The Elastic Properties of Cancerous Skin: Poisson's Ratio and Young's Modulus

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Abstract

Background: The physical properties of cancerous skin tissue have rarely been measured in either fresh or frozen skin specimens. Of interest are the elastic properties associated with the skin's ability to deform, i.e., to stretch and compress. Two constants – Young's modulus and Poisson's ratio – represent the basic elastic behavior pattern of any elastic material, including skin. The former relates the applied stress on a specimen to its deformation via Hooke's law, while the latter is the ratio between the axial and lateral strains.

Objectives: To investigate the elastic properties of cancerous skin tissue. For this purpose 23 consecutive cancerous tissue specimens prepared during Mohs micrographic surgery were analyzed.

Methods: From these specimens we calculated the change in radial length (defined as the radial strain) and the change in tissue thickness (defined as axial strain).

Results: Based on the above two strains we determined a Poisson ratio of 0.43 ± 0.12 and an average Young modulus of 52 KPa.

Conclusions: Defining the elastic properties of cancerous skin may become the first step in turning elasticity into a clinical tool. Correlating these constants with the histopathologic features of a cancerous tissue can contribute an additional non-invasive, *in vivo* and *in vitro* diagnostic tool.

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Many physiologic processes change tissue properties significantly. Pathologic changes are generally correlated with changes in tissue elasticity. Cancerous tissue, such as in carcinoma of the breast, appears as extremely hard nodules [1]. This is the rationale for palpation as a diagnostic tool to detect tumors of the prostate and breast [2,3]. Palpation is a subjective test; however, the aim in medicine is to convert a physiologic process into an objective test. Measuring the elasticity of cancerous tissues can yield an objective tool to be used in diagnostic models.

The properties of skin tissue in biomechanical research are commonly cited in the literature as applying to a material that is purely elastic, homogeneous and isotropic [4]. It should be emphasized that real skin is unisotropic, heterogeneous and elastically non-linear or viscoelastic in either healthy or cancerous tissues. Therefore, the direct measurement of the cancerous skin properties is necessary.

The skin's complex mechanical properties include the elastic properties of solid materials and the viscous properties of fluids [5]. The elastic characteristics of the skin relate to the immediate changes that occur when force is applied to the skin. They govern the skin's ability to deform, i.e., to stretch, contract and compress. These characteristics are defined by two physical constants: Young's modulus, which relates the proportionality of the longitudinal deformation to the applied force (Hooke's law), and Poisson's ratio, which relates the dimensional deformations to one another [6]. The viscous characteristics of skin relate to the delayed changes occurring after time: the decreased stress obtained over time when a constant strain is applied (stress relaxation effect) and the increased length obtained over time when a constant strain is applied (creeping effect) [7]. Surgeons are familiar with these effects, counting on stress-relaxation to release scar tension with time. They use the creeping effect to absorb some irregular scar features and dog-ears, and to generate tissue elongation after inflating expanders.

Our interest is to explore the skin's ability to deform. To gain understanding of the elastic behavior of the skin we measure Young's modulus and Poisson's ratio. A common approach is to controllably compress a sample and measure the resulting deformation. One of the immediate steps is to perform these measurements on a tissue before and after compression in a cryostat. This is a common process for immediate histology evaluation, available from surgeries that produce frozen sections.

Defining the elastic properties of normal and cancerous skin may become the first step in turning elasticity into a clinical tool. In the present work we measured Young's modulus and Poisson's ratio of cancerous skin specimens, the first such measurement to the best of our knowledge.

Materials and Methods

In the analysis we used 23 consecutive specimens excised from patients at our outpatient clinic. The specimen dimensions – length and thickness, in millimeters – were measured before and after compression and freezing using a caliper with an accuracy of 50 μm (0.05 mm). The cryostat chamber was set to -27°C [Table 1], and a weight of 478 g was used to compress the specimen [Figure 1]. The compression in the cryostat is the first stage in producing frozen sections from the specimen. Inspection of the processed specimens under the microscope provides the histologic diagnosis.

