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The Role of Fibers in Forensic Science Examinations

REFERENCE: Grieve, M. C., **"The Role of Fibers in Forensic Science Examinations,"** *Journal of Forensic Sciences*, JFSCA, Vol. 28, No. 4, Oct. 1983, pp. 877-887.

ABSTRACT: The purpose of this article is to draw attention to the potential of fiber evidence, and present some of the reasons why this potential appears to be currently underutilized. The author has tried to summarize state-of-the-art examination of fibers to promote interest, encourage, and assist those less experienced in this specialized field. Fibers are the most frequently encountered type of trace evidence. In comparison with other types of forensic science examinations the number of articles on fibers appearing in the relevant journals is minimal. It is however increasing, showing an awakening interest in the subject that has been given a boost by the findings in the Atlanta murders case which appears to be the first occasion of fibers playing a major part in obtaining a conviction in a case of such importance in the United States. This article presents an overview of the subject of fiber examination ranging from the collection of evidence and some of its attendant pitfalls, through basic and more advanced laboratory techniques past and present, to assessing the value of fiber evidence and commenting on how this may be improved in the future.

KEYWORDS: criminalistics, fibers, identification systems

Collection of Evidence

As with any other type of case the success of one involving fibers begins with the investigating agent. The laboratory involved cannot produce useful findings if they are given inadequate material to work with. Proper specialized scenes of crime training for field agents is imperative and in the author's current experience little attention is paid to fibers in this critical introductory phase.

How often is this also the case elsewhere? Such failure means that agents are not even aware of the possibilities of fiber evidence being useful, nor do they realize what type of examinations may be carried out in the laboratory and the implications that the results may have. The consequence of this inadequate training is poor evidence handling. Failure to consider fiber transfer from the outset may result in the wrong items being secured or lead to improper packaging of the exhibits with resultant possibilities of contamination. It is essential that fibers be considered right from the beginning of the investigation and not as an afterthought.

Here is a short summary of the most important points relating to successful collection of evidence. Chances of contamination *must* be minimized. Suspect and victim must never be interviewed in the same area or by the same agent. This could allow secondary transfer of fibers

The opinions or assertions contained herein are the private views of the author and are not to be construed as official or as reflecting the views of the Department of the Army or Department of Defense. Received for publication 22 Nov. 1982; revised manuscript received 25 March 1983; accepted for publication 1 April 1983.

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from the victim via the agent or via a chair or vehicle seat to the suspect. Crime scene searches must not be carried out by officers having contact with the suspect or with his normal environment. Transferred fibers are soon lost or re-transferred. A very high proportion may be lost during the first 4 h after the initial transfer [*1*], therefore, delay in collecting the exhibits is critical.

Clothing should be packaged as soon as possible in securely sealed brown paper or polythene bags—only *one item per bag*. Paper bags are preferable, since polythene can be destructive of certain types of biological evidence. Never allow garments from suspect and victim to rest on the same surface before packaging. If the items are wet, they should be air dried while hanging up with minimal disturbance and protected by a suitable paper container. The relevant surface of larger items, for example, sheets, blankets, and pillowcases, should be marked and the items folded neatly with that surface innermost. Small rugs or mats may be carefully wrapped and transported directly to the laboratory. Car seats should be protected with plastic sheeting. It is not practicable to search for fibers from clothing on a very large area such as a carpet, only vice versa. A portion of the carpet should be cut out so that it includes all types and colors of fibers present in the carpet and submitted as a control sample. A tape lifting is useless for a control sample as it will include stray fibers. Weapons should be securely packaged and knife blades protected against movement, or chafing will remove any fibers that were adhering to them. Fingernail scrapings, which in the author's experience rarely provide useful evidence, may be affixed to clear adhesive tape and stuck on a strip of glass or plastic (*not* card). The plastic should be thick enough so separation is easily achieved prior to examination. If ropes or string are involved the whole length should be submitted if possible, protecting the ends and indicating if one end has been cut by the investigator. Tapings at the crime scene direct from the body of a victim may yield surprising results. If the body has been wrapped in a blanket or carpet to transport it, this item may be subsequently connected with a suspect. In cases where masks have been worn, fibers may be recovered from the suspect's hair after combing with a special comb pre-packed with cotton wool [*2*].

