Eglee Apolinar,[1] *M.S.F.S. and W. F. Rowe,*[1] *Ph.D.*

Examination of Human Fingernail Ridges by Means of Polarized Light

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ABSTRACT: A method has been developed for the preparation of thin human nail specimens suitable for examination by transmitted light microscopy. The nails to be examined are embedded in an acrylic resin and the upper surface of the nail is sanded and polished until the desired thickness is reached. The resulting thin nail specimens display sharp bands of interference colors when placed between crossed polarizing filters. The widths of the bands are of the same order of magnitude as the widths of the ridges and valleys on the nail surface, indicating that each band of color represents a single ridge or valley on the nail surface. The optimum viewing conditions are obtained when the specimens are oriented so that the direction of the nail ridges is 45 deg from the directions of the polarizing or analyzing filters. Fingernail specimens from the same finger may be matched by using a transmitted light comparison microscope equipped for polarized light observations.

KEY WORDS: criminalistics, fingernails, human identification

Human fingernails and toenails bear longitudinal ridges on both their upper and lower surfaces (Fig. 1). These ridges are formed as the nails grow and correspond to parallel dermal ridges irregularly distributed on the nail bed underlying the keratinized tissue of the nails [*1*]. The dermal ridges are modifications of dermal papillae that underlie the epidermal ridges of the friction skin surface of the hands and feet [*2*]. Because of their association with anatomical structures related to those which produce unique fingerprint patterns and because of their analogy to the striations imprinted on the surfaces of fired bullets by the imperfections in the barrel of a rifled firearm, the longitudinal ridges on fingernails and toenails have been proposed as a means of personal identification by a number of authors [*1,3-5*].

These ridges possess two important characteristics that render them suitable as a means of personal identification: uniqueness and durability. A study of the fingernail ridge patterns of a set of identical twins suggests that such patterns are unique to a particular person [*5*]: the patterns from corresponding fingers of female identical twins showed striking similarities, but it was possible to distinguish the ridge patterns of one twin from those of the other. Like fingerprint patterns, the patterns of nail ridges are stable for years, barring alterations caused by injury or disease [*1,3-5*]. In a number of instances, fingernail clippings or broken fingernails found at the scene of crimes have been matched by means of their ridge patterns with fingernail clippings from suspects [*5*].

Most studies of the ridges on fingernails and toenails have used the traditional tech-

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[1]Graduate student and assistant professor, respectively, Department of Forensic Sciences, The George Washington University, Washington, D.C.

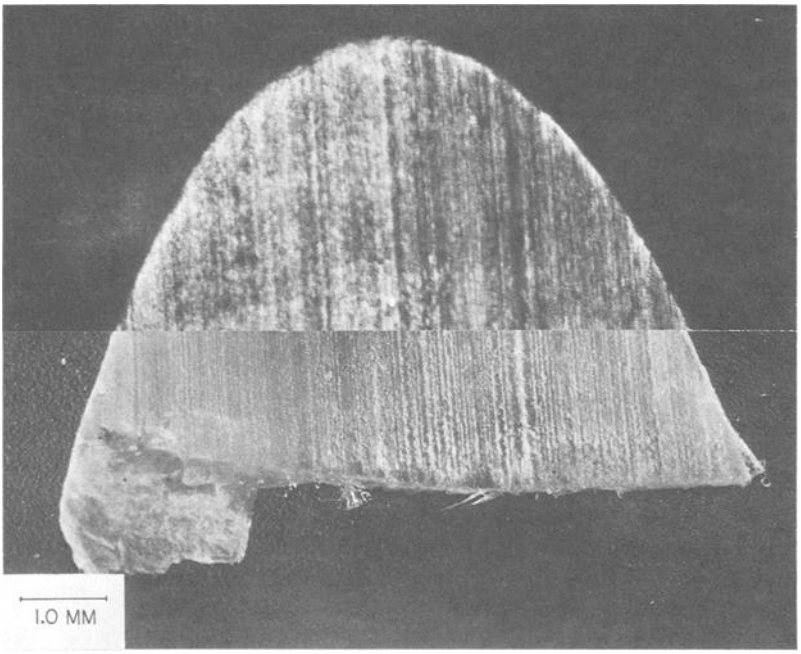

FIG. 1—*Concave surface of human fingernail showing ridges. Upper portion of photograph shows bands of interference colors produced when the nail is placed between crossed polarizing filters.*

niques of firearm and toolmark examinations [*1,3-5*]. Comparisons of nail ridge patterns are made with a comparison microscope equipped with low power objectives; specimens are viewed with oblique reflected light that emphasizes the relief of the nail surfaces. MacDonell and Bialousz [*5*], however, have pointed out that because of the translucence of nails adequate contrast between the tops of the ridges and the bottoms of the valleys may be difficult or impossible to obtain. Light that enters the nail specimen, rather than being reflected, will be scattered by the translucent keratin and may illuminate the bottoms of the valleys almost as brightly as does the light falling on the tops of the ridges. In the course of preparing nail specimens for examination by scanning electron microscopy, MacDonell and Bialousz [*5*] discovered that metallized nail specimens exhibit excellent contrast: light is reflected from the tops of the ridges, while the opaque metal coating prevents light from penetrating into the nail. Unfortunately, this metallization technique, while effective, is time-consuming and requires special equipment.

