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DENEYSEL ÇALIŞMA / EXPERIMENTAL STUDY

FORENSIC SCİENCE

A study to establish the sequence of intersecting strokes using infrared luminescence

Kızılötesi ışın tekniği kullanarak çakışan kalem hatlarının uygulama sırasının tespitine yönelik bir çalışma

Komal Saini[1], **Ridamjeet Kaur**[2], **Vinayak Gupta**[3], **Manpreet Kaur**[4]

0000-0001-5172-4699 0000-0001-8220-6499 0009-0008-5111-3351 0000-0003-0437-9743

ABSTRACT

Establishing the chronology of printing and signing is an important task for forensic document examiners, as many criminal cases have been reported, in which, the authorship of a document is a matter of controversy. In this study, the chronological order of intersections between various printed or typewritten strokes and different writing instrument ink strokes has been determined. For establishing the sequence, 8640 samples were prepared, of which, 4320 samples were printed after writing and the rest 4320 samples were printed before writing. The samples were analyzed under Infrared light using Projectina® DocuCentre Expert. A blind test was also performed to verify the results. The technique gave helpful results for heterogeneous intersections between laser-printed stroke and various pen ink strokes, and inkjet-printed stroke and fountain pen ink stroke.

Keywords: *Forensic science, questioned documents, sequence of strokes, intersecting lines, infrared luminescence*

ÖZET

Adli belge inceleme görevlileri, yazarlığı tartışmalı olan çeşitli belgelerle karşılaşırlar. Sahtekarlar, uydurma belgeler üretmek için baskı cihazları kullanmaktadır. Orijinal belgeler ayrıca eklemeler, ara satırlar, silintiler vb. değişiklikler içerebilir. Bu, o belgenin orijinalliği ve yazarlığı hakkında şüphe uyandırabilir. Basım ve imza kronolojisini oluşturmak önemli bir görevdir. Bu çalışmada çeşitli basılı veya daktiloyla yazılmış yazı hatları ile farklı yazı gereci mürekkep darbeleri arasındaki kesişmelerin kronolojik sırası belirlenmiştir. Bu çalışmada 8640 numune hazırlanmış olup, bunların 4320 adedi yazı yazıldıktan sonra, kalan 4320 numune ise yazı yazılmadan önce basılmıştır. Numuneler, Projectina® DocuCentre Expert kullanılarak kızılötesi ışık altında analiz edildi. Sonuçları doğrulamak için kör bir test yapıldı. Teknik, birkaç kombinasyon için yararlı sonuçlar verdi.

Anahtar Kelimeler: *Adli Tıp, sorgulanan belgeler, vuruş sırası, kızılötesi ışın*

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INTRODUCTION

Printing devices such as laser printers, inkjet printers, dot matrix printers, and typewriters are used universally to print various documents of legal value. It is not uncommon to sign the documents using different writing instruments. Forgers use these printing devices to produce fabricated documents. Genuine documents may also contain alterations that may put a question on their authenticity and

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Corresponding Author: Vinayak Gupta, Department of Forensic Science, Punjabi University, Patiala, Punjab, India.
E-mail: vinayakgupta224@gmail.com

[1]PhD, Professor, Department of Forensic Science, Punjabi University, Patiala, Punjab, India.
[2]PhD, Associate Professor, Department of Forensic Science, Chandigarh University, SAS Nagar, Punjab, India.
[3]M.Sc., Student, Department of Forensic Science, Punjabi University, Patiala, Punjab, India.
[4]PhD, Assistant Professor, Department of Forensic Science, Lovely Professional University, Punjab, India

authorship. Determination of the sequence of strokes may aid in detecting fraud. The intersecting strokes are classified into two broad categories, homogenous intersections (when similar inks cross each other) and heterogeneous intersections (when different types of inks cross each other) (1). When two ink lines cross each other, the overlapping of strokes causes certain distinctive physical features that can be observed at the point of intersection (2).

To determine the sequence of stroke, different techniques are employed by various scientists, for example, stereomicroscope, illumination techniques, spectrophotometer, photographic techniques, indented impression techniques lifting techniques, pre-lifting technique, chemical reactions, and Scanning Electron Microscopy. Some techniques are destructive while others are non-destructive. The infrared luminescence technique is one such non-destructive technique that has been employed for determining the sequence of intersecting strokes (3-8). The present study is devoted to determining the chronological order of intersections between various printed or typewritten strokes and different writing instrument ink strokes under Infrared light using Projectina® DocuCentre Expert.

