# Spectra analysis of allogenic coating of combined biosyntetic mesh implants

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## Objective of the work

To evaluate the feasibility of usinf vibrational spectroscopy for assesing the quality of allogeneic coatings on combined mesh implants.

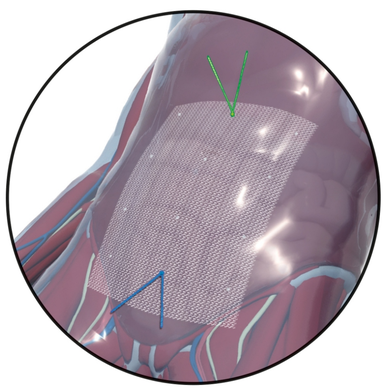

*Figure 1 – Experimental stand implementing the Raman spectroscopy*
*1 – the object under study; 2 – the RPD785 fiber-optic probe; 3 – the Shamrocksr-303i spectrograph; 4 – the DV420A-OE cooled chamber; 5 – the LuxxMasterRamanBoxx - 785.0RB-04 laser module; 6 – the laser module power supply; 7 – the computer; 8-10 – the information electrical cables; 11 – the coordinate table*

To mitigate the foreign body response and chronic inflammation induced by synthetic hernia meshes, a PVDF-based allogeneic biosynthetic implant with a human tissue-derived biocoating has been developed, necessitating rigorous quality assessment as a critical step in its clinical translation.

## The materials of the study

The study used uncoated synthetic polyvinylidene fluoride (Uniflex) implants, a synthetic polyvinylidene fluoride (Uniflex) implant with a collagen-containing hydrogel coating, and a collagen-containing hydrogel derived from human tendons. The samples were divided into 3 groups: **group 1 – collagen-containing hydrogel from human tendons, group 2 – mesh implant made of polyvinylidene fluoride – PVDF (Uniflex) with collagen-containing hydrogel from human tendons, and group 3 – mesh implant made of polyvinylidene fluoride (Uniflex)**.

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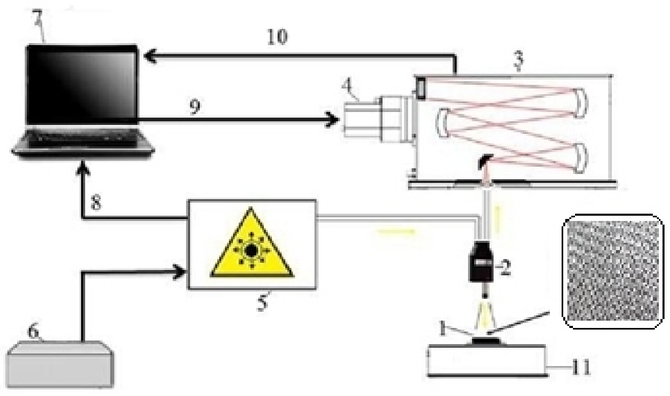


*Figure 2 – Experimental stand implementing the IR-spectroscopy*
*The stand consists of:*
*FT-801 Fourier Spectrometer (manufacturer: NPF "SIMEX" LLC, Novosibirsk), the FT Spectrometer belongs to the class of modulation spectral devices. As a modulator, a two-beam scanning interferometer "Double Cat's Eye" (Russian Patent No. 1552791, 1993) is used, which is resistant to misalignment; NPVO attachment with a diamond measuring element; a personal computer with specialized software..*


The Raman spectra were analyzed in the range of 400-1800 $cm^{-1}$. The laser power was 400 mW. The Raman spectra were recorded using an optical probe that was positioned 7 mm above the object.IR spectroscopy of the samples was performed at a spectral resolution of 8 cm-1, and the number of scans (accumulations) for obtaining the spectra was 100. The analysis of absorption bands was performed in the range of wave numbers 1000-1800 $cm^{-1}$, which is the most informative for most functional groups. Before measuring the samples, it was necessary to record the background spectrum (a pure diamond element) for subsequent automatic compensation.
The spectra of each sample were recorded in 3–5 repetitions to assess the reproducibility.