If fibers have to be removed directly from the crime scene, that is, from a break-in or from a road accident they can be removed with *clean* forceps, provided they are clearly visible to the naked eye, and placed in a small glass or plastic container. Smaller fragments may be removed on clear adhesive tape (approximately 25 mm [1 in.] wide and 150 to 220 mm [6 to 9 in.] long is optimal).

On no account should this be stuck onto paper or cardboard or folded over upon itself, otherwise it becomes extremely difficult to search for and to remove suspect fibers. Tapings should be stuck onto a clear acetate or polycarbonate sheet that can be labeled readily and accurately with a marker pen, and then be placed in a polythene bag for transmittal to the laboratory. In my opinion collection of fibers with a vacuum cleaning device is unsatisfactory because the location from which a particular fiber originates is not precisely known. The chances of contamination are high without proper controls and the problems of separation of individual fibers from a bundle of fluff containing thousands are almost insurmountable, not to mention extremely time-consuming.

In our laboratory many cases are received in which the possibility of fiber transfer exists, but has not been considered. Any case where contact between two individuals has occurred [*3*], for example, rape, assault, or murder, must be considered to be a potential fiber transfer case. Fibers may also be used successfully to link a subject to the scene of a crime, for example:

(1) rug, carpet, car carpet, or floor covering fibers may be present on footwear or clothing;

(2) clothing fibers may be left at the point of entry at a break-in;

(3) traces from stolen material, that is, furs, carpets, clothing, or from the holders used to transport them, for example, sacking, may provide a link to the suspect's clothing, home, or vehicle;

(4) remnants of material used to make masks or to fabricate fuses of a fibrous nature for

bombing, fire raising, or other terrorist activities may be compared with similar incriminating material found in possession of the suspect; and

(5) buttons with threads adhering to them or ropes and other types of cordage may also provide valuable links.

Weapons recovered from a suspect, particularly knives, may bear fibers from the victims clothes. In some cases, such as stabbings, fibers from successive layers of clothing may be present. Tools left at a crime scene may be related to their owners by similar means. In hit-and-run auto accidents it is not uncommon to find fibers or even cloth fragments or fabric imprints on the vehicle responsible. Fiber evidence has also been used in auto accidents to determine who was driving the vehicle at the time of impact [*4*]. These examples may all seem very obvious, yet in so many instances they are overlooked. Why is this? The answer may lie within the laboratory, particularly within the United States where many laboratories only have a limited staff to handle the very large volume of work that they receive. The result is a backlog and only the most important cases receive priority. Many criminalists are obliged to be "generalists" rather than specialists. Analysts who spend the majority of their time carrying our serological examinations may also be required to examine and express opinions on plant material, wood, animal hairs, fibers, and trace evidence. They may however have little experience or knowledge of these subjects. Since they are under pressure, they seldom have the time to expand their expertise. Hence it is likely that many potential fiber cases are dismissed or at best treated in a cursory manner. Thus there is not, or has not been until now, much interest in this field, and consequently little or no feedback to investigators to generate more work. A vicious circle! Even within laboratories there seems to be a tendency for personnel not directly involved with fiber examinations to minimize their value in comparison with, for example, the more traditional field of serological evidence. It should be remembered that evidence provided from serological examinations is also only indicative and not conclusive. Just as the chances of individualizing a blood stain increase with typing a greater number of systems, so does the evidential value of fibers increase, if a greater number of factors are taken into consideration. For example, consider the number of features used to compare two fibers. From less than 1 cm of 20-μm diameter fiber it is possible to determine the following:

generic class;
polymer composition;
finish, that is, bright/dull;
cross-sectional shape;
melting point;
refractive indices;
birefringence;
color;
fluorescence;
absorption spectrum;
dye class; and
dye components.

Additional or alternative parameters may be determined depending on the fiber type. The greater the number of matching features that are shared by two fibers the higher the chance of them having a common origin. If all of these criteria are applied to several different types and colors of fibers from different garments involved in a cross transfer, then the chances of such fibers all being present by multiple coincidence is indeed remote. Location, numbers, and time also have to be considered. Great progress in techniques of comparative examination have been made during the last decade. The area of forensic science concerning fibers has now become complex enough to be considered in its own right and not as a sideline or afterthought.

