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Fibre Discrimination by Various Tests and Analytical Techniques
(Diskriminasi Serat menggunakan Pelbagai Ujian Saringan dan Teknik Analitikal)

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ABSTRACT

Fibres are important trace evidence that can be found during the course of crime scene investigation. The identification and analysis of these fibres shed light as to the circumstances surrounding a particular crime. Identifying the factors that affect the transference of fibres under various environments are crucial in providing robust conclusions of a case per se, as highlighted in this work. Donor garments were made up of four different types of fibre; 100% cotton, 100% nylon, 100% polyester and 100% wool, that were used to observe the differences in the number of transferred fibres to the recipient garment (100% cotton) and vice versa with increasing contact times of 30, 60, 180, and 300 seconds respectively. To simulate contact between the donor garment worn by a suspect and the recipient garment worn by a victim in real-life situations, the donor garment was placed on top of the recipient garment which was laid on a piece of plywood. The numbers of transferred fibres, both from the donor to the recipient garment and from the recipient to the donor garment were observed and tested using microscopic examination, burning test, solubility test and dye extractability test. Results indicated that different types of garments transferred different number of fibres with increasing contact times, and the identification of the fibres are possible via the different tests applied in this work.

Keywords: Fibre transfer; microscopic examination; burning test; solubility test; dye extraction test

ABSTRAK

Serat merupakan salah satu bahan bukti surih penting yang boleh dijumpai semasa penyiasatan kes jenayah. Identifikasi dan analisis serat boleh membantu dalam siasatan jenayah. Identifikasi faktor-faktor yang mempengaruhi perpindahan serat dalam pelbagai keadaan adalah penting untuk konklusi sesuatu kes, seperti di dalam kajian ini. Pakaian penderma adalah diperbuat daripada empat jenis serat; 100% kapas, 100% nilon, 100% poliester dan 100% bulu biri-biri, yang digunakan untuk melihat perbezaan jumlah serat yang berjaya dipindahkan kepada pakaian penerima (100% kapas) dan sebaliknya dengan pertambahan masa sentuhan; 30, 60, 180, dan 300 saat. Untuk mereplikasikan hubungan antara pakaian penderma yang dipakai oleh suspek dan pakaian penerima yang dipakai oleh mangsa seperti dalam kes sebenar, pakaian penderma diletakkan ke atas pakaian penerima yang dibentangkan di atas sekeping papan lapis. Jumlah serat yang berjaya dipindahkan dari pakaian penderma kepada penerima dan sebaliknya dikira dan beberapa ujian serta teknik analisis: pemeriksaan mikroskopik, ujian pembakaran, ujian kelarutan dan ujian kebolehupayaan extrak pewarna telah dijalankan. Keputusan kajian menunjukkan bahawa jenis pakaian berbeza memindahkan jumlah serat berbeza dengan pertambahan masa sentuhan dan serat boleh didiskriminasikan dengan menggabungkan pemerhatian daripada semua ujian yang dijalankan.

Kata kekunci: Perpindahan serat; pemeriksaan mikroskopik; ujian pembakaran; ujian kelarutan; ujian kebolehupayaan extrak pewarna

INTRODUCTION

The basis of any crime scene investigation falls on a principle developed by Dr. Edmond Locard (1877-1966) (Saferstein 2017), which states ‘every contact leaves a trace’. Most crimes involve physical contact of some kind, either directly or indirectly, between the three categories in a crime triangle; victim/s and suspect/s, victim/s and crime scene or suspect/s and crime scene (Mitchell & Holland 1979). The cross transfer between two or more of these categories leave traces that in turn aid in the investigative process by providing evidence for investigators to find and analyse.

Observation of foreign material on a particular surface can be an indicator of potential transferred evidence between two or more categories in a crime triangle (Aitken & Stoney 1991). Soil, fingerprint, footprint, blood, fluids, hair, fibre and paint are common examples of these transferred evidence. Recently, many forensic scientists have appreciated the use of transferred fibre to provide additional evidence in criminal cases (Singh & Singh 2013). Criminals can unconsciously touch certain items at a crime scene, hence increasing the chances of fibre transfer between persons and their surroundings (Singh & Singh 2013). The most frequent fibre transfer in criminal cases is the cross transfer between different individuals; usually in rape, murder, kidnapping and assault cases, whereby rough / violent contact between individuals involved had occurred (Pounds & Smalldon 1975a). Fibres also can be transferred between an individual and an object, and between two objects (Deedrick 2000; Muzaiyana et al. 2016). Whether a fibre is transferred and detected is largely dependent on the nature and duration of contact between the suspect and the victim or crime scene, the persistence of fibres after the transfer, and the types of fabric involved during contact (Deedrick 2000). Pounds & Smalldon (1975a) noted that the number of transferred fibres between wool and acrylic garments against a laboratory coat increased with increasing pressure and decreased when the contacts between individuals were repeated. However, these numbers can be affected by the persistence certain types of fibre on the recipient garment. This is proven by a research done by Robertson et al. (1982). It was noted that transferred fibres persistence was lessened by (1) wearing the recipient garment, (2) wearing other garments over the recipient, (3) transfer of fibres to a site on the recipient garment subject to contact with other surfaces such as in arm movement, (4) low pressure in the transferring contact and (5) fibre size, where fibres of less than 2-5 mm length were lost at a slower rate in comparison to longer fibres (Robertson et al. 1982). Therefore, it can be concluded that transferred fibres with higher persistence has higher possibilities of recovery.