Reflected light observations are difficult to perform with medical or biological microscopes. With the exception of metallographic microscopes, stereomicroscopes, and microscopes specifically designed for firearm and toolmark examinations, optical microscopes are intended to be used with a coverslip (usually 0.18 mm thick) between the specimen and microscope objective. When the coverslip is omitted the microscope displays spherical aberration, a lens aberration that results in light being more strongly refracted by the inner or outer portion of the lens aperture so light rays originating at a point on the axis of the microscope objective are not brought to a common focus. The most common manifestation of spherical aberration is a loss of contrast in the image produced by the microscope [*6*].

MacDonell and Bialousz [*5*] have observed that nail specimens placed between crossed polarizing filters display bands of interference colors as a consequence of the birefringence of keratin. According to the present theory of the structure of fingernails and toenails [*7-9*], the keratin microfibrils that compose the nails are aligned perpendicular to the

direction of the ridges on the nail surface. Cross sections of nails cut parallel to the direction of growth show hexagonally close-packed circles when examined with an electron microscope [*9*]. These circles have been interpreted as cross sections of microfibrils oriented perpendicular to the plane of the nail cross section. X-ray diffraction patterns from human nails show reflections consistent with partially aligned microfibrils running parallel to the nail surfaces and perpendicular to the direction of growth [*7,8*]. If these keratin microfibrils are birefringent, then a partially aligned layer of such microfibrils will also exhibit birefringence.

Matoltsy and Balsamo [*10*] have examined the birefringence of keratin microfibrils in human skin. They determined that keratin microfibrils exhibit two indices of refraction: one for light polarized parallel to the direction of the microfibril and another for light polarized perpendicular to the direction of the microfibril. The larger index of refraction was that for light polarized parallel to the microfibril direction. Fingernails and toenails, therefore, are expected to be birefringent, since they are composed of partially oriented birefringent fibers. Human fingernails and toenails should exhibit one index of refraction for light polarized parallel to their ridges and a second, higher index of refraction perpendicular to the ridges.

The interference colors displayed by birefringent materials depend on the degree of birefringence of the materials and the thickness of the specimens being examined [*11,12*]. The bands of different colors observed when nail specimens are placed between crossed polarizing filters indicate regions of different thickness in the specimens. Since the ridge patterns on fingernails and toenails consist of parallel ridges and valleys, one might expect that when nails are placed between crossed polarizing filters that the locations of these features would be indicated by sharp bands of interference colors. However, this is not the case, since nail specimens of normal thickness are so thick that they produce washed-out, diffuse interference colors. This diffuseness results in adjacent bands of interference showing poor color contrast, even in black and white photomicrographs such as Fig. 1. Such washed-out, diffuse interference colors are also observed with thick specimens of other birefringent materials [*11,12*]; however, the scattering of transmitted light by the transluscent keratin of the nails also contributes to the washed-out interference colors.

In the identification of birefringent minerals, mineralogists frequently examine thin sections of rocks that have been prepared by grinding and polishing thick slabs of rocks to some desired thickness, typically 30 μm [*11,12*]. The present authors have developed a procedure for producing thin nail specimens that display sharp bands of interference colors suitable for comparison. In this technique, nail specimens are embedded in a quick-setting plastic and then sanded and polished to the desired thickness. This technique is a modification of the procedures used in mineralogical examinations [*12*] and in the examination of cross sections of mammalian teeth [*13*]. Since this technique results in conventional microscope slide mounts, specimens prepared by this procedure may be examined with medical or biological microscopes.

Experimental Procedure

Each nail clipping to be examined was first embedded in Quickmount, an acrylic resin produced by Fulton Metallurgical Products Corp. To insure a flat nail specimen, the nail clipping was clamped between a clean microscope slide and a small rectangular piece of glass approximately 13 by 6 mm (½ by ¼ in.) that had been previously coated with paraffin. The paraffin coating on the small piece of glass facilitates its later removal from the embedded nail specimen. The clipping was placed with its concave side toward the microscope slide. This side of the nail bears the most useful ridge patterns since it is not exposed to wear [*1*] and is in direct contact with the dermal ridges of the nail bed. The convex side of the nail is usually worn smooth; hence, its ridge patterns are of very limited

value for comparison purposes. It was therefore decided to thin the nail clipping by grinding it away from the convex side. The solid and liquid components of the Quickmount were mixed according to instructions, and the resulting slurry was pipetted between the two pieces of glass and allowed to flow around the nail clipping embedded in plastic and attached to the microscope slide.

