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Establishing Sequence of Inkjet Printer, Laser Printer and Writing Ink Strokes using Scanning Electron Microscopy (SEM)



تحديد سياق الكتابة لكل من طابعة نفث الحبر وطابعة الليزر وكتابة جرات الحبر باستخدام المسح المجهري الإلكتروني

(SEM)

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Abstract

The aim of the present study is to determine the sequence of laser printer, inkjet printer, and writing ink (ball point pen ink, gel pen ink, pilot pen ink and fountain pen ink) strokes using a low voltage (1kV) scanning electron microscope (SEM).

Intersections were prepared using an inkjet printer, laser printer, and writing instruments on copier paper. About 1cm² of intersection was cut using scissors and mounted to the probe stage of the SEM using double-sided tape. Each sample was analyzed at different operating parameters.

The results were evaluated on the basis of continuity and discontinuity of strokes at intersection point. It was possible to determine the correct sequence of printer strokes versus other writing instruments' strokes; inkjet printer strokes versus fountain and pilot pen ink strokes; however, inconclusive results were obtained in the case of inkjet printer strokes versus ball point pen and gel pen ink strokes. The effectiveness of this technique was determined by analyzing the exact sequence of blind samples.

An SEM could be used as complimentary tool with other optical methods to examine the sequence of strokes.

المستخلص

الهدف من هذه الدراسة هو تحديد سياق الكتابة لطابعة الليزر أو طابعة نفث الحبر أو أقلام حبر الكتابة مثل، قلم الحبر جاف، أو قلم الحبر من شركة بايلوت Pilot أو قلم الحبر النفثات (الريشة)، باستخدام مسح الإلكتروني (SEM) منخفض الجهد (1KV).

تم إعداد التقاطعات باستخدام طابعة نفث الحبر وطابعة الليزر وأدوات الكتابة على ورق نسخ. تم تقطيع حوالي 1 سم 2 من التقاطع باستخدام مقص وتثبيتته على طرف المسبار في مسح الإلكتروني ال SEM باستخدام شريط لاصق ذو الوجهين. تم تحليل كل عينة على معايير التشغيل المختلفة.

تم تقييم النتائج على أساس الاستمرارية والتوقف عند كل جرة قلم عند نقطة التقاطع. كان من الممكن تحديد سياق الكتابة بشكل صحيح لعمليات الجر للطابعات بالمقارنة مع جرات أدوات الكتابة الأخرى؛ مثل طريقة الجر لطابعة نفث الحبر مقارنة مع طريقة الجر لأقلام النفث وقلم الحبر من شركة بايلوت Pilot. ومع ذلك، تم الحصول على نتائج غير حاسمة في حالة جرات طابعة نفث الحبر مقابل جرات قلم الحبر ذو الرأس المدور وجرات قلم حبر الهلام. تم تحديد فعالية هذه التقنية من خلال تحليل التسلسل الدقيق للعينات المجهولة (المعماة).

ومن خلال ذلك نستنتج أنه يمكن استخدام مسح الإلكتروني SEM كأداة تكميلية بالإضافة للطرق البصرية الأخرى لفحص سياق الكتابة لعمليات الجر الكتابي.

Keywords: Forensic Science, Forensic Document, Sequence of Strokes, Inkjet Printer Strokes, Scanning Electron Microscope

الكلمات المفتاحية: علوم الأدلة الجنائية، التزييف والتزوير، تسلسل جرات الكتابة، جرات طابعة نفث الحبر، مسح الإلكتروني (SEM).