MATERIALS AND METHODS

Materials used in sample preparation

By using eight different printing devices (two laser printers, two inkjet printers, two dot matrix printers, and two typewriters) and six different writing instruments (two gel pens, two ballpoint pens, and two fountain pens) each in four colors (black, blue, red and green), 8640 heterogeneous intersection samples were prepared. The effect of substrate and time between intersections were also considered. In order to study the effect of substrate, each intersection was prepared on three qualities of papers and to study the effect of time, a time gap of two minutes, two hours, and one month were considered between all intersections. Table 1 indicates the specification of materials used for the preparation of samples.

Sample Preparation

The samples were prepared in two sets. In the first set of samples, strokes were made on three types of white paper sheets using different writing instruments, and then the text was printed on the same white paper sheets using various printing devices (printed stroke above the writing instrument ink stroke). In the

Table 1. Specification of materials used for preparation of samples

Material	Specifications		
Substrate	High grade paper	Royal executive bond paper	21.5×29.5cm, 13.3g/m²
	Medium grade paper	Power BILT multi-purpose	21.5×34.5cm, 5.6 g/m²
	Low grade paper	Q-Connect A4 white sheets	21.6×34.5cm, 2.35 g/m²
Writing instrument	Gel pens	Montex Hy-speed gel pen	Red, Green, Blue, and Black
		Add gel sorento gel pen	
	Ball pens	Cello fine grip ballpoint pen	Red, Green, Blue, and Black
		Pentek Euro Tip ballpoint pen	
	Fountain pens	Fountain chelpark ink	Red, Green, Blue, and Black
		Fountain camlin ink	
Printing devices	Laser	HP LaserJet PCL 6	Red, Green, Blue, and Black
		HP Colour LaserJet 4500	
	Inkjet	HP Officejet 9100 PCL 6	Red, Green, Blue, and Black
		HP Officejet pro L7580	
	Dot matrix	355-Dot matrix MSP Classic TVS	Black
		Dot-matrix/ Wipro LQ 1050	
	Typewriters	Remington R-621171	Black
		Facit licence no. 676588	

second set, the text was first printed using a printing device, and then strokes were made on those white paper sheets using different writing instruments (printed stroke below the writing instrument ink stroke). This resulted in the preparation of a total of 8640, of which 4320 samples were printed after writing and the rest of 4320 samples were printed before writing.

In the first set, one white paper sheet was written with four colors using a gel pen, ballpoint pen, and fountain pen. These white paper sheets were printed in red color from one printing device. The task was repeated with the other three colors using the same printing device. The methodology was repeated with four printing devices (two laser printers and two inkjet printers) and six writing instruments on three types of substrates at three time intervals, which lead to the preparation of 3456 samples. Another three white paper sheets were written with four colors of all six writing instruments and then the text was printed using the rest of the four printing devices (two dot matrix printers and two typewriters) in black on three types of substrates at three time intervals, leading to the preparation of 864 samples. Hence, a total of 4320 samples were made in which the document was printed after writing.

In the case of set 2, four lines of text were printed on 12 white paper sheets using one printing device. Out of these 12 white paper sheets, 3 white paper sheets each were printed in red, blue, green, and black. Among the 3 white paper sheets printed in red, 1 white paper sheet was written with gel pens of all four colors, 1 white paper sheet with ball pens of all four colors, and 1 white paper sheet with fountain pens of all four colors. This task was repeated with other white paper sheets of paper printed in blue, green, and black. The methodology was repeated with the four printing devices (two laser printers and two inkjet printers) and six writing instruments on three types of substrates at three time intervals, which lead to the preparation of 3456 samples. Another three white paper sheets each were printed using the rest of the four printing devices (two dot matrix printers and two typewriters) in black. Similar steps were repeated to make intersections with four colors of all six writing instruments on three types of substrates at three time intervals, leading to the preparation of 864 samples. Hence, a total of 4320 samples were made in which the document was printed before writing.

Blind Test

A separate 240 samples were prepared in a similar manner for a blind test of the method. For this purpose, all of the eight printing devices were used along with one gel pen, one ball pen and one fountain pen of blue colour only, and one gel pen, one ball pen, and one fountain pen of all four colour. Thus, 120 samples were printed after writing and the remaining 120 samples were printed before writing. The identity of the samples was kept confidential by the lead author as the samples were randomly presented to the other authors for evaluation.