Fibre examinations have been conducted for many years based on the idea of contact transfer (Nickolls 1956). Contact transfer refers to the fibres of textile donors that are transferred to another item via direct contact (primary transfer) or fibres from the surface of a textile donor are transferred together with primary fibres (secondary transfer) (Nehse 2011). Many scientists have argued about the general characteristics of fibres that are not unique can never be said that it comes from a specific garment because fibres are not individualistic enough, hence it is often classified as a class characteristic. However, this class characteristic can still play a major/supporting role in cases where identification of the perpetrator in a line-up of perpetrators wearing garments of similar colour but from different types of fibre. Therefore, for this reason, the current study uses simple methods for fibre identification by examining factors affecting transferred fibres upon contact between each material (increasing contact times) and the ability to discriminate transferred fibres upon contact.

Donor garments that were used in this study were of natural and synthetic origin. Natural fibres (such as cotton and wool) are any hair-like raw material directly obtained from animals, vegetables or mineral source and convertible into non-woven fabrics such as felt or after spinning into yarns or woven cloth (Praveenkumara et al. 2017). On the other hand, synthetic fibres are man-made textile fibres including those from natural materials (such as rayon and acetate from cellulose) that have been processed extensively as well as fully synthetic fibres such as nylon or acrylic (Preston 2016).

Natural fibres are known for its outstanding properties of being low weight, recyclable, and biodegradable. Natural fibres originating from plants source like cotton fibres are composed of 90% α-cellulose. The non-cellulosic components are located on the outer layers of the wall or inside the lumens of the fibres whereas the secondary cell wall is purely cellulose. The percentages of the cellulosic and non-cellulosic components depend largely on the plant species and the growing conditions they are adhered to (Chen 2014). Cotton in particular is relatively strong as it is able to resist being pulled or torn apart when undergoing tension. Cotton is also very absorbent depending on levels of yarn twisting and the fabric structure. Low twist yarn and looser structure will be more absorbent compared to high twisted yarn and tight structure (Boier 2010).

Wool is the natural protein fibre obtained from sheep and certain other animals, including cashmere and mohair from goats, angora from rabbits and other types of wool from camel (Rahman 2018). These fibres belong to a group of proteins known as keratins. It has heterogeneous composition where the protein is made up of amino acids and acidic carboxyl groups. The surface of wool fibres is made up of overlapping cuticles. This property gives an appearance of a scaly surface, which is very different from the smooth surface of synthetic fibres (Wood 2010). Wool differs from silk based on their composition, elasticity, strength, and thermal properties. Wool is composed of hydrogen, carbon, sulphur, and nitrogen. Meanwhile, silk is composed of hydrogen, carbon, oxygen, and nitrogen (Sayed 2015). Wool is more elastic and resilient compared to silk as it possesses folded poly-peptide chain, while silk has extended polypeptide chains. Wool has more amorphous areas and is more absorbent compared to silk that is very crystalline in structure and less absorbent. Silk is also more sensitive to heat compared to wool (Sayed 2015).

Polymers on the other hand made up of heavier and bigger molecular compound of synthetic origin (Preston 2016). One of the features common to all the fibre-forming polymers is the linear structure. Polymers are built up by the joining together, through strong covalent bonds of smaller molecular units known as monomers (Preston 2016). When these monomers are joined end-to-end like links along a chain, a polymer with a simple linear structure is formed. In some polymers, shorter chains grow off the long chain at certain intervals, so that a branched structure is formed. In this project, synthetic fibres involved are of polyester and nylon origin. For polyester fibres, the monomers involved are dicarboxylic acid and a diol (University of York Centre for Industry Education Collaboration 2016). Polyester fibres can either be in form of aromatic or aliphatic polyesters (East 2009). Nylon is made by reacting monomers either lactams, acid/amines or stoichiometric mixtures of diamines and di-acids. Majority of nylons tend to be semi-crystalline, forming a tough material with good thermal and chemical resistance.

As discussed previously, most crimes involve some sort of contact between two or more mediums and this will likely cause the transfer of fibres especially in cases involving violence. The number of transferred fibres after each contact depends on the nature of the fibres used to make the garments, the surface texture, magnitudes of force applied and the frequency of contact (Robertson et al. 2002). Any transferred fibres at the crime scene may be crucial evidence in order to connect the suspect to the crime scene or with the victim involved (Cook & Wilson 1986). Therefore, it is very important to identify the origin of the transferred fibres to facilitate successful identification to support other related circumstantial evidences.

Realizing this fact, this study was conducted and the aims were to observe the number of transferred fibres with increasing contact times and to discriminate fibres by various tests and analytical techniques: microscopic examination, burning test, solubility test and dye extractability test. The results from one or more of the methods can be used for positive identification of the transferred fibres. For this study, cotton and wool represent natural fibres while nylon and polyester represent synthetic fibres. Cotton was chosen as the recipient garment because it is known worldwide as the major fibre used in the textile industry (Shaw 1998). The reason for choosing other textile materials (wool, polyester, nylon) is an arbitrary decision.