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1. Introduction

Determination of sequence confirms the periodicity of executed strokes in important documents like agreements, financial statements, and legal wills, etc., and can be used in order to establish their authenticity. These documents may contain printed text (inkjet or laser) crossed with writing ink (ball pen ink, gel pen ink, fountain pen ink, etc.). Several factors such as optical behavior of media, type of paper and its porosity, the writing instrument, firmness of strokes, thickness of ink layer, its absorption in the paper, and various environmental conditions may affect the examination [1]. Thus, an examiner might not always find answers to all sequence problems using a single technique. A number of techniques have been advised for sequence examination [2-4]. Optical methods are one such widely used technique for sequence examination. However, the sequence of colored inkjet strokes (red, green and blue) with ball point pen ink and gel pen ink (all colors) could not be satisfactorily examined. This may be because of low viscosity of inkjet inks, which acts as a transparent medium for highly viscous writing ink strokes [5]. Determination of sequence in case of color laser printer and writing ink strokes becomes difficult when the intersections are observed through a microscope with the value for angle of illumination being 45° or more [6]. Determination of sequence of intersections has not been found fully satisfactory when examining them with Attenuated Total Reflectance infrared spectroscopy, Video Spectral Comparator, and Energy Dispersive X-ray, etc. [7-9]. The drawbacks reported by the optical methods have been eliminated using electron microscopy techniques such as scanning electron microscope (SEM). An SEM has several advantages over optical methods as it provides higher resolving power, greater depth of focus, higher magnification range, and a 3D view of strokes. [10]. It involves the use of a heated filament which generates an accelerated beam of electrons that fall directly on a sample. When an electron beam strikes the specimen, a variety of signals known as the secondary electrons (SE) and back-scattered electrons (BSE) are emitted. These generated electrons are measured using special detectors. The SE originates close to the surface of the specimen and is

correlated to its topography. The SEM imaging process is based upon the interaction between atoms of the observed specimen and electron beam. Difference in SE emission of samples reveals their original sequence [11]. Other surface analysis based techniques, like atomic force microscopy and laser profilometry, have also been used to study the sequence but suffer from limitations like limited freedom of motion. Scanning is limited to samples having flat and rough surface, and require a longer time to acquire the data [3, 12-14].

Taking into consideration the above facts, the present study aimed to analysis chronological order of printer ink strokes (inkjet printer and laser printer) and writing ink strokes (ball point pen ink, gel pen ink, pilot pen ink and fountain pen ink) using a low voltage SEM.

2. Materials and Methods

An inkjet printer, a laser printer, and four other writing instruments were used to prepare the intersections for the study (Table-1). The samples were prepared in two different sets. In the first set, inkjet printer strokes were placed above the writing ink strokes. In the second set, inkjet printer strokes were placed below the writing ink strokes. All the intersections were prepared on copier paper (Spectra A4 copier paper). Intersections of laser printer stroke and different writing instrument strokes were prepared using a similar methodology. Thus, a total 16 samples were prepared for the study. The prepared samples containing intersections were placed in a vacuum dessicator overnight for the removal of moisture. The samples were then observed using a low voltage (1kV) JEOL JSM-6510LV SEM. Low voltage was preferred to prevent uncoated paper from burning. About 1cm^2 of intersection was cut using scissors and mounted to the probe stage using double-sided tape. The probe stage was then kept in the vacuum chamber of the SEM. Each sample was analyzed at different operating parameters such as different ranges of magnification, working distance, take-off angles, source electron energy, and currents, rather than predetermined adjustments. This is because optimum imaging conditions would vary according to the manufacturer of the written media, firmness



Table 1- Description of samples.

S. No	Writing Instrument/ Printer	Brand
1	Pilot pen	Luxor
2	Gel pen	Rorito
3	Fountain pen	Flair ink tanker
4	Ball-point pen	Cello Trimate
5	Inkjet printer and laser printer	Brother Colour multi-functional Printer

of stroke or impression, thickness of the deposited layer, and other variables. The desired images were selected from the TV-Monitor and saved as jpeg formats.

3. Results and Discussion

The analysis was performed using a low voltage SEM. Evaluation of results was based on the continuity and discontinuity of strokes. No other significant feature was observed that could be considered as conclusive.