From the data we measured the change in the radial length and in the thickness of the tissue and determined the resulting radial and axial strains. Based on the compressing weight and tissue dimensions we determined the stresses acting on the sample. From these, in turn, we determined Young's modulus (the proportion coefficient between the strain and stress) and Poisson's ratio (the ratio between the radial strain and the axial strain). For this study

Table 1. Summary of the measured specimen dimensions, strain, Poisson's ratio and Young's modulus

Initial diameter (mm)	Initial height (mm)	Final diameter (mm)	Final height (mm)	Radial strain (%)	Axial strain (%)	Poisson's ratio	Axial stress-to-strain ratio	Young's modulus (KPa)
8.85	3.15	9.85	2.4	10.70	27.03	0.40	0.026	42.57
9.9	3.15	11.85	2.45	17.93	25.00	0.72	0.021	25.83
9.75	4.85	11.55	2.7	16.90	56.95	0.30	0.009	17.26
8.1	4.85	10.6	2.7	26.74	56.95	0.47	0.012	18.83
10.2	4.65	11.2	3.65	9.35	24.10	0.39	0.022	36.75
8.45	4.65	9.8	3.65	14.79	24.10	0.61	0.030	41.25
9.85	4.55	10.75	3.4	8.74	28.93	0.30	0.020	36.11
9.1	4.55	10.95	3.4	18.45	28.93	0.64	0.021	27.92
7.5	3.95	8.05	3.45	7.07	13.51	0.52	0.075	109.35
8.75	3.15	10.2	2.25	15.30	33.33	0.46	0.020	31.63
9.65	3.15	10.8	2.2	11.25	35.51	0.32	0.016	29.38
5.45	3.15	5.85	2.55	7.08	21.05	0.34	0.091	158.99
7.35	4.05	8.95	2.45	19.63	49.23	0.40	0.019	30.67
4.15	3.85	5.2	2.5	22.46	42.52	0.53	0.065	95.73
10.45	3.95	12.5	2.55	17.86	43.08	0.41	0.011	17.41
4.5	3.95	5.55	2.45	20.90	46.88	0.45	0.051	80.98
7.15	2.4	8.9	1.55	21.81	43.04	0.51	0.022	32.71
6.5	2.5	8	1.5	20.69	50.00	0.41	0.023	37.60
9.9	2.45	11.35	1.85	13.65	27.91	0.49	0.019	29.24
6.35	2.45	7.3	1.95	13.92	22.73	0.61	0.057	78.28
8.85	3.15	10.75	1.9	19.39	49.50	0.39	0.013	21.24
3.8	2.75	4.25	1.85	11.18	39.13	0.29	0.096	177.98
10.05	3.7	12.15	2.1	18.92	55.17	0.34	0.009	15.61
			Average	15.86	36.72	0.43		51.88
			SD	5.33	12.83%	0.12		44.85

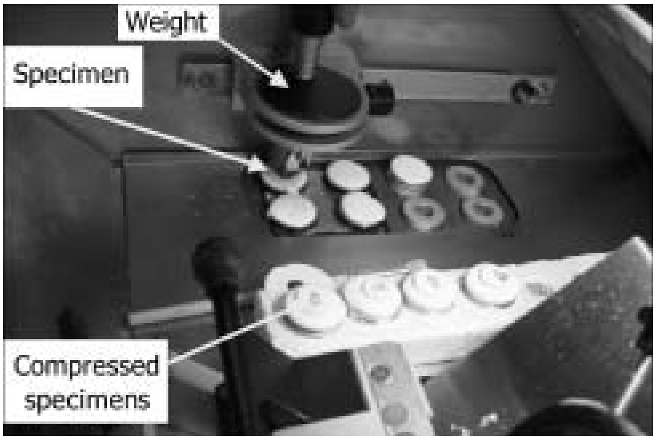

Figure 1. Photograph of the cryostat chamber containing specimens and a weight

we used only frozen sections that were further histologically proven to be basal cell carcinoma.

