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Note

Structural Changes in Cuticles on Violin Bow Hair Caused by Wear

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A bow with horse tail hair is used to play the violin. New and worn-out bow hairs were observed by atomic force microscopy. The cuticles of the new bow hair were already damaged by bleach and delipidation, however the worn-out bow hairs were much more damaged and broken off by force, which relates to wearing out.

Key words: violin; bow hair; delipidation; atomic force microscope; Helmholtz motion

The violin is a member of the string instrument family. The player holds the bow in his right hand and draws it across the strings. Horse tail hair is used for the bows of stringed instruments. In performance, the strings are vibrated by the bow hair, and sound is created. The structure of human hairs has been thoroughly observed by atomic force microscopy (AFM) and scanning electron microscopy (SEM).[1,2] Bow hair is gradually worn out by repeated violin playing, resulting in decreased sound quality. However, little investigation has focused on how the cuticles of bow hair are worn down. In the present study, we used AFM to observe the nanometer-scale surface structures of horse tail hair, new bow hair that had not been used in violin playing, and worn-out bow hair. Based on the results, we discuss the structural changes in the cuticles of the bow hair.

Horse tail was provided by Riding Club Crane (Ibaraki, Japan), and new bow hair for a violin bow was purchased from Bunkyo Gakki (Tokyo, Japan). Worn-out bow hair brought to Bunkyo Gakki was provided by the shop. It was expected that the surface structure was typical of worn-out bow hair. The middle part was selected as a sample because of the noticeable damage. A 1.5 cm-long middle part of each hair was cut and cleaned twice by sonication (Branson Ultrasonics, Danbury, CT, USA) as follows: The hairs were immersed in 1% sodium dodecylsulfate solution, sonicated for 2 min at room temperature, and then washed in a large amount of distilled water to remove the many rosin particles that adhered to the surface of the worn-out bow hair. As a control, this cleaning procedure was also carried out twice for the new bow hair. The washed hair was dried sufficiently. SPI400 and SPA3800 were used for AFM observation. A silicon cantilever (SI-DF40P, SII Nanotechnology, Chiba, Japan) with an oscillation frequency of 300 kHz and a spring constant of 42 N/m was used. The scanning rate was 0.11 to 0.2 Hz. AFM imaging was performed under ambient conditions in tapping mode.

Figure 1a depicts the surface structure of the horse tail hair. Square cuticles covered the cortex in a root–to-tip direction (right to left in the figure). The edge of the cuticles in the middle part of the hair was smooth, and no defect or degradation was observed. However, at the tip part of the horse tail hair, the cuticle was chipped away, with attrition among the hairs, and the shape was not square. Occasionally, fine circumferential lines on the surfaces of the cuticles were observed. These lines were considered a kind of damage and are reported as cuticle "ghost" edges.[3] The ghost edge arises as follows: Each cuticle cell consists of various sublamellar layers and the cell membrane complex. In some endocuticle layers of the cuticles, part of layer is eliminated and removed during the formation of the hair, and novel fine lines appear on the cuticle surface. Ghosts are probably generated in horse hair for similar reasons to those generated in human hair. A typical cross section of horse hair at the middle part is depicted in Fig. 1b. The pitch of the cuticles was $8.3 \pm 1.3\,\mu m$ ($n = 16$), and the step height of the cuticles was 420 ± 125 nm ($n = 16$), as presented in Fig. 1b.

The AFM images revealed that the cuticles of the new bow hair were already damaged (Fig. 2a and b). In some outer sublamellar layers, part of layer was peeled off, and underlying layers were exposed near the edges of some cuticles. The cuticle edges were chipped away, and the structural components were removed, as indicated by the arrows in Fig. 2a. The section profiles indicated that the second cuticle from the left had a rough surface; however, the overall shapes of the cuticle sections were similar to those of the horse tail hair (Fig. 2b). On the surface of some cuticles in different regions, hole-like depressions were generated (indicated by arrows in Fig. 2c). The depth of these holes was about 400 nm. In the processing of the bow hair, the horse hair was generally bleached to a white color and delipidated. In this study, although bow hair from a white horse was used, bleaching and delipidation were performed. We speculated that the hole-like depressions might have been generated by these processes.