Methods of Examination

Fifteen years ago the identification and comparison of fibers in forensic science laboratories were at a relatively simple level which relied heavily on microscopy [5]. Synthetic fibers were identified only by determination of sign of elongation and bireringence using a polarizing microscope [6] backed up by chemical (solubility) testing, measurement of refractive indices using the Becke line test, density and melting point determinations [7], and the preparation of cross sections [8]. The two major problems are that test methods should ideally be nondestructive and also have to be applicable to very small quantities of material. Having established that suspect and control fibers were of the same generic type, comparisons of color, width, delustrant, and cross-sectional shape were made using a comparison microscope and then fluorescence examinations under ultraviolet light were carried out as a further check. Since color played such a considerable part in comparison two problems that were given a lot of attention were whether the color of the fibers would be affected by their storage on the adhesive tape that was used to collect them [9] and whether they would be affected in any way by the mounting medium used to make permanent mounts.

Mounting media have to meet rigid criteria for forensic science work and over the years several have been tried and then discarded but these problems have now been thoroughly investigated [10]. However, new developments do not change the fact that microscopic examination and comparison is an essential first step in any fiber case.

In the 1970s two major developments occurred. One was the introduction of infrared spectroscopy to identify generic subtypes indistinguishable by microscopic examination and the other was the use of thin-layer chromatography (TLC) to examine and compare fiber dyes. At first these techniques were only applicable to large sample sizes. Various methods of preparing samples for infrared spectroscopy were proposed [11–13] and further differentiation in chemical types was found to be readily possible for acrylic [14], modacrylic,[2] and polyamide and polyester [15] fibers. The first attempts at the extraction of dyes from small quantities of textile fibers and their comparison by TLC were based on the work of Feeman [16].

In the last few years these two techniques have been refined continuously and are now routinely applicable to single fibers only a few millimetres in length and weighing as little as 1 μg. A great deal of this success has been due to the work carried out in the Metropolitan Police Forensic Science Laboratory, London [17]. The preparation of solvent cast films for recording spectra from acrylic fibers has now been further improved by Garger [18]. The use of a Diamond Cell for recording infrared spectra from single fibers was introduced in 1978 by Read and Kopec [19] and the method was then refined by Laing and Dudley at Home Office Central Research Establishment (HOCRE), Aldermaston [20]. Good quality solvent cast films and the squashed fiber films produced in a Diamond Cell can be retained and filed, thus providing an effective counter-argument to those who maintained that infrared spectroscopy is a destructive technique.

Advances in the use of TLC have involved improving techniques for dye extraction, making it possible to apply them to smaller quantities of single fiber [21]. About 5 mm of a 20-μm diameter fiber is a rough indication of the minimum quantity required but this varies depending on the color of the dye and its ease of extraction. Thanks to extensive work carried out at HOCRE, selection of suitable extracting solvents has become much less haphazard and dyes may be classified by following schematic extraction procedures that are available for wool [22], polyester, polyamide [23], polyacrylonitrile, [23.24], cellulose acetate/triacetate [25], and cotton and viscose rayon fibers [26]. Choice of suitable TLC plates and suitable eluting solvent systems [27] has widened considerably and greater experience has led to reducing time wasted in the selection of unsuccessful ones. The discriminating power of TLC has been shown to be increased by running the dyes in two different solvent systems [28,29]. The systematic choice of the best eluting systems was begun by Macrae et al [29] for wool fibers and continued by

[2]M. C. Grieve, unpublished observations.

other workers at HOCRE for dyes extracted from polyester, nylon, and polyacrylonitrile fibers [*30*] and dyes extracted from cellulosic fibers [*31*]. The importance of running dye samples from several different fibers in the control sample has become apparent especially with wool fibers where it is advisable to run several fibers. Variation on the dye used on the fibers of one synthetic garment is not as frequent, nor as extensive, but can occur.

The work of Lloyd [*32*] has contributed to improvements in the detection of fluorescent brighteners on fibers and interesting results have been obtained from colorless cotton and polyester samples. Unfortunately at the moment a relatively large quantity of material, that is, perhaps ten 1-cm threads, is required. It cannot be over emphasized that if any TLC comparisons are to be done in case work that control and suspect fibers must receive identical treatment at *every* stage of the entire examination. TLC is still particularly valuable for the examination of very dark, that is, black fibers that absorb light so strongly that they may be difficult to compare by microspectrophotometry, depending on the instrument. In the author's opinion TLC should be always used as a complementary technique to microspectrophotometry because some fibers of the same color that give the same absorption spectra may in fact be dyed with a mixture of different components.