3.1 Determination of Sequence of Inkjet Printer Stroke and Writing Instrument Strokes

The results of the observations are presented in Table-2. It was possible to determine the sequence of pilot pen, fountain pen, and inkjet printer strokes using an SEM. Continuity of fountain pen stroke and discontinuity of inkjet printer stroke (Figure-1A) clearly indicate that the fountain pen ink stroke was above the inkjet printer stroke. Discontinuity of fountain pen ink stroke and continuity of inkjet printer stroke (Figure-1B) indicate the presence of inkjet stroke above the fountain pen stroke. Similarly, the sequence of

pilot pen stroke versus inkjet printer stroke has also been determined. It was not possible to determine the original sequence of intersections prepared with gel pen ink, ball point ink, and inkjet printer stroke. Continuation of gel pen (Figure-2A and 2B) and ball point stroke (Figure-3A and 3B) were observed to ascertain whether they were below or above the inkjet printer stroke. The two most probable reasons reported for this phenomenon are as follows: The first reason was the high viscosity of ball pen ink and gel pen ink strokes, which makes them appear on top of inkjet

**Figure 1a****Figure 1b**

Figure 1A- Continuity of fountain pen stroke “O” above printed alphabet “M”. **1B-** Discontinuity of fountain pen stroke “X” by printed alphabet “M”.

Table 2- Physical features observed at the point of intersections of inkjet printer stroke with writing instrument stroke.

Writing Instrument	Inkjet Printer Strokes	
	Above	Below
Fountain pen	Discontinuity of pen stroke	Continuity of pen stroke
Pilot pen	Discontinuity of pen stroke	Continuity of pen stroke
Ball-point pen	Continuity of pen stroke	Continuity of pen stroke
Gel pen	Continuity of pen stroke	Continuity of pen stroke



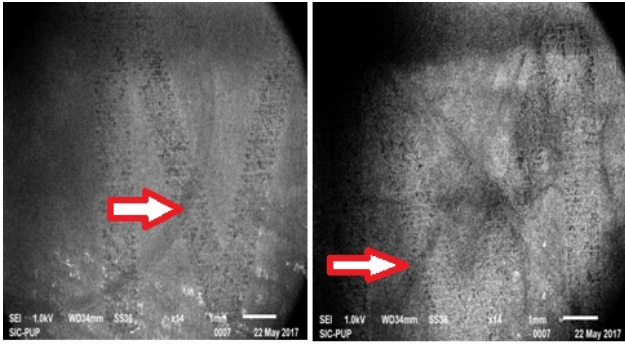


Figure 2a

Figure 2b

Figure 2A- Continuity of gel pen stroke “O” above printed alphabet “M”. **2B-** Continuity of gel pen stroke “X” above printed alphabet “M”.

printer strokes irrespective of their actual sequence. The obtained results were in agreement with earlier studies [15-16]. The second reason was the low accelerating voltage (1kV) used for analyzing the sequence. Ball point pen inks and gel pen inks being highly viscous remain on the surface rather than penetrating deep into the fibers like inkjet inks [3]. The accelerating voltage (1kV) selected for analysis was not sufficient to penetrate deep into the paper fibers. Therefore, it was only possible to get topography of ball point pen inks and gel pen inks present on the uppermost layer of the paper surface.

3.2 Determination of Sequence of Laser Printer Stroke and Writing Instrument Strokes

The results of the observation are presented in Table-3. It was possible to determine the correct sequence of pilot pen, fountain pen, ball point pen, gel pen, and laser printer stroke using a low voltage (1kV) SEM. Continuity of pilot