METHODOLOGY

In this project, a recipient garment indicates the garment worn by victim during crime occurrence. Meanwhile, donor garments indicate the garments possibly worn by the suspect during the crime.

TYPES OF FIBRES

The recipient garment used in this experiment was made from 100% cotton fibres, while donor garments used were made of 100% cotton fibres, 100% polyester fibres, 100% nylon fibres and 100% wool fibres. Different colour between the recipient garment and donor garments were used to facilitate the identification process of transferred fibres for lifting and during microscopic examination. Table 1 tabulates the garments and labelling of fibres used in this study.

TABLE 1.Types of garments used and their surface texture

	Number of garments used	Type of garments	Colour of garments	Surface texture
Donor garments				
100% Cotton (D1)	1	T-shirt	Black	Soft, Smooth
100% Cotton (D3)	1	T-shirt	Black	Soft, Smooth
100% Nylon (D2)	1	T-shirt	Black	Soft, Smooth
100% Polyester (D4)	1	T-shirt	Black	Soft, Smooth
100% Wool (D5)	1	T-shirt	Black	Soft, Smooth
		Sweater	Black	Rough
Recipient garment				
100% Cotton (R)	1	T-shirt	Blue	Soft, Smooth

PREPARATION OF REFERENCE SAMPLES

Reference fibre samples were obtained from all garments involved in this study; donor and recipient garments, before contact occurred, and the fibres obtained was visualised under a stereomicroscope (Leica DM500M). This is done to identify the physical features for fibres of interest such as colour and appearance of the fibres under the microscope before proceeding the study. This is important to ensure easier identification for the later part of the study that involves the transfer of fibres. The reference fibres were collected by tape lifting method using clear adhesive tape (Brand UNICORN OPP, size 48 mm x 40 TR 1'S). The lifting was conducted done on the front part of donor and recipient garment (between chest and waist) that involved in the contact (30 cm × 30 cm). Lifting was done once for each sampling. The tape was then pasted on a clear and transparent plastic sheet.

METHOD OF TRANSFERENCE

Foreign fibres are fibres that do not originate from the garment itself. They can present themselves on a garment due to contact, such as contact with a person or contact from another fibrous or non-fibrous surface. All garments used in this project were examined using a magnifying glass and any foreign fibres found on them were removed prior to contact simulation. Contact simulation occurs when a donor garment and the recipient garment was applied on two different pieces of plywood, to simulate two different garments worn by two different humans. Then both garments were placed on top of each other, the front part of donor garment was facing the front part of the recipient garment. A 3250 g iron disc was placed on the back of donor garments for four different periods of time; 30, 60, 180 and 300 seconds as shown in Figure 1. Both garments were then examined for any transferred fibres, which were collected using tape lifting method and analysed using the

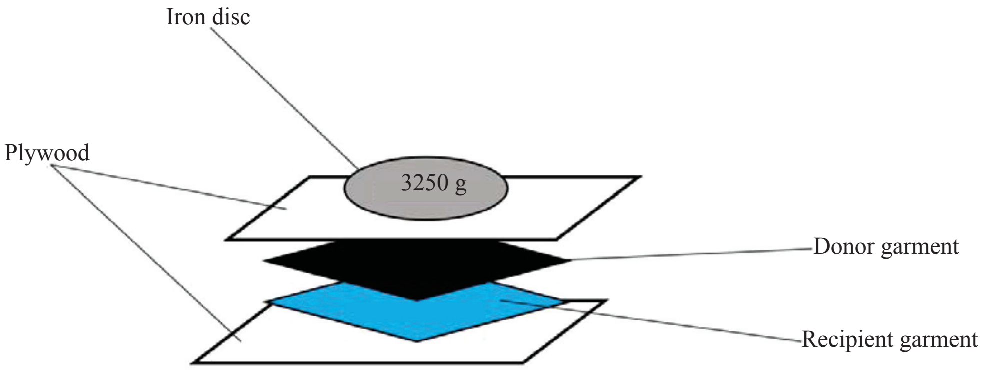

FIGURE 1.A 3250g iron disc was placed on the plywood to simulate a contact

previously described methods (microscopic examination, burning test, solubility test, dye extraction test). The lifting is done once, on the front part of donor and recipient garment (between chest and waist) that involved in the contact (30 cm × 30 cm). Both garments were carefully examined again to remove any foreign materials before the next contact simulation. These steps were repeated with all donor garments (D1 to D5).

RECOVERY OF TRANSFERRED FIBRES

The recovery of transferred fibres was done using a tape-lifting method (clear adhesive tape brand UNICORN OPP, size 48 mm x 40 TR 1'S). An area measuring 30 cm × 30 cm (front part of the donor and the recipient garments, between the chest and waist) was selected for tape lifting in order to collect any transferred fibres. Previous research suggested that tape lifting was very convenient and a good method for the recovery of fibres (Grieve 2002) and it recovered over 90% of extraneous fibres that had been transferred by direct contact with the donor (Schotman & van der Weerd 2015). Tape lifting was done once for each simulation and then pasted on a clear and transparent plastic sheet. A grid of approximately 2 cm × 3 cm was drawn on the tape to facilitate observation of fibres using a stereomicroscope. The images (100× magnification) were captured using LEICA application suite/software LAS EZ. The labelling for transferred fibres is shown in Table 2. Fibres from the recipient and donor garments were differentiated based on colours and appearance under microscopic examination (Wong et al. 2016).

