# MEASUREMENT OF NONLINEAR-ELASTIC PROPERTIES OF SKIN AND SUBCUTANEOUS TISSUES VIA UNCONFINED COMPRESSION TESTS

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## INTRODUCTION

Knowledge of the nonlinear-elastic properties of soft tissues is essential for the development of reliable finite element models for biological systems. The compressive nonlinear-elastic properties of soft tissues are usually determined using unconfined compression tests. To determine the nonlinear-elastic behavior of skin and subcutaneous tissues using a conventional approach, the skin and subcutaneous tissues have to be separated before testing [1,2,3]. Using such an approach, measurement errors may be increased as a consequence of the reduced specimen dimensions and cumulative experimental errors. In the present study, we propose a novel method to determine the nonlinear-elastic behaviors of the skin and the subcutaneous tissues simultaneously using specimens of skin/subcutaneous composites.

## METHODS

If two unconfined compression tests (labeled A and B) are performed with specimens of different skin/subcutaneous tissue height ratios ($\gamma_s$ and $\gamma_f$), two different stress-strain relationships will be obtained (Fig. 1a). At the same stress level, the total tissue strains can be obtained from these two distinct stress/strain relationships. Assuming that the tissue samples A and B are taken from two adjacent locations, the mechanical characteristics of the skin and subcutaneous tissues in specimen A should be similar to those in specimen B. Consequently, for a given stress, the strains in the skin ($\varepsilon_s$) and in the subcutaneous tissues ($\varepsilon_f$) for specimen A should be identical to those for specimen B. Therefore, the strains in the skin and subcutaneous tissues for a given stress can be solved from:

$$\varepsilon^A = \gamma_s^A \varepsilon_s + \gamma_f^A \varepsilon_f, \qquad \varepsilon^B = \gamma_s^B \varepsilon_s + \gamma_f^B \varepsilon_f \qquad (1)$$

Because of scattering of test data of soft tissues, multiple unconfined compression tests are to be performed using tissue samples with different skin/subcutaneous height ratios (as sketched in Fig. 1b). The stress/strain curves of skin and subcutaneous tissues are derived from stress/strain curves of the skin/subcutaneous composite soft tissue specimens using a least square method. In the present study, a total of eight samples of skin/subcutaneous composite were used. Tissue samples were collected from the palmar surface of the front feet of a pig (Landrace-Yorkshire-Duroc hybrid).

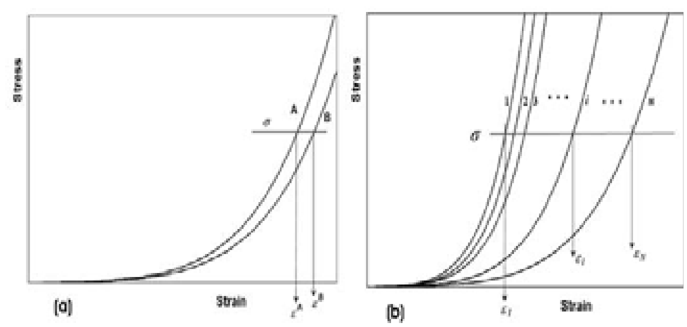


**Figure 1**: Schematics of the stress/strain relationships of soft tissue samples with different height ratios of skin and subcutaneous tissues. (a) Two samples; (b) Multiple samples

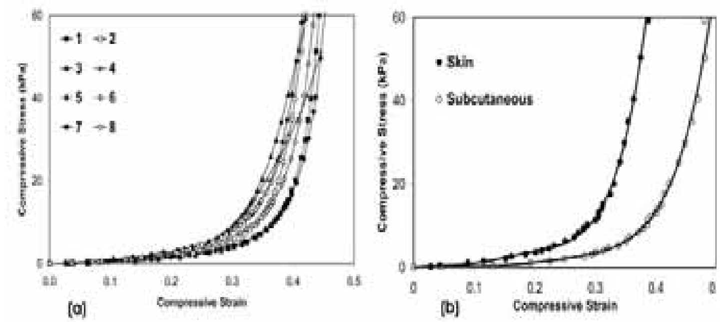


**Figure 2**: (a) The stress/strain curves of the eight unconfined compression tests using skin/subcutaneous composite specimens. (b) The stress/strain curves of the skin and subcutaneous tissues obtained using the proposed method.

## RESULTS AND DISCUSSION

The stress/strain relationships for the eight unconfined compression tests were found to depend on the height ratio of skin/subcutaneous tissue – the specimens with a higher ratio of skin/subcutaneous tissue tend to produce a stiffer stress/strain curve (Fig. 2a). Using the proposed approach, the stress/strain relationships of skin and subcutaneous tissues were derived (Fig. 2b).

## CONCLUSIONS

Compared to conventional test procedures, our method offers the advantages that the skin and subcutaneous tissues do not need to be separated prior to testing, and that the soft tissue composite specimens reflect physiological loading conditions much more accurately than testing of isolated skin and subcutaneous tissues. Using the proposed approach, material properties of soft tissues can be obtained in a cost- and time-efficient manner, which simultaneously improves the physiological relevance.

## REFERENCES

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