Analysis

The intersecting strokes were analyzed under infrared light using Projectina® DocuCentre Expert (Heerbrugg, Switzerland) enabled with PIA-6000 software. The samples were placed on the stage of Projectina® DocuCentre Expert and intersections were exposed to infrared light at 800-1000nm. A combination of emission and excitation filters was also used. The ink/printed strokes gave emission in the visible spectral range of 630–645 nm and were categorized as luminescent ink/printed strokes. Some ink/printed strokes did not interact with infrared light and were categorized as non-luminescent ink/printed strokes. The intersections were viewed on a monitor at 15×12X magnification and photographs were made using an inbuilt 5-megapixel camera. When both the intersecting strokes were non-luminescent, no phenomenon suggesting a sequence of intersecting strokes has been observed. However, if either of the intersecting strokes were luminescent, the results were documented.

RESULTS AND DISCUSSION

Under Infrared light, red gel pens; black, blue, and red ballpoint pens; green fountain pen inks; red laser printer inks; and red inkjet printer inks showed luminescence. These strokes were termed as luminescent ink/printed strokes. The ink strokes made by other writing instruments and printing

devices (laser, inkjet, dot matrix printer, and typewriter) did not give luminescence under infrared light and were termed non-luminescent ink/printed strokes.

Intersections between laser-printed strokes and writing instrument ink strokes

When luminescent laser-printed strokes were above luminescent or non-luminescent writing pen ink strokes, the continuation of laser-printed strokes could be observed. When luminescent laser-printed ink strokes were below luminescent or non-luminescent writing pen ink strokes, skipping of ink was observed at the point of intersection and few traces of writing pen inks could be observed. The skipping of ink occurs due to minimal adhesion of writing instrument inks over the laser-printed stroke that causes a gap at the point of intersection (1–2, 9–10). Therefore, the sequence can be determined.

When non-luminescent laser-printed strokes were above or below luminescent writing pen ink strokes, the laser-printed stroke interrupted the luminescence of writing pen ink strokes because it forms a thick compact layer that masks the luminescence of writing pen ink strokes (6). Hence, the sequence cannot be determined. Table 2 indicates the features observed at the point of intersection between laser-printed ink strokes and various writing instrument ink strokes. Figure 1 shows the results obtained for some intersections between laser printed ink strokes and different writing instrument ink strokes in IR light using Projectina® DocuCentre Expert.

Intersections between inkjet-printed strokes and writing instrument ink strokes

When luminescent inkjet-printed strokes were above or below luminescent gel pen and ballpoint pen ink strokes, the pen ink strokes seem to be continuous. This is due to the fact that ink of gel pen and ballpoint pen inks were not absorbed completely into the paper surface as they were more viscous than inkjet printer ink (11-13). The gel pen and ballpoint pen ink strokes produce brighter luminescence than inkjet ink (4,7). Therefore, the brighter luminescence of writing pen inks quenched luminescence of inkjet-printed stroke at the point of intersection. Similar observations were made when luminescent inkjet-printed strokes were above or below non-luminescent gel pen and ballpoint pen ink strokes. Therefore, the sequence cannot be determined.

When non-luminescent inkjet-printed strokes were above or below luminescent gel and ballpoint pen ink strokes, they act as opaque ink and mask the luminescence of pen ink strokes. Hence, the sequence cannot be determined.

When luminescent inkjet-printed strokes were above luminescent or non-luminescent fountain pen ink strokes, continuity of fountain pen ink strokes was observed. However, when luminescent inkjet-printed strokes were below luminescent or non-luminescent fountain pen ink strokes, the spreading of fountain pen ink is observed. As a result, the sequence can be determined.

When non-luminescent inkjet-printed strokes were above luminescent fountain pen inks, non-luminescent inkjet printer ink masks the luminescence of fountain pen ink stroke. However, when luminescent inkjet-printed strokes were below luminescent fountain pen ink strokes, the spreading of fountain pen ink is observed. Hence, the sequence can be determined. Table 3 indicates the features observed at the point of intersection between inkjet-printed ink strokes and various writing instrument ink strokes. Figure 2 shows the results obtained for some intersections between inkjet-printed ink strokes and different writing instrument ink strokes in IR light using Projectina® DocuCentre Expert.