Next the embedded nail clipping was thinned by sanding and polishing. The clipping was first sanded with 3M Co. 340-grit emery paper. The progress of the sanding was monitored by observing the interference colors of the specimen. By a process of trial and error, it was found that when the sanded specimen displayed bright green or blue-green interference colors it had been sanded sufficiently. When the sanding was continued until a yellow or white interference color was produced, significant portions of the nail were sanded away. The abrasions produced by sanding were polished away with an aqueous slurry of 5-μm alumina particles (Buehler, Ltd.). The plastic film containing the embedded nail was detached from the first microscope slide (now extensively scratched). The nail specimen was gently freed from the embedding plastic, placed on a second microscope slide, and covered with Permount mounting medium (Fisher Scientific Co.) and a coverslip.

Nail specimens prepared as described were examined with a Leitz comparison microscope with the capability for orthoscopic polarized light observations. The microscope was equipped with rotating stages so that the specimens could be rotated with respect to the fixed direction of the analyzing filters to obtain maximum contrast between adjacent bands of interference colors.

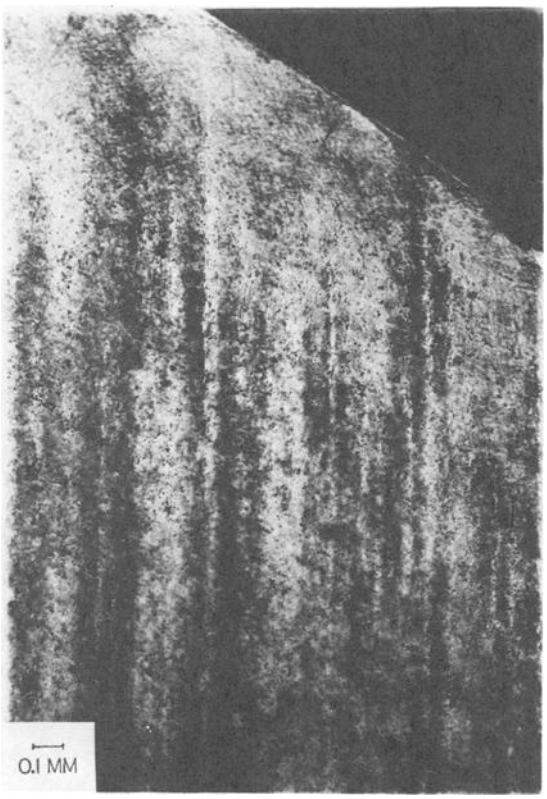

FIG. 2—*Thinned nail specimen viewed with unpolarized transmitted light.*

Photomicrographs were made with a Leica CL camera equipped with a behind-the-lens light meter. The light sources were filtered to provide a color temperature of 3200 K for photomicrography with daylight color film. Measurements of the widths of the bands of interference colors were made from enlarged prints of photomicrographs. The degree of magnification of the photomicrography system was determined by photographing a ruled microscope slide (American Optical Company) having a 2-mm ruling divided into 0.01-mm increments.

Results and Discussion

When viewed with unpolarized transmitted light, nails that have been thinned by the described procedure are virtually transparent; the ridges and valleys on the lower surface of the nail are faintly visible (Fig. 2). When viewed between crossed polarizing filters, the nails show sharply contrasting bands of interference colors (Fig. 3), whose locations correspond to the faintly visible ridges and valleys observed with unpolarized transmitted light. The widths of the bands of color are on the order of 0.05 mm, which is consistent with the widths of nail ridges reported by Thomas and Baert [*1*]. Therefore, each band of color represents a single ridge or a single valley between two ridges. The surface detail on these thinned nail specimens is therefore resolved to a degree comparable with reflected light observations.

The orientation of the nail specimen with respect to the directions of the crossed polarizing and analyzing filters was found to influence greatly the contrast between adjacent

FIG. 3—*Thinned nail specimen viewed between crossed polarizing filters.*

bands of colors. Best results were obtained when the direction of the nail ridges made an angle of 45 deg with the direction of the polarizing and analyzing filters. When the nails were oriented so that the ridges were parallel or perpendicular to the direction of the two filters, the bands of interference colors were fainter; in some instances, the bands disappeared altogether. Regardless of their orientation, however, the nails always displayed considerable birefringence: there was no orientation of the nail at which extinction could be obtained.

