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Stiffness measurements on spherical surfaces of prostate models, using a resonance sensor

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Abstract — Prostate cancer is one of the most common forms of cancer among men in Europe and the United States. Piezoelectric resonance sensors can be used in medical research for measurements of stiffness of human tissue. Cancer tissue is usually stiffer and has different biomechanical properties compared to healthy tissue. The frequency shift observed when a piezoelectric resonance sensor comes into contact with a tissue surface has been suggested to correlate with the stiffness variations, e.g. due to cancer. An instrument has been developed, with which it is possible to scan flat and spherical objects and where the sensor can be tilted for different contact angles. Measurements performed in this study on spherical tissue models made of silicone, showed the importance of keeping the contact angle perpendicular to the surface of the sphere. The results are promising for future studies on prostate tissue to complete the evaluation of the instrument.

Keywords — Resonance sensor, Piezoelectric, Prostate cancer, Detection, Frequency shift

I. INTRODUCTION

The use of piezoelectric resonance sensors for medical research in order to detect differences in stiffness in tissue has been shown by Omata and Terunuma [1]. The biomechanical properties such as stiffness of tissue can vary due to different pathophysiological conditions. The frequency shift observed when a resonance sensor comes into contact with tissue can be correlated to the stiffness of the tissue. This has been shown in previous studies and indicates the potential for several biomedical applications [2, 3, 4, 5]. For example, studies on prostate tissue show the possibility to differentiate between benign and malignant prostate tissue [6]. In a study where a resonance sensor probe was attached to a counter balance arm, the measured frequency shift was evaluated on silicone discs and prostate tissue [7].

Prostate cancer is one of the most common forms of cancer. The American Cancer Society estimates that about 218000 new cases will be diagnosed in the US during 2010 [8]. The situation in Sweden is that about 10000 men were

diagnosed with prostate cancer in year 2009, which was an increase by 18% compared to year 2008 [9].

Evaluation of a new instrument used for measurements on flat silicone models has been reported earlier [10]. To scan for the presence of cancer in the surface layer of the whole prostate after radical prostatectomy, a suitable instrument is needed. It is necessary to have a fixture that can both hold and rotate the prostate. The spherical shape of the prostate requires that the angle of the movement of the sensor must be adjustable, to keep it close to perpendicular towards the surface of the prostate during measurements.

The aim of this study was to evaluate a newly developed instrument for the possibility to distinguish soft and hard areas on spherical tissue models made of silicone.

II. MATERIALS AND METHODS

A. Theory

In this study, the piezoelectric material used as a resonance sensor was a ceramic made of lead zirconate titanate (PZT). A resonance transducer can be made by combining two PZT elements where one is used to generate oscillations and the other for detecting vibrations, as shown by Omata and Terunuma in 1992 [1]. Both PZT elements are connected to an electronic circuit, where oscillation is generated by an electronic feedback circuit consisting of an amplifier, a band pass filter and a phase-shift circuit. The signal from the pickup element is constantly transferred to the feedback circuit. A phase-shift circuit ensures that a zero phase condition is maintained between the pickup and drive signal. This keeps the whole sensor oscillating at its resonance frequency [10]. When the tip of the sensor comes into contact with a material, there will be a change in the frequency, Δf . A soft material that can be deformed by the sensor will result in an increase in frequency, and the opposite applies to a hard material [1].

B. Experimental setup

The sensor probe used in this study consisted of a piezoelectric resonance sensor (Morgan electro ceramics, Bedford, Ohio, USA) in the shape of a 15 mm long cylinder with the outer diameter of 5mm, and a strain gauge (PS-05KC; Kyowa, Tokyo, Japan) used as a force sensor. The sensors were mounted in a probe with an aluminium casing [7]. To make it possible to approach the measured object with different angles, the probe and the vertical translation stage were attached to a manual rotary stage (NT55-030; Edmund Optics, York, UK). For vertical movement a compact translation stage (VT-21; Micos, Irwin, PA, USA) was used. It was controlled by a motorized stage controller (Pollux Box; Micos, Irwin, PA, USA) with a resolution of 2.5 μm .

For movement in horizontal directions, two translation stages were used (M4424; Parker Hannifin Corporation, Daedal Division, Irwin, PA, USA). They were modified with stepper motors (17HD1008; Moons', Shanghai, P.R China) attached to the micro meter screws. All translation stages were controlled by a PC via a LabView® program (National Instruments, Austin, Texas, USA).

The signals from the piezoelectric sensor, the force transducer and the translation stages were collected at a sampling rate of 1 kHz, and fed into a computer with a data acquisition card (NI6036E; National Instruments, Austin, Texas, USA).

The developed instrument shown in Fig. 1 exemplifies measurements on a flat silicone model in a Petri dish that is attached to the mounting platform.

Fig. 1. The complete instrument in position to measure on a flat specimen. 1) Rotational stage, 2) Vertical translation stage, 3) Sensor probe, 4) Flat silicone model, 5) Horizontal translation stages, 6) Spherical silicone

model. The spherical model is covered in red rubber and the flat silicone has been covered by a yellow paper for better viewing.

In Fig. 2, the instrument is repositioned for measurements on spherical bodies, like a prostate gland. The object is held in position by two concave plates, of which one is spring loaded. The load of the spring is adjustable and the force by which the object is held was measured by a cantilever strain gauge (CEA-06-240UZ-120, Measurements Group Inc. Raleigh, NC, USA). The measured object could be rotated around its horizontal axis. The position of the sensor head for vertical movements is tilted so that the motion is perpendicular to the surface plane of the spherical silicone model.