Characteristic damage on the surface of the worn-out bow hair was observed. Two AFM images of the worn-out bow hair revealed that the cuticles were markedly damaged (Fig. 3). As Fig. 3a indicates, the outline of the

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Abbreviations: AFM, atomic force microscopy; SEM, scanning electron microscopy cuticle edges was greatly disordered. Although the cuticle edges of the new and worn-out bow hair were chipped away, the shapes of the chipped cuticles were completely different from one another. In some outer sublamellar layers, part of layer was peeled off, and underlying layers were exposed near the edges of the cuticles (indicated by arrows in Fig. 3a). The section profile indicated that the upper edge of the right cuticle was cut, and the shape of the cuticle changed from a triangular to trapezoidal due to repeated peeling and removal of the layered structure. The left cuticle had a warped slope (Fig. 3b). Figure 3c presents a different morphology. Local defections of the cuticle edges were observed (indicated by arrows in Fig. 3c). These structural changes were expected to continue during practice. It is generally understood that the cuticles are scraped by friction and that the step height of the cuticles decreases during practice. However, the images obtained by AFM (Fig. 3) suggested that quite different events occurred.

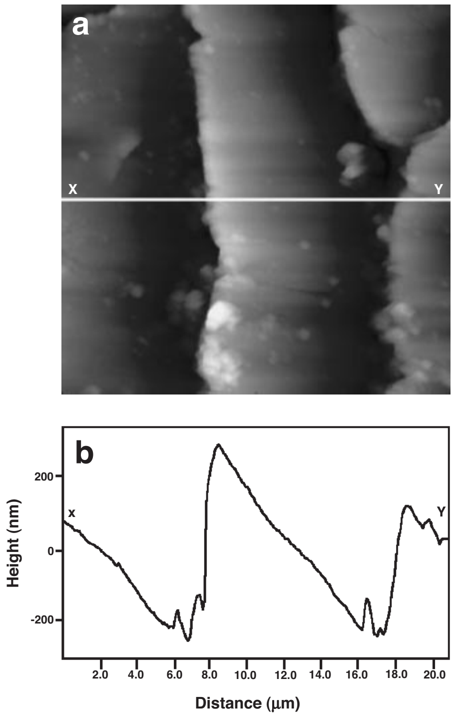

Fig. 1. AFM Images of Horse Hair Surface and Section Profile.
a, AFM image of horse hair surface. b, Section profile of the cuticle along solid line X-Y in a. The scan range was 20 μm × 20 μm.

Helmholtz first investigated violins in terms of physics.[4)] He idealized that Helmholtz motion is a possible pattern of vibration of strings. In Helmholtz motion, a regular cycle of stick-and-slip interaction is repeated between the bow hair and strings. Recent report indicates that the vibration speed of the string is fast during the sticking interaction, however, decreases suddenly during the slipping interaction in spite of the steady sliding speed.[5)] In addition, a twist of the string also occurres coincidentally with the vibration. The degree and frequency of twisting depends on the technical level of the violinist. On the other hand, rosin also plays an important role in making violin sounds. You cannot make a sound with a violin using a bow hair without rosin. Using SEM, Matsutani observed that most rosin particles adhere to the step of the cuticle edge.[6)] The typical size of a rosin particle is 20 μm by ten coating strokes. After the violin is played, the rosin particles on the bow hair decrease in size, and the surface of the string is covered with many rosin particles. Our observation by stereomicroscopy revealed that the surface of the strings is rough (data not shown).