## Experimental results

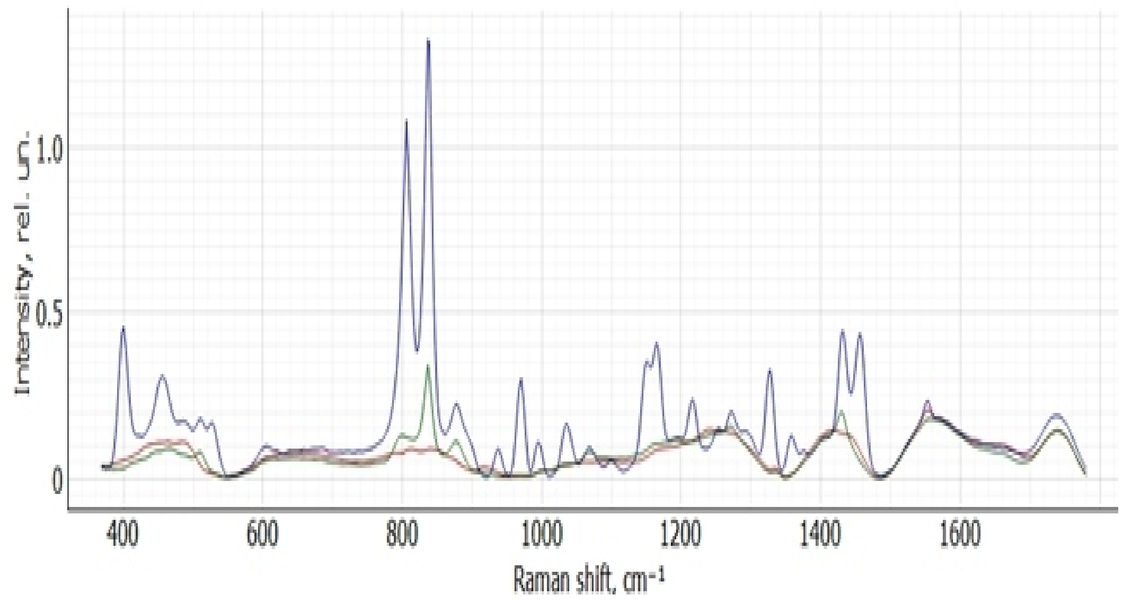


*Figure 3 – Average Raman spectra of the studied samples: red – collagen-containing hydrogel from human tendons; blue – mesh of PVDF implant; green – mesh of PVDF implant with collagen-containing hydrogel from human tendons*.

**Mesh made of PVDF:** ~810 $cm^{-1}$ ($CH_2$ rocking, α-phase), ~840 $cm^{-1}$ ($CF_2$ stretch β/γ), 881 $cm^{-1}$ (β-phase), ~974 ($CH_2$ α), ~999 $cm^{-1}$ (F–C–Cl skeletal), ~1065 $cm^{-1}$ (C–C skeletal), ~1153 $cm^{-1}$ (antisym. C–C + sym. $CF_2$), ~1200–1290 $cm^{-1}$ ($CF_2$ β), ~1332 $cm^{-1}$ (P=O and C–F), and ~1450–60 $cm^{-1}$ ($CH_2$ scissoring). The Raman spectra of the gel and the gel applied to the mesh implant are nearly identical over the entire 400–1800 $cm^{-1}$ range, except for the bands at ~810 $cm^{-1}$, ~840 $cm^{-1}$, and 881 $cm^{-1}$.
**The collagen-containing gel** and **the gel deposited on the implant surface** share common protein/collagen type I bands: 618 $cm^{-1}$ (C–C twisting, protein), ~859, ~921, and ~1429 $cm^{-1}$ (collagen I vibrations), ~1152 $cm^{-1}$ (C–N, protein), ~1250 and 1270 $cm^{-1}$ (collagen Amide III), 1335 $cm^{-1}$ ($CH_3CH_2$ wagging, collagen), ~1554 $cm^{-1}$ (Amide II), and ~1661 $cm^{-1}$ (collagen Amide I), with the main peak positions being identical for both samples.

LDA showed that the first two discriminants account for 97 % of the variance (93 % – LD1, 4 % – Ld2), with LD1 indicating similarity between **the gel and the gel-coated implant** due to contributions **from 859 $cm^{-1}$** (Collagen I) **and 1554 $cm^{-1}$** (Amide II), while the LD2 differences (4 %) arise from the PVDF implant bands: ~810 $cm^{-1}$ ($CH_2$ rocking, α-phase), 881 $cm^{-1}$ (β-phase of PVDF), and ~1153 $cm^{-1}$ (antisym. C–C + sym. $Cf_2$).

In the IR spectra of collagen, three main amide bands are observed — amide I (1600–1700 $cm^{-1}$, C=O stretch, ~80 % contribution), amide II (1500–1600 $cm^{-1}$, N–H bending + C–N stretch), and amide III (1200–1300 $cm^{-1}$, C–N stretch + N–H bending) — with the most native conformation and well-ordered secondary structure found for the combined PVDF implant with collagen gel, which exhibits splitting of amide II (1555 + 1543 $cm^{-1}$) and a shoulder at 1636 $cm^{-1}$ in amide I.

