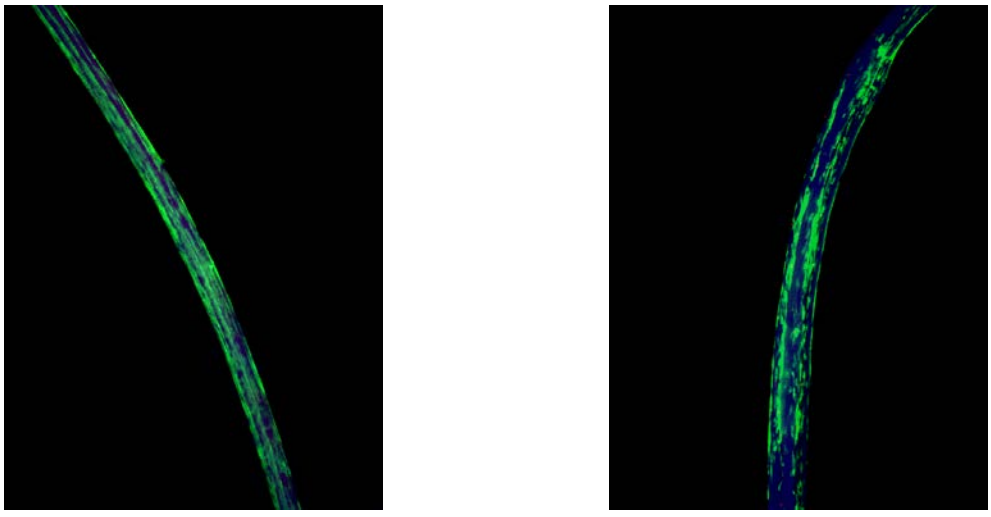


Figure 2 Scanning electron microscopy image of the surface structure of a wet-spun collagen filament

Scanning electron microscopy images revealed the fibrillar structure of the collagen filaments, which arises from the self-assembled collagen molecules. The filaments were formed from an anisotropic fibril network aligned along the fiber axis, which consisted of larger fibrils (diameter 100…500 nm) on the surface and smaller fibrils (diameter < 100 nm) underneath (Figure 2).



a **b**

Figure 3 Confocal LSM image stacks of glutaraldehyde cross-linked and riboflavin/UV-light cross-linked collagen monofilaments on day 14 after seeding with human mesenchymal stem cells. Actin cytoskeleton of cells stained appear green, cell nucleus appear blue, and collagen appears blue (autofluorescence). The diameter of the filaments is 80 µm.

Biocompatibility of the cross-linked collagen filaments was analyzed by the response after seeding the filaments with human mesenchymal stem cells. The viability of cells was visualized

by staining. After a cultivation period of 14 days, cells were spread out on the entire surface of the filaments, showed an elongated shape and were aligned along the fiber axis (Figure 3).

A detailed description of collagen yarns cross-linking as well as its biocompatibility towards human mesenchymal stem cells can be found in a previously published article [13] and of multifilament collagen yarns as well as its fibrillar structure can be found in a previously published article [14].

3. CONCLUSION

The collagen yarn production approach proposed above leads to the conclusion, that collagen filaments can be successfully manufactured by wet spinning. A scalable production of collagen multifilament yarns is facilitated by a specially designed spin pack. The applied collagen type I/III and the yarns produced on the basis thereof are considered suitable for medical applications as tissue engineering. The availability of collagen multifilament yarns and its production method enables the fabrication of collagen fiber based scaffolds by conventional textile manufacturing processes.

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