Intersections between dot matrix-printed strokes and writing instrument ink strokes

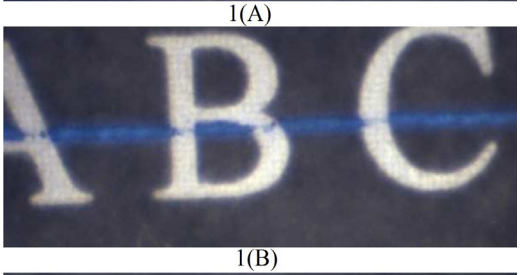
When non-luminescent dot matrix-printed strokes were above or below luminescent writing pen ink strokes, interruption of luminescence of writing pen ink strokes has been observed. This is because non-luminescent dot matrix-printed strokes mask the luminescence of writing pen ink strokes at the point of intersection. Hence, the sequence of strokes cannot be determined. Table 4 indicates the features observed at the point of intersection between dot matrix-printed ink strokes and various writing instrument ink strokes. Figure 3 shows the results

Table 2. Features observed at the point of intersection between laser-printed ink stroke and various writing instrument ink stroke

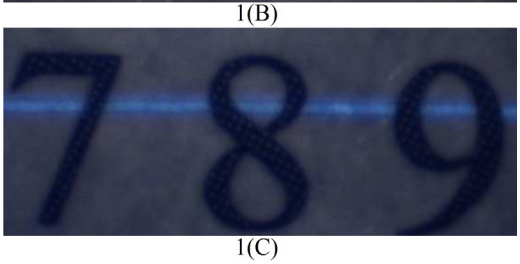
Gel pen ink strokes	Laser printed ink strokes							
	Black		Blue		Red*		Green	
	Above	Below	Above	Below	Above	Below	Above	Below
Black	×	×	×	×	B	C	×	×
Blue	×	×	×	×	B	C	×	×
Red*	A	A	A	A	B	C	A	A
Green	×	×	×	×	B	C	×	×
Ballpoint pen ink strokes	**Laser printed ink strokes**							
	Black		Blue		Red*		Green	
	Above	Below	Above	Below	Above	Below	Above	Below
Black*	A	A	A	A	B	C	A	A
Blue*	A	A	A	A	B	C	A	A
Red*	A	A	A	A	B	C	A	A
Green	×	×	×	×	B	C	×	×
Fountain pen ink strokes	**Laser printed ink strokes**							
	Black		Blue		Red*		Green	
	Above	Below	Above	Below	Above	Below	Above	Below
Black	×	×	×	×	B	C	×	×
Blue	×	×	×	×	B	C	×	×
Red	×	×	×	×	B	C	×	×
Green*	A	A	A	A	B	C	A	A

* Luminescent ink.
×- No feature observed
A- Luminescence interrupted
B- Continuity of pen ink stroke
C- Skipping of ink
D- Spreading of ink

1(A)



1(B)



1(C)

Figure 1. The results obtained for some intersections between laser-printed ink strokes and different writing instrument ink strokes in IR light using DocuCentre Expert. (A) Continuity of non luminescent ballpoint pen ink stroke, when luminescent laser printed stroke was above non luminescent ballpoint pen ink strokes. (B) Skipping of luminescent fountain pen ink stroke, when luminescent laser printed stroke was below luminescent fountain pen ink strokes. The skipping of ink occurs due to minimal adhesion of writing instrument inks over the laser-printed stroke that causes a gap at the point of intersection. (C) Interruption of luminescence of fountain pen ink stroke, when non luminescent laser printed stroke was above luminescent fountain pen ink strokes. The laser printed stroke forms thick layer which mask the luminescence of fountain pen ink strokes.

Table 3. Features observed at the point of intersection between inkjet-printed ink stroke and various writing instrument ink stroke

Gel pen ink strokes	Inkjet printed ink strokes							
	Black		Blue		Red*		Green	
	Above	Below	Above	Below	Above	Below	Above	Below
Black	×	×	×	×	A	A	×	×
Blue	×	×	×	×	A	A	×	×
Red*	A	A	A	A	B	B	A	A
Green	×	×	×	×	A	A	×	×
Ballpoint pen ink strokes	**Inkjet printed ink strokes**							
	Black		Blue		Red*		Green	
	Above	Below	Above	Below	Above	Below	Above	Below
Black*	A	A	A	A	B	B	A	A
Blue*	A	A	A	A	B	B	A	A
Red*	A	A	A	A	B	B	A	A
Green	×	×	×	×	A	A	×	×
Fountain pen ink strokes	**Inkjet printed ink strokes**							
	Black		Blue		Red*		Green	
	Above	Below	Above	Below	Above	Below	Above	Below
Black	×	×	×	×	A	D	×	×
Blue	×	×	×	×	A	D	×	×
Red	×	×	×	×	A	D	×	×
Green*	A	D	A	D	B	D	A	D