FIBRE BURNING TEST

Transferred fibres were removed from the tape using acetone. The fibres were then allowed to dry at room temperature for at least three minutes. After that, the individual fibres were burnt using a flame from a Bunsen burner for 10 seconds. This step is repeated three times by using different fibers from the same garment. Several observations related to the fibres were recorded: while

TABLE 2.Labelling the transferred fibre samples observed under stereomicroscope

Sample	Description
D1-R	Transferred fibres from D1 to recipient
R-D1	Transferred fibres from recipient to D1
D2-R	Transferred fibres from D2 to recipient
R-D2	Transferred fibres from recipient to D2
D3-R	Transferred fibres from D3 to recipient
R-D3	Transferred fibres from recipient to D3
D4-R	Transferred fibres from D4 to recipient
R-D4	Transferred fibres from recipient to D4
D5-R	Transferred fibres from D5 to recipient
R-D5	Transferred fibres from recipient to D5

approaching the flame, in the flame, removal from the flame, odour and residue.

FIBRE SOLUBILITY TEST

Transferred fibres were removed from the tape using acetone and allowed to dry at room temperature. The fibres were then immersed in four different type of solvents: 75% sodium hydroxide (NaOH), 40% sulphuric acid (H_2SO_4), 85% formic acid and dimethyl formamide (DMF). These solvents were chosen based on the technical procedure issued by Physical Evidence Section Forensic Scientist Manager (2014). Once the fibres were immersed in the solvents, its' solubility were observed by looking at the length of the fibres before and after immersion. If the length of the fibers decreased after the immersion, it can be said that the fibers are soluble in the specific solvent.

DYE EXTRACTABILITY

Transferred fibres were removed from the tape using acetone and allowed to dry at room temperature for five minutes. Fibres were then placed into three different types of solvents: Absolute acetic acid (100%), 20% sodium hypochlorite and 99.8% pyridine to observe the dye extractability. For each solvent, three fibers were used for this method. The dye extractability from the fibres were observed by looking at the changes in the colour of the solvents used (the solvents are colourless) and fibres.

RESULTS AND DISCUSSION

NUMBER OF TRANSFERRED FIBRES RECOVERED BETWEEN THE RECIPIENT AND DONOR GARMENTS

Numbers of transferred fibres between the recipient and donor garments are shown in Table 3 and Table 4 respectively.

When looking at the fibres on the recipient garment, as the duration of contact increases, transferred fibres from all donor garments (D1, D2, D3, D4, D5) to the recipient garment showed an increasing trend. Based on Table 3, at 300 seconds, the highest number of transferred fibres from donor to the recipient garment was 195 for D5 (wool) and the lowest is D2 (Nylon) (31 fibres). In terms of the number of fibres transferred from the recipient garment to all donor garments (D1, D2, D3, D4, D5), an increasing trend is also observed with increase in contact duration. The highest number of transferred fibres from the recipient to donor garments at 300 seconds is D1 (cotton) with 266 fibres and the lowest is D5 (wool) with 31 fibres (Table 4). Surface texture can be used as a preliminary method to distinguish and discriminate different types of fibres. Table 3 showed that wool (D5) gave the highest total number of transferred fibres (195) to the recipient garment because it is rougher than other donor garments. Rough surface garments have more fragmentations of fibres, causing the fibres to be easily transferred to recipient garment as compared to smooth donor garment, during contact, as suggested by previous researcher (Roux & Robertson 2013).

Table 3 also showed that polyester (D4) gave the second highest total number of transferred fibres (177) to the recipient garment, followed by cotton (D3) with 43 transferred fibres, cotton (D1) with 40 transferred fibres, and nylon (D2) with 31 transferred fibres. Even though the surface texture for these fibres are quite similar (soft and smooth surface), the total number of fibres that were successfully transferred from donor garments to recipient garment differ especially between polyester garment and other donor garments (cotton and nylon fibres).

Pounds and Smalldon (1975a) noted that, number of transferred fibres will increase simultaneously when the duration of contact is increased, supporting the results of this current study. Prolong duration of contact will increase the number of transferred fibres between recipient and donor garments, as suggested by the mechanism of fibre transfer. There were three mechanisms of fibre transfer between garments; (1) transfer of loose fibre already on the garment itself, (2) fibres forcefully being pulled by friction upon contact and (3) fibre fragments being transferred from the contact between garments (Pounds & Smalldon 1975b).