The use of microspectrophotometry to compare color has given a new impetus to fiber examinations. It has finally removed the subjectivity from such comparisons and it does not suffer from any limitations imposed by sample size as fragments of fiber 1 mm or less in length may be examined. It is a nondestructive technique, examinations are carried out on a simple slide mount, and there are no problems when dealing with spun dyed fibers or those where the dye is too pale to produce a satisfactory result from TLC.

Most of the initial work involving microspectrophotometry was carried out in Switzerland by Halonbrenner [*33*] using a Zeiss double beam instrument. Today simpler and less expensive instruments have been developed and the technique is used routinely in all the Home Office laboratories in the United Kingdom and throughout Germany in the regional Landeskriminalamt (LKA) laboratories as well as in the Bundeskriminalamt, Wiesbaden. One of the most popular instruments is the Nanospec 10 S.

Initial work on solution coloristics using extracted fiber dyes necessitated the development of a special beam condenser and micro capillary sample holders for use with an ultraviolet/visible spectrophotometer [*34*]. This led to the possibility of color coding by converting spectral transmission or absorbance measurements to numerical chromaticity coordinates. Using a Beckman 25 instrument coupled to data processing facilities Paterson and Cook showed that this was possible for microgram quantities of textile fibers [*35*]. They then went on to show that it was possible to measure the color in situ using a Nanospec 10 S microspectrophotometer which overcame the problems of certain inaccuracies at low dilutions, difficulties caused by incomplete dye removal, and the fact that different solvents have to be used for different types of fiber. Objective color measurement gives a firm basis for the statistical evaluation of the frequency of occurrence of various fibers.

The Value of Fiber Evidence

Until very recently the significance of the findings after a fiber examination has depended on the interpretation of the reporting officer as a result of his own experience, but it is clearly impossible for him to know the true frequency of occurrence of any particular fiber type or color in various varieties of garments. Hence the value of establishing data banks to try and answer the inevitable question "how common is this type of fiber?" In 1977 a joint collection of fibers from casework was carried out by all forensic science laboratories in England to represent typical items of summer and winter clothing [*36*]. Fibers were identified and color coded using the *Methuen Handbook of Colour* [*37*] and classified according to origin and distribution of fiber type. The percentage of polyester, polyamide, and acrylic fibers found corresponded closely to World Production figures for 1976. Dominant fiber colors became apparent for the most pro-

lific fiber types. Such information is not likely to be particularly useful for anyone working in a laboratory outside the United Kingdom because of regional variations—for example, wool is one of the more common fiber types in England but is only rarely encountered in the U.S. Army Criminal Investigation Laboratory (USACIL), Frankfurt. In our laboratory, because of the Army connection, we do not really receive representative samples of clothing compared to the other laboratories in Germany.

In 1980 Home and Dudley of HOCRE [*38*] attempted to assess the power of infrared spectroscopy to discriminate within generic types and also to assess the frequency of occurrence of the major dye classes among fibers encountered in casework, to help in interpreting the value of findings on completion of examinations. It was found that acrylonitrile/methylacrylate and acrylonitrile/vinyl acetate were by far the most common of the acrylic polymer variants. Polyamides were evenly divided between Nylon 6 and Nylon 66. The frequency of the major dye classes was determined on wool, polyester, polyamide, acrylic, cotton, and viscose fibers and the results summarized. This knowledge contributed greatly to success in choosing suitable solvents for dye extractions from certain fiber types.

A major breakthrough in the storage of data by using a small computer came about as a result of the previously mentioned work of Cook and Paterson. Since it is possible to express color numerically these figures (together with other information on chemical type, cross-sectional shape, diameter, presence or absence of delustrant, and the origin of the fiber) can be conveniently stored on floppy disks and programs written to allow data searches to be made using all or only one or two parameters [*39*]. Data can be accumulated and pooled from several sources provided that there is prior agreement on which characteristics should be recorded. Caution should be exercised so that sweeping inferences are not made from a limited input of data from a restricted source.