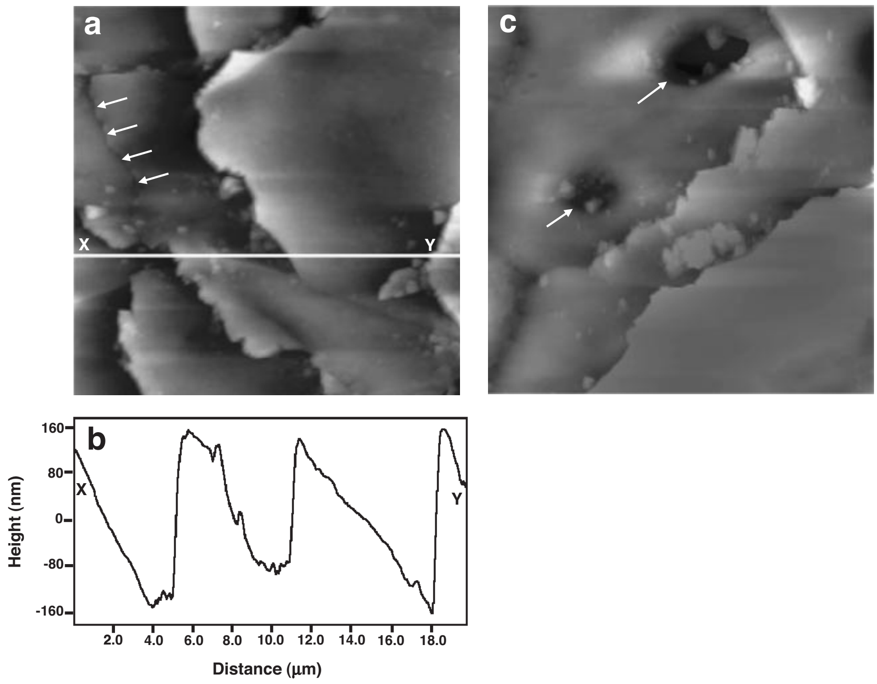

Fig. 2. AFM Images of New Bow Hair Surface and Section Profile.
a, The cuticles were damaged by bleach and delipidation. Arrows indicate the fine line on the cuticle. The scan range was 20 μm × 20 μm. b, Section profile of the cuticle along solid line X-Y in a. c, Cuticle damaged by bleach and delipidation. The arrows indicate hole-like depressions on the cuticle. The scan range was 20 μm × 20 μm.

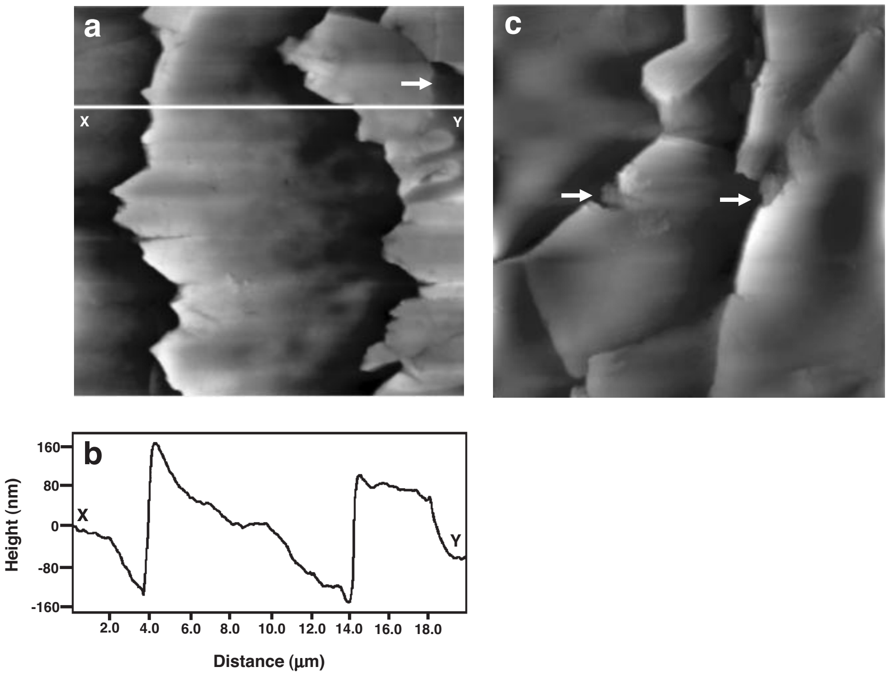

Fig. 3. AFM Images of the Surface Structure of Worn-Out Bow Hair and Section Profile.
a, The outline of the edge has a disordered sharp appearance. The arrow indicates the fine line on the cuticle. The scan range was 20 µm × 20 µm. b, Section profile of the cuticle along solid line X-Y in a. c, Worn-out bow hair. The arrows indicate a local defection at the cuticle edge.

Every violin string is fiber-wrapped with a flat, thin ribbon made of silver or aluminum around a core material, such as steel. String diameters range from 0.2 to 0.85 mm.

Although stick-and-slip interaction was considered to be facilitated by the rosin particles, it is not clear whether the bow hair and strings contact directly or through the rosin. During the sticking interaction, one possibility is that the edge of the cuticle hooks directly onto the grooves in the surface of the string. Alternatively, the corner of the groove on the string keeps hitting a particular region of a bow hair when the bow is pulled across the strings. Another possibility is that the friction of the rosin causes the cuticle edges to be chipped away, and local defections of the edges cross several cuticles. As a result, the outline of the cuticle edges on the worn-out bow hair becomes disordered.

The technical level of the violinist might relate to the disordered patterns in the outline of the cuticle edges. We assume that further structural analysis by AFM will provide new insight concerning the relationship between sound quality and damage to bow hair cuticles.

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