Ice granules do not interfere with the measurement of the specimens for two main reasons: a) the time needed to freeze water for our smallest sample size is only a few minutes, longer than the duration of the compression in the cryostat; and b) frozen water, or ice, would dramatically decrease the deformability of the tissue. Considering that Young's modulus of ice is about 8 GPa, under the weight of 478 g the deformation of the typical 10 × 2 mm is less than the dimension of an atom! Therefore, what was measured was the deformation of the cancerous tissue, with minimum freezing effect.

Since our statistical evaluation assumes the present sample as normal, we calculated the statistical averages, standard deviations and *P* values accordingly.

Results

We analyzed 23 consecutive cancerous tissue specimens prepared during frozen sections. These analyzed tissue segments showed, after compression in the cryostat, an axial elongation varying from 12.66% to 44.33%, with a mean of 17.7% [Table 1] and a standard deviation of 0.06. These tissues varied in width (radial thinning) from 7.33% to 30.86%, with a mean of 30.55% and SD of 0.09. Poisson's ratio determined by the mean dimensions, with a measurement error of about 1%, resulted in 0.43 ± 0.12. With the positive stress being the ratio of the weight of 478 g and the specimen area, we found Young's modulus to be 52 ± 45 KPa. Note that the Poisson's ratio calculated is not a regular average of the measured lengths. The reason is that commonly accepted elastic properties and Hooke's law pertain to small deformations of the specimen. Because the present specimens underwent large deformations, the known formulae must be used carefully. Thus, we use the mean lengths rather than the initial lengths as the normalizing dimensions.

The *P* values were calculated based on the assumption of normal distribution: 15% for Poisson's ratio and 17% for Young's modulus. These large values are consistent with the large variation of elastic properties of the skin cited in the literature [4,8,9].

SD = standard deviation

Discussion

Normal skin and pathologic skin possess different characteristics. For instance, cancerous tissue can appear as extremely hard nodules [1]. The abnormal skin can be either cancerous, infected or scarred tissue [8,10,11]. Defining the elastic properties of cancerous skin and correlating these constants with the histopathologic features of a cancerous tissue can contribute an additional non-invasive, *in vivo* and *in vitro* diagnostic tool [12]. Poisson's ratio, a skin elastic characteristic, describes the behavior of materials under stress. For biological materials this constant ranges from 0.25 to 0.85 (8,13–20]. Our measured Poisson's ratio for cancerous skin is 0.43, well within the range cited in the literature for biological tissues. In comparison, Poisson's ratio for healthy human skin at room temperature was cited by Larrabee and Sutton as 0.5 [8].

An example of the clinical use of Poisson's ratio was presented at the last annual meeting of the American College of Mohs Micrographic Surgery and Cutaneous Oncology [21]. By using finite element analysis (ANSYS 5.6 Finite Element software package, with tetrahedron-shaped elements represented by 1,000 nodes) and inputting Poisson's ratio, we calculated the minimum angle for an unobstructed view of a Mohs micrographic surgery cut. The angle was found to be 10, smaller than the current norm in Mohs. This approach is an example of how elastic properties of the cancerous skin have a clinical application [22].

The further measured Young's modulus showed an average of 52 KPa, well within the known values for various skins [4,12,23,24). Its deviation of 45 KPa about the mean is also well understood due to the significant variations in skin elasticity as a function of age, location, actinic changes and racial features. This variation explains the large *P* value that we found: 17% for Young's modulus and 15% for Poisson's ratio.

Our further objective is to investigate the correlation between the skin's elastic properties and the histologic findings of healthy skin and cancerous skin morphology. Such clinical research is presently underway in our departments with the aim of specifying the skin's elastic properties according to the cancer features. With regard to the future practical uses of the *a priori* knowledge of the elastic characteristics of cancerous tissues, one example is to identify the exact border between healthy and malignant tissue by a non-invasive measurement on the skin surface. Thus, cancer screening, diagnosis and treatment modalities can benefit from a well-defined, compiled and stored data body of these characteristics.

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