Fig. 2. 1) The sensor in position for measurement at a predefined angle towards a spherical silicone model clamped in the holder. 1) Sensor head, 2) Clamps holding the sphere, 3) Spherical silicone model, 4) The vertical translation stage tilted at an angle, 5) Cantilever strain gauge.

C. Tissue models

Silicone models were found to be very suitable for evaluation of new sensor techniques regarding human soft tissue characterization [11, 12]. Silicones can be cast with different stiffness and it is also possible simulate areas of different stiffness by enclosing small pieces of harder or softer objects.

The silicone used in this study, was a two-component silicone (Wacker SilGel 612; Wacker-Chemie GmbH, Germany).

This silicone was used successfully in earlier studies by Eklund et al [11]. The mixing of the two components A and B at different ratios in accordance with the manufacturer,

gave different degrees of stiffness measured with DIN ISO 2137 using a 150g hollow cone [13]. The mixing of the silicone was done on a laboratory scale (BL 310; Sartorius GmbH, Göttingen, Germany) with a resolution of 0.01 g. For the spherical tissue model, a table tennis ball with the diameter of 40 mm served as a mould. A semi-soft silicone was used. To simulate a minor region with increased hardness near the surface of the sphere, a small piece of stiffer silicone was arranged on a thin (0.25 mm) wire inside the ball, (Fig. 3). Thereafter the mould was filled with silicone. The wire was removed after the silicone had cured and the plastic table tennis ball was carefully cut open to take out the silicone model.

Fig.3. Illustration of how a table tennis ball was used as a mould for casting spherical objects. 1) Table tennis ball, 2) An opening through which the silicone was to be poured. 3) A thin wire holding the inserted object in place during curing. 4) A small piece of stiff silicone. 5) Silicone filling.

D. Measurements

The stiffness of the silicone model used for the sphere was defined by the cone penetration value of $163 \text{ mm} \times 10^{-1}$, and the enclosed piece of a more stiff silicone had a cone penetration value of $49 \text{ mm} \times 10^{-1}$. Measurements were made with 6 repetitions in each position, with a period of one minute in between each measurement. Each measurement lasted 2 s and the total indentation depth was set to 0.6 mm at a constant penetration speed of 5 mm/s with a sampling rate of 1 kHz. From the measurements, the applied force, F , and Δf were obtained.

Measurements were made in 9 points with 2 mm apart, in a straight axial line across the sphere, with the stiff piece in the middle (at position 8 mm from the first measurement). The enclosed harder piece of silicone was not of a symmetrical shape. Two series of measurements were made. First the sensor tip was moved in a vertical direction, and a second where the angle of the sensor movement was adjusted so a perpendicular movement to the surface of the sphere was obtained. The points of contact were the same in both measurement series. The measurements with the vertical movement of the sensor towards the sphere resulted in varying angles of contact. The angles towards the surface

in the different positions were calculated to 67, 73, 79, 85 and 90 degrees, where 67° was in position 0 mm and 16 mm. The middle position, 8 mm, has the angle 90°, i.e. was perpendicular to the surface in both measurement series, Fig.4.

III. RESULTS

The results showed that the Δf reached a maximum at the midpoint and in vertical direction systematically deviated from the measurements perpendicular to the surface of the silicone (Fig. 4). For the F , the two measurements series showed a similar appearance (Fig. 5).

Fig. 4. Measurements on a spherical tissue model made of silicone. One series of measurements where the sensor tip moved vertically towards the sphere, and one where the sensor tip moved perpendicular to each point of contact on the sphere. The figure shows Δf (mean $\pm$ SD, $n=6$) in different positions of the sphere at the impression depth of 0.2 mm.

Fig.5. Measurements on a spherical tissue model made of silicone. Two series of measurements of F (mean $\pm$ SD, $n=6$) for the impression depth of 0.2 mm. Measurements were made both vertically towards the sphere and perpendicular to the point of contact.

IV. DISCUSSION

The results indicate that for this sensor system it was important to approach the measurement object perpendicular to the surface.

The Δf for the two measurement series differed significantly at several of the measurement locations on the silicone sphere (Fig.4). The contact angle that occurred due to the vertical movement resulted in a systematic error as compared to the measurements perpendicular to the surface. For the vertical measurements this was especially noticeable at measurements with a large deviation from perpendicular contact (measurement location 8 mm).

The force did not seem to be affected to a large extent by varying angles for the movement of the sensor tip (Fig.5). No systematic difference was seen between the two measurement series of F , as compared to the difference seen for Δf . The force sensor in this instrument was not sensitive to the contact angle, at least not for the angles studied.

From both Fig. 4 and 5 it was seen that the stiffer piece of silicone could be distinguished from the softer surrounding silicone, as an increase in both Δf and F .

V. CONCLUSIONS

A new resonance sensor instrument has been developed with the intention of including flexibility and many degrees of freedom. The motor controlled translation stages make it possible to measure from different angles on both flat and spherical surfaces. This study suggests that it is possible to measure stiffness of spherical objects with the developed instrument. The results indicate that it is important to obtain a perpendicular movement of the sensor tip relative to the surface of the spherical silicone model.

Further studies on tissue models and prostate tissue must be done to evaluate the contact angle sensitivity on spherical objects.

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