

Pressure Sensed Non-Invasively Directly On the Extra Corporeal Bloodline Tube

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Abstract-To clinically measure blood pressure at extra corporeal bloodlines involves a hazard due to the infection risk and a risk for thrombosis formation. The aim was to design a non-invasive pressure sensor, measuring directly on a tube section. A modified tube cross-section was used to improve sensitivity. Using the developed sensing principle, a consistent relation ($r=0.999$) was obtained between pressure and output signal. The output was stable and an acceptable drift within the temperature-range. The method shows great promise for applications in monitoring of the dialysis process.

I. INTRODUCTION

At certain clinical treatment modalities, extra corporeal tubing is extending the patients cardio-vascular system. Mainly two clinical objectives exist: to relief pumping of the heart, oxygenate the blood at surgery or to artificial mimic the renal function. At these occasions it is vital to accurately monitor the flow and pressure of the blood within the tubing. At haemodialysis, the common method of pressure measurement on the bloodline tubes is to connect an external pressure transducer via an airtrap. The added airtrap, complicates the tube-set, add costs and creates a risk for thrombosis formation. Furthermore, at the airtrap an added tube segment invokes a risk for infection. The aim of this work was to design a non-invasive pressure sensing principle where the pressure can be measured directly at a certain section of the tube.

II. METHOD

The idea was to estimate the pressure in the tube from the force created at the expansion. An increased tube expansion in a predefined direction due to intraluminal pressure was achieved by a modified tube cross-section. For a tube with uniform wall thickness, the expansion is axi-symmetric.

The investigation on the pressure measurement principle was divided in two parts:

1) macro scale investigation of the expansion of tubes with modified cross-section,

2) applying the findings to realistic tube size that can be used as pressure sensor primarily for dialysis tubes.

A modified macro scale tube cross-section with two thin sides was produced in silicone by choosing essentially an elliptical outer cross-section boundary and a concentric circular inner lumen (typical shape, see Fig.1). The inner radius was 7.5 mm for all tube configurations with values of the thin and thick segments as seen in Table I. To test for the most suitable tube cross-section configuration, a factorial experiment was performed [1]. The intraluminal pressure was related to tube expansion force measured with the tube enclosed in a rigid holder.

For the second part, the macro scale tube that was regarded optimal was scaled down to realistic bloodline size. The tube was then placed in a specially designed aluminium holder with surrounding stiff walls and a mounted force transducer element at the bottom (Fig. 1). A stiff aluminium lid with a lock was put on top of the tube to facilitate an easy tube assemblage. When applying a pressure in the tube, a force was generated on the force transducer. The holder-lid arrangement prevented tube expansion and was used to minimise the sensor's sensitivity to tube mechanical characteristics. The investigation of the sensor principle concerning the responses to pressure in the range 0-46.7 kPa (0-350 mm Hg) within temperature in the range 18-42 °C.

TABLE I
Constructions values for the modified tubes

Tube nr.	Thin segment (mm)	Thick segment (mm)
T6	0.5	2.0
T7	2.0	2.0
T8	0.5	3.0
T9	2.0	3.0
T10	1.25	2.5

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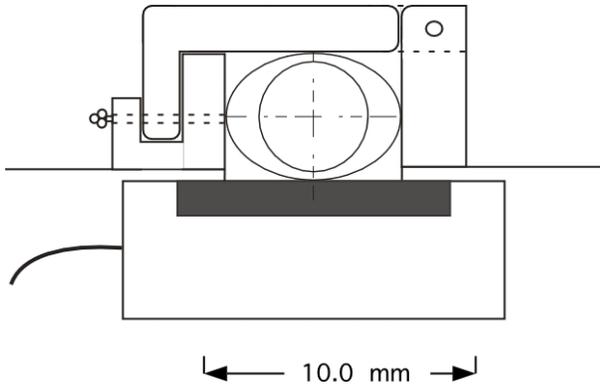


Fig. 1. Cross section view of the suggested pressure measurement principle. The tube with modified cross-section is enclosed in the tube holder. The shaded part below the tube is the transducer element.