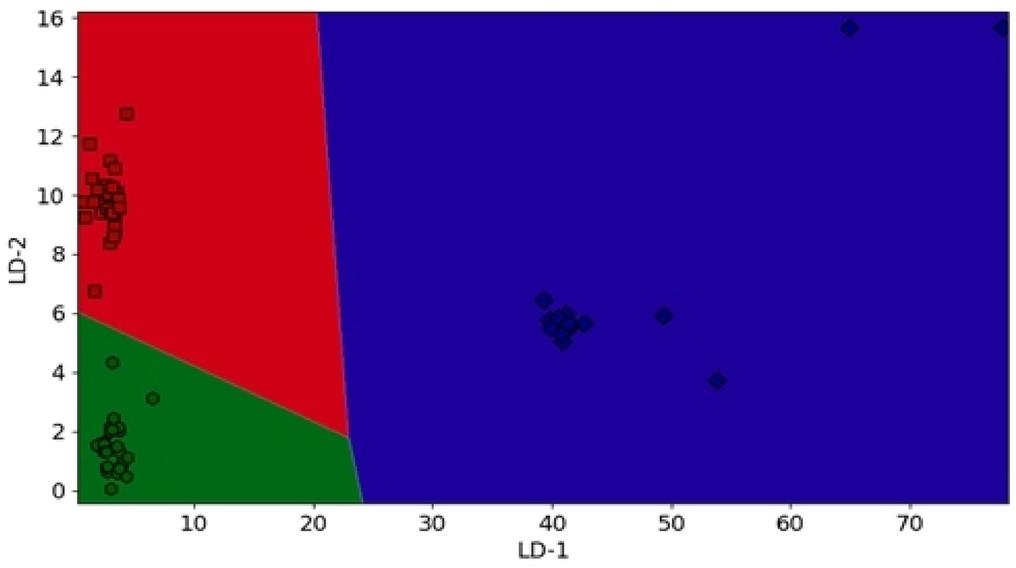


*Figure 4 – LDA-analysis of the studied samples: red – collagen-containing hydrogel from human tendons; blue – mesh implant; green – mesh implant with collagen-containing hydrogel from human tendons.*

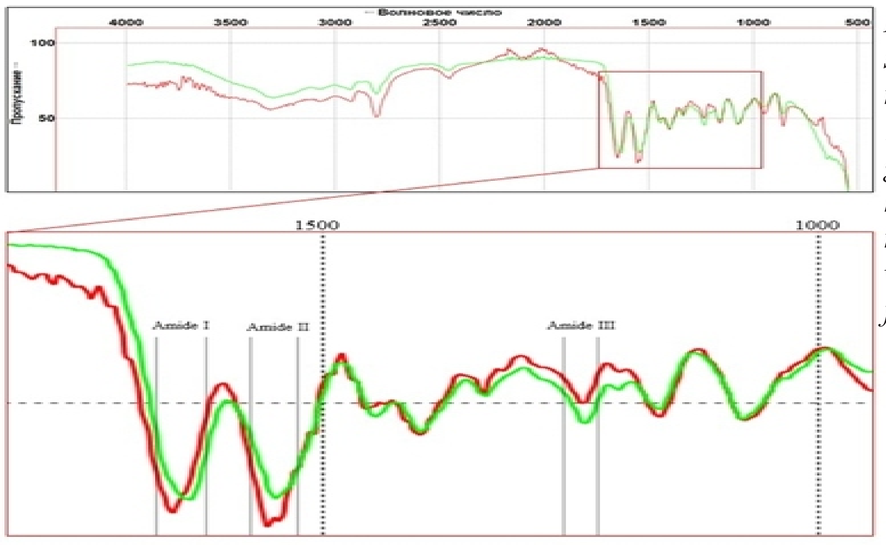


*Figure 5 – IR spectra of the studied groups of samples in the range of wave numbers (1800-1000) $cm^{-1}$:*
*green line – collagen-containing hydrogel from human tendons;*
*red line – mesh of PVDF implant with collagen-containing hydrogel from human tendons.*

## Conclusion

As a result of studies conducted using Raman spectroscopy and linear discriminant analysis, the spectral characteristics of a collagen-containing hydrogel applied to the surface of a mesh implant, as well as the gel in its pure form, were determined. The spectral similarity between these two groups is 93%, indicating a uniform distribution of the collagen-containing gel on the implant surface.
Using IR spectroscopy, it was established that applying a collagen-containing gel to a PVDF implant does not cause collagen denaturation and that collagen stabilization on the surface of the studied implant is observed. The combination of vibrational spectroscopy methods in conjunction with linear discriminant analysis represents an effective method for non-destructive quality control of biocoatings of biosynthetic mesh implants.