TABLE 3. Number of transferred fibres from different donor garments to the recipient garment

Duration of contact (sec)	Type of donor garment				
	D1 (Cotton)	D2 (Nylon)	D3 (Cotton)	D4 (Polyester)	D5 (Wool)
30	4	1	9	29	35
60	6	4	7	40	31
180	13	12	11	52	57
300	17	14	16	56	72
Total of fibres transferred	40	31	43	177	195

TABLE 4.Number of transferred fibres from the recipient garment to different donor garments

Duration of contact (sec)	Number of transferred fibres from recipient garment to different donor garments				
	D1 (Cotton)	D2 (Nylon)	D3 (Cotton)	D4 (Polyester)	D5 (Wool)
30	48	9	52	51	6
60	44	13	61	54	8
180	79	13	93	73	7
300	95	18	92	87	10
Total of fibres transferred	266	53	298	263	31

As shown in Table 3, all types of fibre showed increasing trend on number of fibres being successfully transferred to recipient garment with increasing contact time. It is also noted that wool (D5) donor garment contributed to the highest total number of fibres transferred (195 fibres) with 35 fibres when in contact with recipient garment for 30 seconds, slightly decreased at 60 seconds with 31 fibres transferred, and continue to increase at 180 seconds and 300 seconds with 57 and 72 fibres transferred respectively. Slight decrease at 60 seconds of contact between wool and recipient garment can also be seen during contact between cotton (D3) and recipient garment. The number of transferred fibres decreased from 9 fibres at 30 seconds to 7 fibres at 60 seconds. These were probably caused by errors during the process of recovering transferred fibres from recipient garment or during the counting of fibres under the microscope. Meanwhile, Table 4 show the number of fibres transferred from recipient to donor garments at four different duration of contact. Similar increasing trend can be seen for all fibres transferred from recipient to donor garment. Cotton (R) transfers the highest total number of fibres to other cotton type (D3) donor garment (298 fibres), with 52 fibres when in contact for 30 seconds, increased to 61 and 93 fibres at 60 and 180 seconds respectively, and decreased slightly at 300 seconds with 92 fibres successfully transferred. This slight decrease in the number of fibres transferred can also be seen in cotton (D1) at duration of contact 60 seconds. The number of fibres transferred decreased from 48 fibres at 30 seconds to 44 fibres at 60 seconds. These decreased numbers were probably caused by random errors that can be minimised by increasing number of sampling under same condition and asking another person to do the counting for a second time for confirmation.

MICROSCOPIC EXAMINATION OF REFERENCE FIBRES SAMPLES

Reference fibre samples were observed using a stereomicroscope followed by transferred fibre samples. The results are shown in Table 5 and Figures 2-7 illustrate the morphology of the reference fibres samples whereas Table 6 shows morphology of the transferred fibres samples microscopically.

TABLE 5. Microscopic examination of reference fibres samples

Sample	Description	Fibre type
Reference fibres samples		
D1 (*Figure 3*)	Ribbon-like appearance, twisted, long	Cotton
D2 (*Figure 4*)	Rod-like appearance, short	Nylon
D3 (*Figure 5*)	Ribbon-like appearance, twisted, long	Cotton
D4 (*Figure 6*)	Rod-like appearance, short	Polyester
D5 (*Figure 7*)	Presence of scale on epidermis	Wool
R (*Figure 8*)	Ribbon-like appearance, twisted, long	Cotton

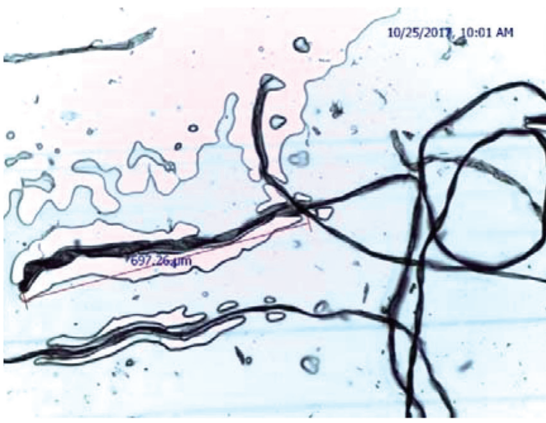

FIGURE 2. D1 (Cotton)

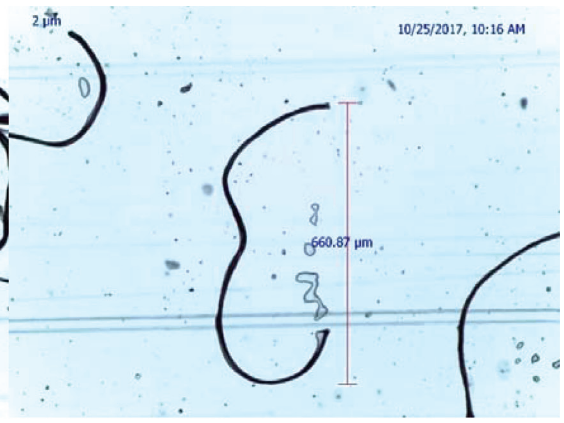

FIGURE 3. D2 (Nylon)

Description for (R-D1), (R-D2), (R-D3), (R-D4) and (R-D5) are similar because the transferred fibres originated from the same source, the recipient garment. Synthetic fibres (nylon and polyester) can be discriminated microscopically from natural fibres (cotton and wool) (Farah et al. 2015). Synthetic fibres have shorter fibre fragments compared to natural fibres. However, it is hard to differentiate between nylon and polyester, microscopically because of their similar morphology (rod-like appearance, short). This is not the case with natural fibres as each of their morphology their morphology differs from one another. When observed under microscope, longitudinal view and cross sectional view for cotton and wool fibres showed some differences. As for cotton fibres, the longitudinal view showed