The interference effects observed when nail specimens are examined between crossed polarizing filters are consistent with the prevailing theory of the structure of nail. The failure to find a position at which complete extinction occurs indicates that the keratin microfibrils composing the matrix of the nail are not all oriented in one direction; in contrast to minerals, nails have a significantly disordered internal structure. The fact that the sharpest and most contrasting bands of interference colors are seen when the nails are oriented so that the ridge direction made a 45-deg angle with the polarized analyzed directions clearly indicates that the keratin microfibrils are not completely disordered or randomly oriented, but rather tend to lie in one direction. The observed birefringent effects are consistent with keratin microfibrils partially aligned either parallel or perpendicular to the nail ridges. Which of these alternatives is correct cannot presently be determined. We hope our future research into the nature of fingernails will answer this question.

Thinned nails may also be examined between parallel polarizing filters (Fig. 4). The

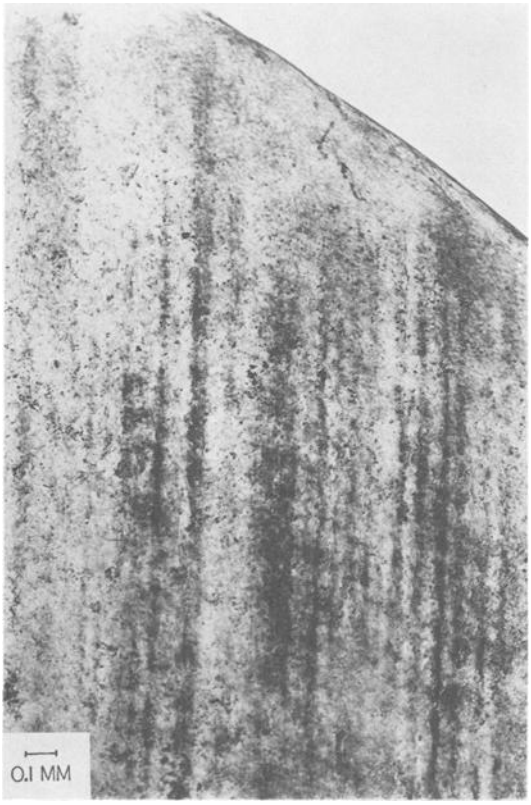

FIG. 4—*Thinned nail specimen viewed between parallel polarizing filters.*

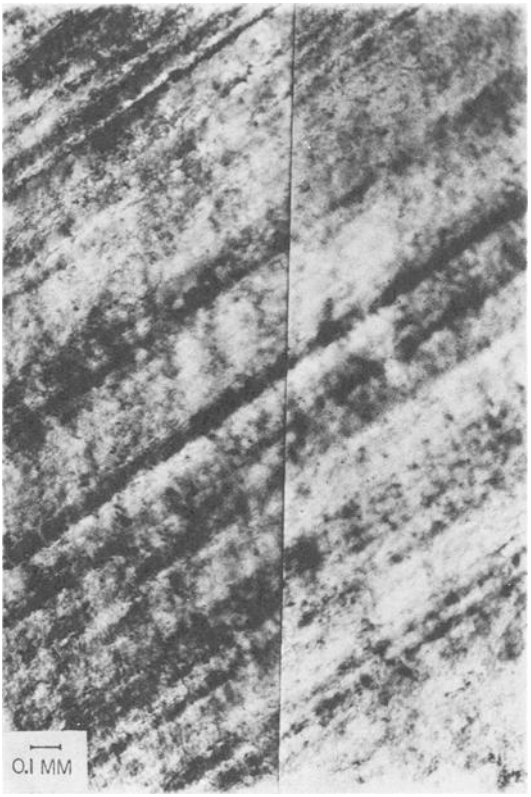

FIG. 5—*Matching of nail specimens using bands of interference colors. Specimens are clippings from the right thumb of one of the authors.*

interference colors produced in this instance are the colors complementary to those observed with crossed polarizing filters [*11,12*]. The observed colors are not as vivid as those obtained with crossed polarizing filters, but they may photograph better on black and white film. The orientation of the nail with respect to the direction of the filters is again important: the most prominent bands are obtained when the ridge direction makes a 45-deg angle with the direction of the filters.

The matching of the bands of interference colors of nail specimens from the same finger is a straightforward procedure (Fig. 5). Care must be taken, however, to orient nail specimens so that the bands of interference colors are as prominent as possible. Comparisons may be made with either crossed or parallel polarizing filters; however, because of the vividness of the colors observed with crossed polarizing filters, such an orientation of the filters is preferable.

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Address requests for reprints or additional information to
Walter F. Rowe, Ph.D.
Department of Forensic Sciences
The George Washington University
2036 H St. N.W.
Washington, D.C. 20052