Low-cost measurement of hair mechanics using tensile force and torsion

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Introduction

Hair loss, or alopecia, is a prevalent condition impacting over 80 million individuals in the United States alone, with significant psychological and social implications. Although alopecia can be caused by numerous things, including autoimmune diseases, mechanical stress, genetics, and chemical treatments, there is a lack of accessible, low-cost diagnostic tools to assess hair health in clinical settings and underserved communities. Methods currently available to evaluate hair mechanical properties are often expensive, complex, or limited to research laboratories. Hair has viscoelastic properties that exhibit both viscous and elastic responses to mechanical forces. When a hair fiber experiences tension, it elastically deforms, then becomes plastically deformed, and eventually breaks. The mechanical properties of hair, particularly its shear modulus and tensile breaking force, can provide insight into its structural properties and potential underlying health conditions. In this study, we aim to develop a low-cost, reproducible method to measure the shear modulus and breakage force of a single hair strand using a torsion pendulum that can superimpose uniaxial stress and torsion. We further aim to assess how conditioning treatments affect the mechanical strength of hair. We hypothesize that quantifying the viscoelastic properties and breakage force of hair would help differentiate between healthy and damaged hair. This low-cost approach paves the way for the development of accessible diagnostic tools to aid clinics in assessing hair loss conditions and formulating early detection strategies within dermatology.

Materials and Methods

We designed a low-cost medical device to measure the shear modulus and breaking force of single human hair strands. A hair strand was firmly held in place by a 3D-printed component, modeled after a mechanical pencil's lead dispenser. The hair was attached to a torsion pendulum setup supported by a LEGO-based frame. A magnet secured the top end of the hair, while the bottom was connected to a lightweight disk with a red marker indicator and an attached magnet held at the hair's bottom end. Hair oscillation was induced and recorded using TrackerOnline, a free, open-source motion analysis software. Each trial consisted of 45 seconds of torsional motion, allowing for the extraction of the time constant of the oscillation, required for the calculation of the hair's shear modulus. Subsequent measurements were performed with increasing tensile forces (0.005N per step) induced by moving closer a ferromagnetic block. A scale was used to measure the applied force, exerting a force until the hair exhibited visible plastic deformation and subsequently broke, as recorded on video. Measurements were performed on both conditioned and unconditioned hair to examine the effects of treatment on the viscoelastic properties of hair. In each condition, the modulus was calculated after every tensile force increment, allowing for the monitoring of changes in stiffness and elasticity leading up to breakage. The elastic-to-plastic transition and point of breakage were tracked to fully characterize the mechanical properties of the hair samples. Our setup enables the precise and repeatable characterization of hair mechanical properties using low-cost, common tools and materials, allowing for accessible diagnostics.

Results

According to initial findings, the shear modulus of hair varies with applied tensile force across different strand lengths and conditioning states. As shown in Figure 1, unconditioned hair has a higher shear modulus as compared to conditioned hair, across all measured applied tensile forces and hair strand lengths, suggesting greater resistance to torsional deformation. For example, an unconditioned strand of the length 0.019 m reached a shear modulus of approximately 1.3×10^{11} Pa (shown as a yellow solid line and triangle), while the same hair type that has been conditioned exhibited a modulus of 1.8×10^{10} Pa (shown as a dashed purple line) under similar force levels. This pattern suggests that conditioning may soften or plasticize the hair, reducing its torsional stiffness. The results also indicate a general trend of increasing modulus with applied forces, particularly in unconditioned samples. This evidence may reflect strain stiffening behavior, where hair fibers become more rigid under greater tension. In conditioned samples, the modulus values remain relatively low and stable. These findings are based on a single individual's hair, so the impact of different hair types has yet to be accounted for. Future steps are currently being taken to determine the exact point of breakage of the hair. Ultimately, this low-cost, accessible approach may help inform clinical settings and support early diagnosis and intervention for patients experiencing hair loss, particularly in underserved communities.