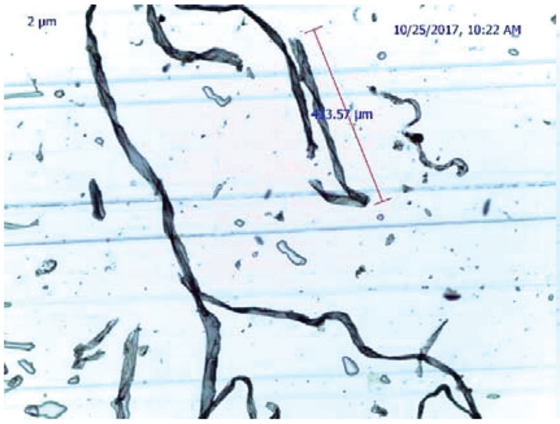

FIGURE 4. D3 (Cotton)

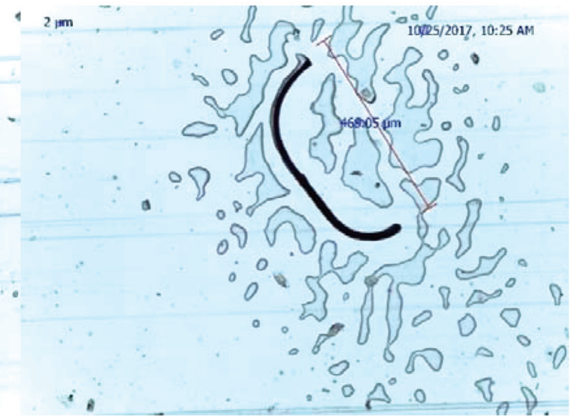

FIGURE 5. D4 (Polyester)

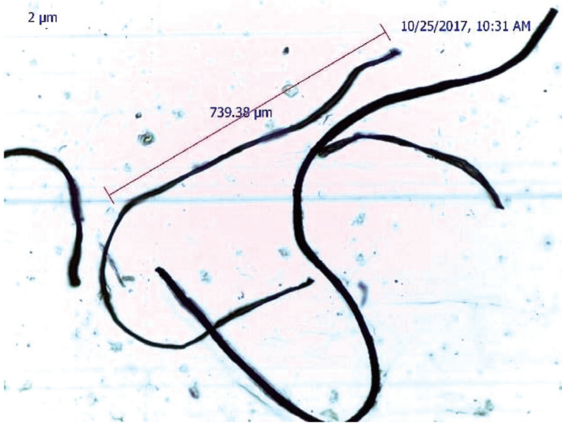

FIGURE 6. D5 (Wool)

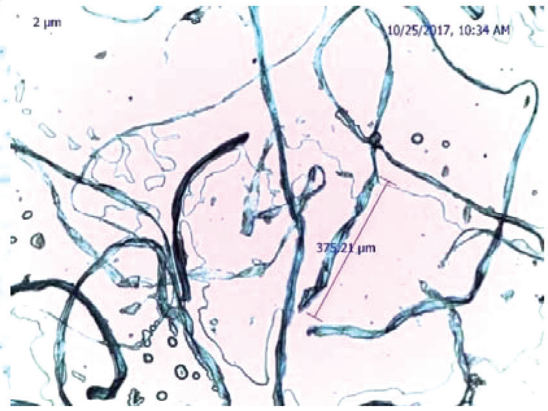

FIGURE 7. R (Cotton)

TABLE 6.Microscopic examination of transferred fibres samples

Sample	Description	Fibre type
Transferred fibres		
D1-R	Ribbon-like appearance, twisted, long	Cotton
R-D1	Ribbon-like appearance, twisted, long	Cotton
D2-R	Rod-like appearance, short	Nylon
R-D2	Ribbon-like appearance, twisted, long	Cotton
D3-R	Ribbon-like appearance, twisted, long	Cotton
R-D3	Ribbon-like appearance, twisted, long	Cotton
D4-R	Rod-like appearance, short	Polyester
R-D4	Ribbon-like appearance, twisted, long	Cotton
D5-R	Presence of scale on epidermis	Wool
R-D5	Ribbon-like appearance, twisted, long	Cotton

appearance of flat and ribbon-like fibres with convolutions and lumen may be present. For its' cross sectional view, the fibres can be observed as kidney-shaped and appeared very thin similar to a strip. Meanwhile for wool fibres, appearance of cylindrical, irregular and scale-like structure can be observed. Its' cross sectional view showed nearly round or circular shaped and medulla may appear.

FIBRE BURNING TEST

Both reference fibres samples and transferred fibres were brought to approach the flame. The fibres characteristic when approaching the flame, in the flame, when removed from the flame, the odour produced and the residue left were observed and recorded in Table 7 (reference fibres samples) and Table 8 (transferred fibres).