Prior to 1975 very little published material existed on the actual process of fiber transfer. A series of papers published by Pounds and Smalldon of HOCRE summarized the most important features noticed during studies of fiber transfer [*40*], the persistence of transferred fibers [*41*], the recovery of transferred fibers [*42*], and the physical mechanisms of transfer [*43*]. This material has helped analysts to make an appraisal of the chances of transfer occuring under particular circumstances and to estimate whether an examination is likely to prove fruitful in relation to the time interval since the offense was committed and in relation to the nature of the materials involved. Problems of secondary transfer were discussed. As a direct result of the better understanding of the transfer of fibers it was possible to develop more efficient searching techniques. One of the most significant facts to emerge was that approximately 80% of transferred fibers are lost during the first 4 h after transfer.

This means that if a positive result is obtained from clothing taken within this time frame, the chances of identical fibers having originated from a different source other than the suspect one are very small, unless contact was also made with the alternative source during the same time period, otherwise the chances are that the transferred fibers would have already been lost. The number of fibers found is of course an important factor. Further findings on fiber transfer after simulated contacts which generally support the work of Pounds and Smalldon have recently been published [*44*].

The fact that no fibers are found in the transfer case does not automatically mean that no contact occurred. Garments may be made of fabric that does not shed fibers easily, if at all; the recipient garment surface may not be conducive to retention of the transferred fibers; the time interval before seizure of the garments may have been too great; fibers may have been lost by secondary transfer, an attempt at cleaning by their owner, by poor evidence handling; or there may not have been any direct contact between those particular garments even though there was contact between those wearing them. Recovery or searching techniques may be inefficient. An improved method of searching fiber tapings has recently been developed in this laboratory [*45*].

Since fibers are mass produced and garments with popular brand names may sell in thousands every year, the question must arise as to the chances of fibers that match those sought in

a case examination being present on a garment by sheer coincidence, having been transferred from a completely random nonrelated source. A study currently being carried out at the Metropolitan Police Laboratory in England [*46*] indicates that the chances of this happening are much less than might have previously been imagined. Two-hundred-and-fifty items of clothing from case work were searched for fibers indistinguishable from those of four popular mass produced garments. Matching fibers were found on only five of the garments with a maximum of only two fibers on any one item. The fibers were compared by microscopy, visible spectroscopy, and TLC. Another feature that came to light during this study was that where garments are made of a mixed fiber composition, one fiber type may shed considerably more than the other.

Another question frequently posed by the defense is "couldn't these fibers have originated from any garment of this type, color, and brand name apart from the one owned by my client?" Again, the answer is that this may be less likely than might be presupposed. The author has examined fibers from two outwardly identical jogging jackets of the same brand name which were received shortly after one another in two different cases. Each jacket contained the same four types of acrylic fiber. One was a bicomponent type and two were pale yellow. The fourth variety was a dark gray-green color of which the samples from the two jackets showed a slight but consistent color difference under the comparison microscope. TLC of the dyes extracted from these dark gray-green fibers however showed quite different components to be present in the fibers of one jacket when compared to fibers from the other jacket. Matching fibers that have the same absorption spectra occasionally give different TLC results, particularly wool fibers, and both techniques should be carried out for this reason. Occasionally fibers taken from different areas of the same garment can show a different TLC pattern for their extracted dyes, if the garment has been made up from different batches of yarn.

It is very likely that subtle alterations are made to the mixture of components in a dye bath to maintain a constant color shade during the dyeing of successive batches of fiber. When a new dye solution is made up, some of the original components may not be available, but others can be substituted to give the same end color.[3]