* Luminescent ink.
×- No feature observed
A- Luminescence interrupted
B- Continuity of pen ink stroke
C- Skipping of ink
D- Spreading of ink

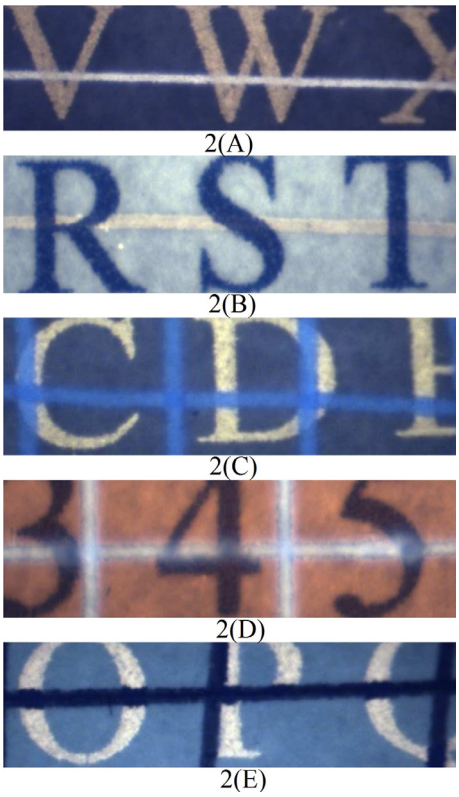


Figure 2. The results obtained for some intersections between inkjet-printed ink strokes and different writing instrument ink strokes in IR light using DocuCentre Expert. (A) Continuity of luminescent gel pen ink stroke, when luminescent inkjet-printed stroke was below luminescent gel pen ink strokes. The ink of gel pen is not absorbed completely into paper surface as they are more viscous than inkjet printer ink. The gel pen inks produce brighter luminescence than the inkjet-printed stroke. (B) Interruption of luminescence of gel pen ink stroke, when non luminescent inkjet-printed stroke was above luminescent gel pen ink strokes. The inkjet-printed stroke act as opaque layer over the gel pen ink stroke and mask the luminescence of gel pen ink strokes. (C) Continuity of luminescent fountain pen ink stroke, when luminescent inkjet-printed stroke was above luminescent fountain pen ink strokes. (D) Spreading of non luminescent fountain pen ink stroke, when luminescent inkjet-printed stroke was below non luminescent fountain pen ink strokes. (E) Spreading of luminescent fountain pen ink stroke, when non luminescent inkjet-printed stroke was below luminescent fountain pen ink strokes.

Table 4. Features observed at the point of intersection between dot matrix printed ink stroke and various writing instrument ink stroke

	Dot Matrix Printed Ink Strokes	
	Black	
Gel Pen Ink Strokes	**Above**	**Below**
Black	×	×
Blue	×	×
Red*	A	A
Green	×	×
	Dot Matrix Printed Ink Strokes	
	Black	
Ballpoint Pen Ink Strokes	**Above**	**Below**
Black*	A	A
Blue*	A	A
Red*	A	A
Green	×	×
	Dot Matrix Printed Ink Strokes	
	Black	
Fountain Pen Ink Strokes	**Above**	**Below**
Black	×	×
Blue	×	×
Red	×	×
Green*	A	A

* Luminescent ink.
×- No feature observed
A- Luminescence interrupted
B- Continuity of pen ink stroke
C- Skipping of ink
D- Spreading of ink

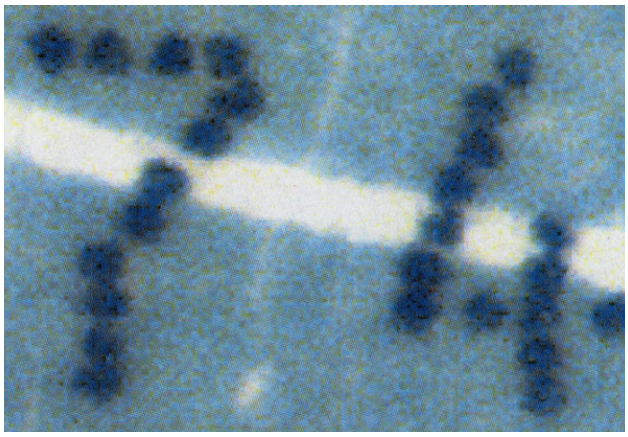


Figure 3. Interruption of luminescence of gel pen ink stroke, when non luminescent dot matrix printed stroke was below luminescent gel pen ink stroke. The dot matrix printed stroke forms thick layer over the gel pen ink stroke which mask the luminescence of gel pen ink stroke.

obtained for the intersection between dot matrix-printed strokes and gel pen ink strokes in IR light using Projectina® DocuCentre Expert.