TABLE 7. Characteristic of reference fibres samples in burning test

Sample	Approaching flame	In the flame	Removed from flame	Odour	Residue
Reference fibres samples					
D1 (Cotton)	Ignites	Burn quickly	Not self-extinguished	Burning paper	Grey ash
D2 (Nylon)	Shrinks	Burn quickly, melt	Self-extinguished	Burning plastic	Hard, brown bead
D3 (Cotton)	Ignites	Burn quickly	Not self-extinguished	Burning paper	Grey ash
D4 (Polyester)	Shrinks	Burn quickly, melt	Self-extinguished	Sweet smell	Dark, hard bead
D5 (Wool)	Shrinks	Burn slowly	Self-extinguished	Burning hair	Black, hollow bead
R (Cotton)	Ignites	Burn quickly	Not self-extinguished	Burning paper	Grey ash

TABLE 8.Characteristic of transferred fibres in burning test

Sample	Approaching flame	In the flame	Removed from flame	Odour	Residue
Transferred fibres					
D1-R	Ignites	Burn quickly	Not self-extinguished	Burning paper	Grey ash
R-D1	Ignites	Burn quickly	Not self-extinguished	Burning paper	Grey ash
D2-R	Shrinks	Burn quickly, melt	Self-extinguished	Burning plastic	Hard, brown bead
R-D2	Ignites	Burn quickly	Not self-extinguished	Burning paper	Grey ash
D3-R	Ignites	Burn quickly	Not self-extinguished	Burning paper	Grey ash
R-D3	Ignites	Burn quickly	Not self-extinguished	Burning paper	Grey ash
D4-R	Shrinks	Burn quickly, melt	Self-extinguished	Sweet smell	Dark, hard bead
R-D4	Ignites	Burn quickly	Not self-extinguished	Burning paper	Grey ash
D5-R	Shrinks	Burn quickly	Self-extinguish	Burning hair	Black, hollow bead
R-D5	Ignites	Burn quickly	Not self-extinguished	Burning paper	Grey ash

Results for D1, D3 and R are similar for reference fibres because they are from cotton (Table 7). Nylon and polyester show similar characteristics when approaching the flame, in the flame and removed from the flame, but differ in odour and residue left behind. Burnt nylon fibres gave off burning plastic odour and hard, brown beads were left behind as residue. Meanwhile for burnt polyester fibres, it gave off a sweet smell and left behind dark and hard beads as residue. D5 (wool) can be distinguished from other garments as it left behind black and hollow beads as residue. These hollow beads can easily be crushed and destroyed.

Description for (R-D1), (R-D2), (R-D3), (R-D4), and (R-D5) are similar for transferred fibres because the transferred fibres originated from the same source, the recipient garment (Table 8). The results showed that synthetic fibres portrayed similar characteristic: Shrank when approaching the flame, melt in the flame and self-extinguished. These characteristics can be used to assist in discrimination of synthetic fibres from natural fibres because natural fibres do not melt in the flame and continue burning for some time after removed from the flame. However, it is apparent that many fibres have similar burning reactions that might cause doubt and occasional confusion.

FIBRE SOLUBILITY TEST

Both reference fibres samples and transferred fibres were submerged into four different solvents; H_2SO_4, NaOH, formic acid and DMF. The results were tabulated in Table 9 for reference fibre samples and Table 10 for the transferred fibres. Results for D1, D3 and R are similar for reference fibres because they are from similar type of fibre; cotton (Table 9).

TABLE 9.Solubility of reference fibre samples

Sample	Solvent			
	75% H2SO4	40%NaOH	85% Formic acid	DMF
Reference				
D1	Soluble	Insoluble	Insoluble	Insoluble
D2	Soluble	Insoluble	Soluble	Insoluble
D3	Soluble	Insoluble	Insoluble	Insoluble
D4	Insoluble	Soluble	Insoluble	Soluble
D5	Insoluble	Soluble	Insoluble	Insoluble
R	Soluble	Insoluble	Insoluble	Insoluble

TABLE 10.Solubility of transferred fibres

Sample	Solvent			
	75% H2SO4	40%NaOH	85% Formic acid	DMF
Transferred fibres				
D1-R	Soluble	Insoluble	Insoluble	Insoluble
R-D1	Soluble	Insoluble	Insoluble	Insoluble
D2-R	Soluble	Insoluble	Soluble	Insoluble
R-D2	Soluble	Insoluble	Insoluble	Insoluble
D3-R	Soluble	Insoluble	Insoluble	Insoluble
R-D3	Soluble	Insoluble	Insoluble	Insoluble
D4-R	Insoluble	Soluble	Insoluble	Soluble
R-D4	Soluble	Insoluble	Insoluble	Insoluble
D5-R	Insoluble	Soluble	Insoluble	Insoluble
R-D5	Soluble	Insoluble	Insoluble	Insoluble

Observation for (R-D1), (R-D2), (R-D3), (R-D4), and (R-D5) are similar for transferred fibres because the transferred fibres originated from the same source, the recipient garment. For the solubility test, nylon (D2) is soluble in formic acid, polyester (D4) is soluble in DMF and polyester (D4) and wool (D5) are soluble in NaOH. Cotton fibres failed to be differentiated using this method as both cotton fibres from donor garments were soluble in 75% sulphuric acid. These observations matched with previous researches (Appleyard 1978; Corbman 1983; Physical Evidence Section Forensic Scientist Manager 2014). However, results from this study did manage to reveal that nylon showed that nylon, polyester and wool can be differentiated based on solubility in specific solvents.