Animal and Vegetable Fibers

These are not encountered very frequently in most forensic science laboratories and perhaps for this reason most of the techniques used in their examination are well-established ones and references to these subjects are relatively scarce. Animal hairs are usually characterized by three types of examination. The first is microscopical, initially by using a low power stereoscope to look at general form and shape, scale pattern, medullary structure, distribution of pigment, and so on. A scanning electron microscope may also be used to examine scale patterns and their changes along the length of the hair in much greater detail. In the absence of such a facility it is normal practice to examine the scale patterns by a process known as casting or replication. There are various alternative ways of doing this [*47*] but basically they all involve placing the hair in a medium which will harden around its lower surface allowing the hair to be easily removed after setting leaving behind the impression of the scales. Very good results can be achieved after a little practice. The third method of examination is to embed the hairs in a suitable medium such as a methacrylate based cement [*8*] and then cut sections using a microtome. Selection of a suitable cement is critical in obtaining good sections. Cross sections are useful in examination of shape, medullary form, pigment distribution, and cuticle thickness. Extensive photographs and keys involving such characteristics as scale patterns, medulla type, and cross-sectional shape form the basis of various reference books [*48–51*] commonly used to assist in the identification of unknown

[3]R. Cook, personal communication.

samples. Length is a feature also mentioned in some keys, but the limits quoted should be treated with a degree of caution. It is vital to compare unknowns with hairs of known origin from a reference collection not only microscopically, but using the other techniques as well. Even this is not infallible and it is important not to overstate conclusions. This was admirably demonstrated by the results of a recent Crime Laboratory Proficiency Testing Program [*52*].

There appears to have been a revival of interest in the use of medullary fraction analysis [*53*] to discriminate between very similar hairs, in this instance cat and dog. A computer was used to evaluate the results along with other information derived in the study [*54*].

Techniques used for the identification of vegetable fibers include microscopy on temporary mounts, before or after maceration, to observe various botanical features; ashing the sample in an oven and subsequent examination for the presence of certain types of characteristic crystals; and examination of cross sections prepared exactly the same way as for other fiber types. Conclusions should not be reached without consulting Refs *55–57* and examining known control samples. Most laboratories probably have difficulty in establishing an adequate collection of vegetable fibers to use as standards. The characteristics attributed to various vegetable fibers vary in different reference works and caution is necessary in interpretation. Polarized light and interference microscopy [*58*] have also been used in distinguishing between such vegetable fibers as hemp and flax. Vegetable fibers can cause many problems for a forensic science analyst, particularly if he/she has no botanical training.

Future Developments

Many instrumental techniques have been tried in recent years to find additional or improved means of characterizing the polymer materials used in the manufacture of synthetic fibers. Ardrey, et al [*59*] used pyrolysis/mass spectroscopy (MS) to classify a series of polyester samples. Their results were parallel to those of Grieve and Kotowski [*16*] who examined the same samples using infrared spectroscopy. Fibers of chemically distinct polyester types may be readily distinguished but homopolymers of poly(ethylene terephthalate) (PET) all give qualitatively similar pyrograms. The pyrolysis/MS technique however only required 5-mm sample lengths. The potential of this technique was discussed by Hughes and others [*60*] who considered that sensitivity was such that detection limits are imposed by sample handling rather than instrumental limitations.

Thermogravimetric analysis enabled Ardrey et al [*61*] to classify 27 acrylic fibers into 14 groups, but sample sizes of 500 to 800 μg were used. Bortniak and others [*62*] had already shown it was possible to classify the same number of acrylic samples into 15 groups using a pyrolysis GC technique that required only 40 μg of sample. The sensitivity of thermogravimetric analysis may be vastly improved by combining the technique with MS allowing data to be obtained from 10 μg samples of acrylic fiber [*63*]. Trace element analysis by X-ray fluorescence spectrometry would be possible on the residue of samples examined by thermogravimetry/MS. Capillary pyrolysis/GC appears to be a technique that can produce very promising results. Gunthur et al [*64*] claimed that the method not only allowed distinction between polyesters from different manufacturers and between different production types but also can provide information on dye "carriers" and polymers of mixed composition. No information is given concerning sample size.

Elemental composition of synthetic fibers can be determined by using an electron probe in conjunction with energy dispensive X-ray [*65.66*]. Detection of trace element "markers" has been a much talked about topic for many years but as yet has yet to bear fruit. Application of new methods to very tiny samples still remains a problem.

The search for new fiber-forming polymers continues together with modification and copolymerization to existing types to improve their physical properties or make them more suitable for specific or specialty end use. Familiar fiber types continue to appear with unfamiliar cross sections or other new physical or chemical modifications. However as new analytical

techniques become available and existing ones improve to allow the determination of more and more points of comparison so the value of fiber evidence will continue to rise accordingly.

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