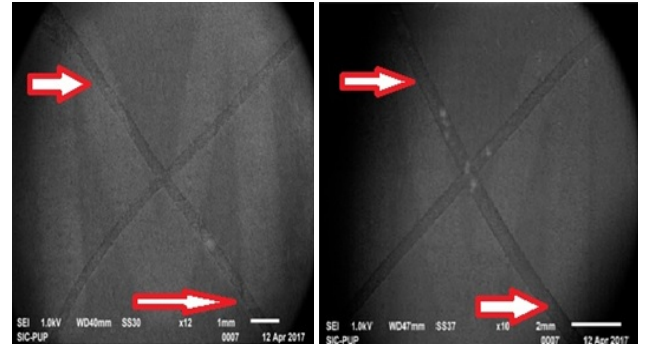


Figure 3a

Figure 3b

Figure 3A- Continuity of ball point pen stroke “X” above printed alphabet “M”. **3B-** Continuity of ball point pen stroke “X” above printed alphabet “M”.

pen stroke and discontinuity of laser printer stroke clearly indicate that pilot pen stroke was above the laser printer stroke. Discontinuity of pilot pen ink stroke and continuity of laser printer stroke indicate the presence of laser printer stroke above pilot pen ink stroke (Figure-4A and 4B). Similar findings were used for the evaluation of sequence of gel pen ink, ball point pen inks, and fountain pen ink strokes.

The reliability of the technique was determined by examining the exact sequence of 2 blind samples. The only disadvantage of using an SEM in the present study was the cutting of a small section of intersection because of the small probe stage. This pitfall could be eliminated by using an SEM associated with a large probe stage. The technique could be used as a complimentary tool to other analytical approaches. Future studies must incorporate analysis of different ink types on various substrates.

4. Conclusion

Table 3- Physical features observed at the point of intersections of laser printer stroke with writing instrument stroke.

Writing Instrument	Laser Printer Stroke	
	Above	Below
Fountain pen	Discontinuity of pen stroke	Continuity of pen stroke
Pilot pen	Discontinuity of pen stroke	Continuity of pen stroke
Ball-point pen	Discontinuity of pen stroke	Continuity of pen stroke
Gel pen	Discontinuity of pen stroke	Continuity of pen stroke

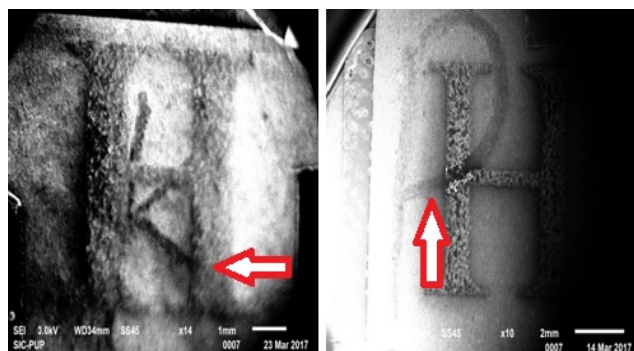


Figure 4a

Figure 4b

Figure 4A- Continuity of laser printer stroke “H” above ball point pen stroke “k”. **4B-** Discontinuity of laser printer stroke “H” by ball point pen stroke “p”.

The chronological sequence of heterogeneous strokes prepared with inkjet printer inks, laser printer inks, ball point pen inks, gel pen inks, and fountain pen inks was examined using an SEM. The reason for using low voltage was to prevent burning the paper. Continuity and discontinuity of strokes were considered for evaluation of sequence. It was possible to determine the correct sequence of laser printer strokes versus other writing instruments' strokes; inkjet printer stroke versus fountain and pilot pen ink stroke; however, inconclusive results were obtained in the case of inkjet printer strokes versus ball point pen and gel pen ink strokes. This was due to the difference in the viscosity of intersecting inks. No such problem was encountered in intersections prepared with laser printer strokes and writing instrument strokes. This is because laser printer ink consists of toner, which is a bi-component mixture of polymer base that melts and fuses over the surface on heating, whereas liquid inkjet inks diffuse into the bottom layer of paper fibers. Being on the surface, it is possible for the atoms of toners to interact easily with low voltage (1kV) electrons and express their topography.

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Conflict of Interest

None

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