If several types of different fibres are present, the ability to discriminate and differentiate fibres using this test will decrease as other fibres can also be soluble and dissolve in similar solvent as nylon, polyester, cotton and wool fibres (fibres used in this study). For examples, silk, rayon, acetate and nylon can be soluble in 75% H_2SO_4. Apart from polyester and wool fibres, silk fibres are also soluble in 40% NaOH. Acetate fibres are soluble in 85% formic acid and not specific for nylon fibres only. Acetate, acrylic, spandex, and certain type of nylon fibres are also soluble in DMF. Solvents aside from the one used in this study for example, glacial acetic acid, acetone, and acetonitrile are required to increase the ability for discrimination and differentiation of specific fibres (Physical Evidence Section Forensic Scientist Manager 2014).

DYE EXTRACTABILITY

Both reference fibre samples and transferred fibres were placed into three different solvents: Acetic acid, pyridine and sodium hypochlorite. The results were recorded in Table 11 reference fibre samples and Table 12 for the transferred fibres.

Observation for (R-D1), (R-D2), (R-D3), (R-D4), and (R-D5) are similar because the transferred fibres originated from the same source, the recipient garment. Extractions of dye from fibres were visualized by looking at the colour changes of solvents similar. The fibres are said to have good dye extractability (good extraction) when the colour of the solvents changed from colourless to dark colour (as garments used were black in colour) and the fibres itself showed some discolouration when compared to before immersion in solvents. On the other hand, poor extraction was when there was noticeable but not too drastic colour changes on the solvents (light grey) and no observable discolouration of fibres were recorded. No extraction was when the colour of the solvents showed no noticeable colour change and the fibres showed no discolouration. For this test, only polyester (D4) can be differentiated from others, with good extraction in acetic acid and pyridine.

TABLE 11. Dye extractability of reference fibre samples

Sample	Solvent		
	Acetic acid	Pyridine	Sodium Hypochlorite
Reference			
D1	No extraction	No extraction	No extraction
D2	No extraction	No extraction	No extraction
D3	Poor extraction	No extraction	No extraction
D4	Good extraction	Good extraction	Poor extraction
D5	Poor extraction	No extraction	No extraction
R	No extraction	Good extraction	No extraction

TABLE 12. Dye extractability of transferred fibre samples

Sample	Solvent		
	Acetic acid	Pyridine	Sodium Hypochlorite
Transferred fibres			
D1-R	No extraction	No extraction	No extraction
R-D1	Poor extraction	Good extraction	No extraction
D2-R	No extraction	No extraction	No extraction
R-D2	Poor extraction	Good extraction	No extraction
D3-R	Poor extraction	No extraction	No extraction
R-D3	Poor extraction	Good extraction	No extraction
D4-R	Good extraction	Good extraction	Poor extraction
R-D4	Poor extraction	Good extraction	No extraction
D5-R	Poor extraction	No extraction	No extraction
R-D5	Poor extraction	No extraction	No extraction

The dye extractability from fibres using related solvents (acetic acid, pyridine, sodium hypochlorite) were hugely influenced by how the dyes are bound to the fibres, either physically through a variety of different attractive forces such ionic, Van der Waal's, and hydrogen bonding, or chemically, through covalent bonds (Gregory 2000). Classification of dyes also influenced the ability of solvent to extract the dye from the fibres. Examples of dye classifications are acid dye, reactive dye, azoic dye, metallised dye, and direct dye (Robertson et al. 2002). Extraction for acid dyes and direct dyes are good in Pyridine solvent, metallised dyes show good extraction in 2% aqueous oxalic acid, azoic dyes show good extraction in glacial acetic acid.

Discrimination of fibres involved in this study can be executed microscopically, through fibre burning test, solubility test and dye extractability test. However, when large number of different fibres is involved, combination of other methods and techniques is needed to obtain more accurate discrimination and identification. With reference to the results obtained from this study, as a whole, it can be said that the morphology of synthetic fibres' (polyester, nylon) are rod-like synthetic fibres' morphology (polyester, nylon) is rod-like with shorter segments when observed microscopically as compared to natural fibres' (cotton) ribbon-like appearance, twisted and longer segments. Synthetic fibres' shrink, melt and self-extinguished when flame is applied while natural fibres' ignites quickly and continue to burn. Nylon is soluble in formic acid and polyester is soluble in DMF while both polyester and wool are soluble in NaOH. Only polyester possessed good extraction with acetic acid. These observations do not represent other types of fibres which were not involved in this study as different types of fibres can give different observations even though they fall under the same classification of fibres; synthetic and natural fibres.

CONCLUSION

The result from this study showed that more fibres can be transferred with longer period of contact between donor and recipient garments. The types of fibres chosen in this study were able to be discriminated using a combination of results from four different tests; microscopic examination, burning test, solubility test and dye extractability test. However, the results obtained from this study is not representative of other types of fibres, apart from the ones directly used in the study.

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