III. RESULTS

The relation between the tube radial expansion and intraluminal pressure is non-linear for the large pressure range (0 - 44 kPa). The non-linearity gets more pronounced with decreasing thickness on the tube segments and arise at lower pressures as well. There is no significant difference ($p=0.05$) in radial direction expansion between the uniform tube (T7) and the tube with smallest thickness difference (T9).

Factor analysis reveals strong effect from tube configuration in respect to dimensional changes. An optimal tube cross-section was a geometry configuration with a wall thickness relation 0.5 between tubes thin and thick sides tube T10 in Table I.

In the investigation of the suggested pressure measurement principle, a linear relation ($r=0.999$) between pressure in the tube and detected force could be estimated, Fig. 2. With the tube wall thickness configuration the expansion pattern is altered. In the investigated temperature-range, the force response declines about 93 Pa (0.7 mm Hg) per °C, the output was stable at a distinct temperature.

IV. DISCUSSION

The first part in this study shows that we can find a tube with modified cross-section that for applied intraluminal pressure shows a higher controlled increase in radial dimension as compared to a circular tube with uniform wall-thickness. This expansion can be obtained in a predetermined radial direction and without obtaining axial bulging and other phenomena that disturb controlled expansion. This indicates

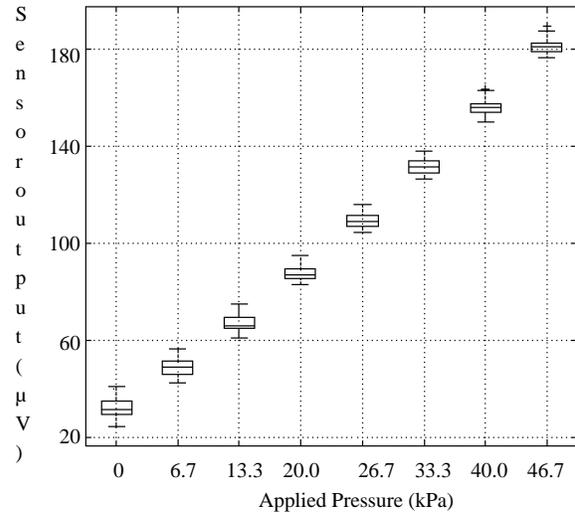


Fig.2. Sensor response to applied pressures the boxes represents 1.5 standard deviations.

that we can use the tube it self and its expansion as part of a pressure sensor in an extracorporeal tube line.

The suggested pressure sensor method uses a zero-balance technique, similar to the applanation method [2]. The restraining force detected on the transducer as an expansion force balance the intraluminal pressure. By this approach, the characteristics of the tube material should have minor effect as well as the temperature.

At haemodialysis, there are at least two crucial objectives to monitor the pressure at the bloodlines: patient security and treatment efficiency. The candula can lose its position at the fistula, partly or totally. The later can cause severe haemorrhage. Furthermore, the dialysis process uses a pressure gradient between the different compartments separated by the semi-permiable membrane in the dialyzer, a gradient that has to be monitored.

To transfer the conclusions in this study to tube with other diameter we regard this as a linear scaling problem. The reason behind this is that for the linear Hookean material approximation, the strain should be the same as long as the relation between tube diameter and wall thickness is kept constant. With similar reasoning regarding different tube material, the strain should be same as long as the relation between the applied pressure and Young's modulus is kept constant. A limitation here is that the tube material is non-hookean.

Other non-invasive methods have been investigated for bloodline pressure measurement, for example [3], [4]. These investigations have used a circular tube with uniform wall thickness. A disadvantage of this approach is the dependency

of the tube material characteristics as well as the temperature sensitivity.

V. CONCLUSION

The study shows that we can design a non-invasive pressure measuring principle which measure directly on a modified tube cross-section.

Using the sensing principle, a consistent relation was obtained between pressure and output signal. The output was stable and an acceptable drift within the temperature-range. The method shows great promise for applications in monitoring of the dialysis process.

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