Decay of Tissue Mechanical Properties Over a 24-hr Period[1]

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1 Background

Soft tissue models are frequently used in surgical simulation [1] and have recently been applied to online tissue identification [2]. Despite this wide use, the fundamental premise of these models may be inaccurate. Current models are derived and validated from ex vivo tissue data, which literature suggests may be different from in vivo tissue [3]. Little work has been done to determine the true model parameters for tissue property decay, or to verify whether or not these model changes over time are significant. In this work, we assess the uniaxial stress–strain tissue properties of porcine liver for a 24-hr period postmortem.

2 Methods

A modified da Vinci Si EndoWrist® surgical grasper was used for all porcine data collection as shown in Fig. 1. A detailed design of this "smart" tool is found in Ref. [4]. Force and position data are collected directly from sensors on the tool. In this experiment, porcine liver was resected 10 min after euthanasia and data collection began immediately after resection. Data were collected at frequent time intervals after the initial data collection. These intervals are specified in Table 1; an additional grasp was taken 24 hrs postmortem. Immediately following the liver resection, the tissue was placed in a saline solution at a constant 37 °C in order to keep the tissue hydrated at temperatures similar to in vivo. For each new time interval, tissue was grasped once at a new location spaced evenly around the liver to avoid effects of preconditioning as explained in Ref. [3]. Tissue thickness was near-uniform at each grasp point and was measured to be 2.5 mm; the grasper area was measured and assumed constant at 15 mm^2.

Grasp data were segmented from first touch of tissue to fully closed via a postprocessing algorithm and fit to the nonlinear tissue model proposed by Rosen et al. [5] as shown in the following equation:

$$\sigma = \alpha[e^{\beta\varepsilon^2} - 1] + \gamma\varepsilon \tag{1}$$

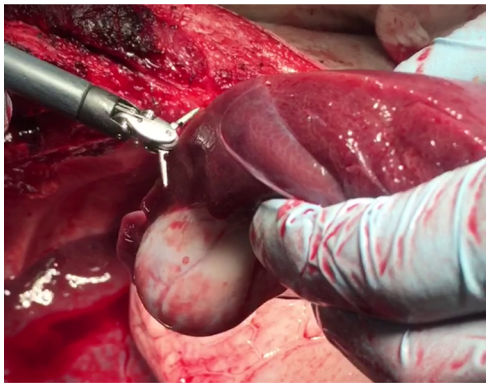

Fig. 1 Example data collection with modified daVinci tool

Table 1 Data collection protocol

Time after euthanasia (min)	Time interval between data collection (min)
10–60	5
60–120	10
120–180	15
180–240	30
1440	N/A

Here, σ is tissue stress, ε is tissue strain, and α, β, and γ are model parameters. Rosen et al. demonstrated that this model resulted in the best fit for liver tissue [5]. The root mean square error (RMSE) between initial and each subsequent grasp was computed via the following equation:

$$E_i = \left[\frac{1}{\varepsilon_f}\int_0^{\varepsilon_f} (\sigma_0 - \sigma_i)^2 d\varepsilon\right]^{1/2} \tag{2}$$

Here, E_i is the error of a given trial grasp i with respect to the initial trial grasp. The integral was evaluated from limits 0 to 0.8 since this was the applicable range of tissue strain.

3 Results

The raw data for all grasps are shown in Fig. 2. These grasp data are plotted relative to the time the data were collected after euthanasia. The initial grasp ($t = 10$ min) and final grasp ($t = 24$ hrs) are annotated for clarity. Additionally, the error metric as calculated by Eq. (2) is graphed on a semilog scale to depict the overall change over time in error from first grasp. This plot is shown in Fig. 3. Qualitatively, the liver changed considerably in visual appearance as well as tactile feel over the 24-hr period. This visual change is depicted in Fig. 4.

4 Interpretation

The results indicate that the uniaxial stress–strain relationship of liver tissue does in fact change over time as suggested in the previous literature [3]. The immediate change in properties from the first grasp to consecutive grasps may have been amplified due to the first grasp being taken before the liver was placed in the saline solution. The saline bath was intended to maintain the liver at a temperature consistent with in vivo conditions, but it may have had more impact on tissue properties than anticipated.

A significant change in properties was seen 24 hrs after euthanasia as indicated in Fig. 3. This suggests that tissue properties taken at this point in time are not a good approximation for in vivo tissue models unless temperature changes (e.g., sample refrigeration and reheating) can mitigate the decay of tissue properties effectively. For applications in medical simulations and

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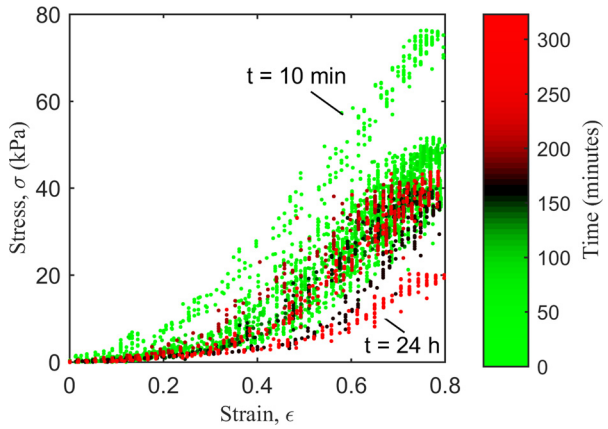

Fig. 2 Raw grasping data with first grasp ($t = 10$ min) and final grasp ($t = 24$ hrs) annotated for clarity

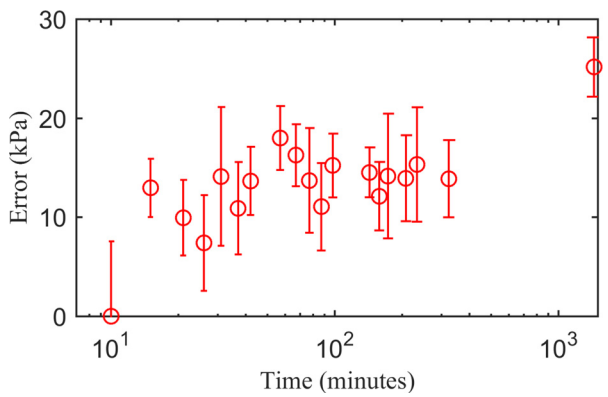

Fig. 3 RMSE of each trial compared with the first trial along with error bars of the root mean square deviation of each trial's fit

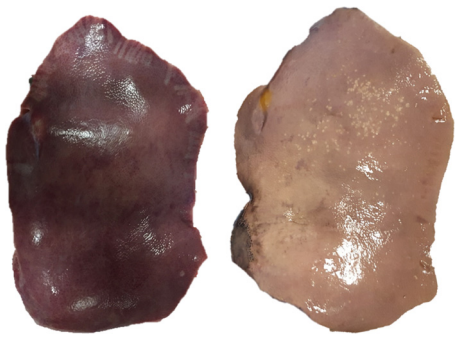

Fig. 4 Liver 30 min postmortem (left) and 24 hrs postmortem (right)

robotic surgeries, tissue properties would ideally be taken as close to time of death as possible. Additional studies beyond this pilot study will need to be performed to obtain a full tissue decay model for multiple tissue types and across different temperature profiles. With this information, current medical simulations and online tissue identification could be improved.

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