Intersections between typewritten strokes and writing instrument ink strokes

When non-luminescent typewritten strokes were above or below luminescent writing pen ink strokes, interruption of luminescence of writing pen ink strokes has been observed. This is because non-luminescent typewritten strokes mask the luminescence of writing pen ink strokes at the point of intersection. Hence, the sequence of intersecting strokes cannot be determined. Table 5 indicates the features observed at the point of intersection between typewritten ink strokes and various writing instrument ink strokes. Figure 4 shows the results obtained for the intersection between typewritten strokes and ballpoint pen ink strokes in IR light using Projectina® DocuCentre Expert.

From the observations, it is evident that the sequence of strokes can be determined in the case of intersections between:

- Luminescent laser-printed stroke with luminescent and non-luminescent writing pen ink stroke (gel pen, ballpoint pen, and fountain pen ink).

Table 5. Features observed at the point of intersection between typewritten ink stroke and various writing instrument ink stroke

	Typewritten Ink Strokes	
	Black	
Gel Pen Ink Strokes	**Above**	**Below**
Black	×	×
Blue	×	×
Red*	A	A
Green	×	×
	Typewritten Ink Strokes	
	Black	
Ballpoint Pen Ink Strokes	**Above**	**Below**
Black*	A	A
Blue*	A	A
Red*	A	A
Green	×	×
	Typewritten Ink Strokes	
	Black	
Fountain Pen Ink Strokes	**Above**	**Below**
Black	×	×
Blue	×	×
Red	×	×
Green*	A	A

* Luminescent ink.
×- No feature observed
A- Luminescence interrupted
B- Continuity of pen ink stroke
C- Skipping of ink
D- Spreading of ink

Figure 4. Interruption of luminescence of ballpoint pen ink stroke, when non luminescent typewritten stroke was above luminescent ballpoint pen ink stroke. The typewritten stroke forms thick layer over the ballpoint pen ink stroke which mask the luminescence of ballpoint pen ink stroke.

- Luminescent and non-luminescent inkjet-printed stroke with luminescent fountain pen ink stroke.
- Luminescent inkjet-printed stroke with non-luminescent fountain pen ink stroke.

The sequence of heterogeneous intersecting strokes could not be determined in the rest of the cases. Previous studies conducted by Poulin (1), Mathyer (3), Radley (4), McKasson (7), Ellen (14), Mann (15) and Wu (16) reported similar findings.

Effect of substrate and time

Different types of papers used for the study produced a different type of luminescence under infrared light. Nevertheless, this has not produced any additional effect on the intersections produced between different types of printing inks and writing instrument inks. Similar results have been obtained on all three different qualities of papers used in this study (high, medium, and low grade). Intersections produced at different time intervals (two minutes, two hours, and one month) have also given similar results. The results were in accordance with the previous study (17).

Blind test

Separate 240 samples were prepared for the combinations that showed positive results. The blind test samples were examined using the same methodology. The results of blind test were evaluated on the basis comparison of results

obtained and the key prepared by the lead author. After careful examination of all 240 blind samples, correct interpretation was made for 231 samples, which accounts for approximately 96% of samples. Hence, the results of the blind test were similar to the results in this study. This validated the methodology and the results obtained in this study.

CONCLUSION

The present study was performed to determine the chronological order of heterogeneous intersections between various printed or typewritten strokes and different writing instrument ink strokes under Infrared light using Projectina® DocuCentre Expert. The technique proved fruitful in the case of intersections between luminescent laser-printed stroke with luminescent (gel pens, ballpoint pens, and fountain pen) and non-luminescent (gel pen, ballpoint pen, and fountain pen) ink stroke; luminescent inkjet-printed stroke and non-luminescent inkjet-printed stroke with luminescent fountain pen ink stroke; and luminescent inkjet-printed stroke with non-luminescent fountain pen ink stroke. However, the technique was unable to give results for the rest of the combinations, when either one or both ink/printed strokes were luminescent.

Ethics approval and consent to participate: *This is not applicable for the paper.*

Consent for publication: *This is not applicable for the paper.*

Availability of data and materials: *The research papers reviewed for the study were obtained from various reputed journals of Forensic Science.*

Competing interests: *No competing interests are declared by the authors.*

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Authors' contributions: *All the authors have cooperatively worked for the completion of the work.*

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