Naif Arab University for Security Sciences
Arab Journal of Forensic Sciences and Forensic Medicine
المجلة العربية لعلوم الأدلة الجنائية والطب الشرعي
https://journals.nauss.edu.sa/index.php/AJFSFM

Variations in Line Quality of Handwritten Strokes Due to the Photocopying Process- A Preliminary Study

الاختلافات في جودة الخط في الخطوط المكتوبة باليد الناتجة عن عملية النسخ الضوئي: دراسة أولية

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Received 07 Dec. 2021; Accepted 23 Jan. 2022; Available Online 12 June. 2022

Abstract

An examination of the line quality of handwritten strokes plays an important role in the detection of forgery. This paper deals with the study of morphological variations in line quality of multi-generation photocopied handwriting (up-to the fifth generation of reproduction) produced by thirty-four different writing instruments. The purpose of the study is to find out the extent to which such line quality features are dependent on the nature of the writing instrument used to prepare the original, as well as the possibility of their survival (or distortion) and, consequently, their detection in the multi-generation photocopies. The overall effect of writing instrument on morphology is seen and felt in varying degrees in photocopier reproductions of all the five generations. Pen characteristics, such as striations, ink gooping, pen skips, ink bleeding/ feathering, nib marks and lead particle deposition have caused a significant difference in the morphology of stroke's line in photocopy. The effect is much more pronounced in some of the features in photocopies beyond the second generation. There are other features, such as ink feathering and pen skips which could not be reproduced with sufficient clarity in any photocopy generation.

Keywords: Forensic Science, Handwriting, Variations, Photocopy, Subsequent Generations, Writing Instruments.

المستخلص

يؤدي فحص جودة الخط في الخطوط المكتوبة باليد دورًا مهمًا في عملية كشف التزوير. وتتناول هذه الورقة دراسة الاختلافات الشكلية في جودة الخط في الخطوط المكتوبة باليد باستخدام أربعة وثلاثين أداة كتابة مختلفة منسوخة ضوئيًا عدة مرات (حتى المرة الخامسة). ويتمثل الهدف من هذه الدراسة في معرفة مدى اعتماد خصائص جودة الخط هذه على طبيعة أداة الكتابة المُستخدمة في إعداد النسخة الأصل، بالإضافة إلى إمكانية بقائها (أو تشوهها)، وبالتالي اكتشافها في النسخ التي تم إنتاجها على عدة مرات من النسخ الضوئي. ويظهر التأثير الكلي لأداة الكتابة على شكل الخط بوضوح ويبدو بدرجات متفاوتة في النسخ التي تم إنتاجها عبر جميع المرات الخمس من عملية النسخ الضوئي. وقد تسببت خصائص الأقلام، مثل التشققات، وترسب الحبر، والفراغات التي يتركها القلم، وتسرب الحبر إلى الجانب الآخر من الورقة/تفشي الحبر، والعلامات التي يتركها سن القلم، وترسب جزيئات الرصاص، في وجود اختلاف كبير في شكل خط القلم في النسخ المنسوخة ضوئيًا. ويبدو التأثير أكثر وضوحًا في بعض خصائص النسخ التي تم الحصول عليها بعد المرة الثانية من النسخ الضوئي. كما توجد بعض الخصائص الأخرى، مثل تفشي الحبر والفراغات التي يتركها القلم، والتي لا يمكن إعادة إنتاجها بوضوح كافٍ في أي من مرات عملية النسخ الضوئي.

الكلمات المفتاحية: علوم الأدلة الجنائية، خط اليد، اختلافات، النسخ الضوئي، الأجيال التالية، أدوات الكتابة.

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doi: 10.26735/BMAA5795

1. Introduction

There are several types of writing instruments available in the local market that are used by people in carrying out their official financial, judicial and legal documentation. Modern fountain pens no longer use the earlier metallic splitting-nibs which have been replaced with new nib material that is less flexible but more comfortable. Technology has also provided a wide variety of other kinds of writing instruments ranging from the ballpoint pens using viscous inks; porous point pens having writing tips made from felt, fiber or plastic material; to roller ball-pens using less viscous and more fluid inks [1]. Studies have revealed that the writing characteristics produced by these commonly used writing instruments can be discriminated reasonably by the document examiners [2, 3]. Flexible but more stable writing tips tend to conceal fine detail of line quality features like tremor and fluency, line continuity, pen position, pen-pressure, pen lifts and even overwriting, making the task of document examiner more difficult [1]. The use of specific pen or ink class has a significant role in the investigation of questioned document cases.

Sometimes, it becomes necessary to know what type of writing instrument was used to write a document and under what conditions it was prepared [4]. Every type of writing instrument leaves some unique line quality features due to difference in their respective inking mechanism and behavior towards the paper surface [5]. A forensic evaluation of such line features could lead to the possibility of their identification [3]. It is normally difficult to identify the type of writing instrument that was used to prepare an original document from its photocopies. This being so, it would be rather too much to expect from a photocopy to indicate if its corresponding original was prepared using a single or multiple writing instruments [6]. With each successive generation of copying, image quality of photocopier reproduction goes on degrading. Further, with some photocopiers, the quality of photocopy also depends on the colour of the ink that was used to prepare its corresponding original [7]. Jasuja et al. [8] reported that, in some higher generation photocopier reproductions of ball point writings, peculiar artifacts were observed due to the merging of ink-traces along the writing-line. Consequently, there was an appreciable change in morphology of the ink-line resulting from the photocopying process. In another study, line quality features of handwriting like ink gooping and striations were not reproduced with sufficient clarity in photocopy beyond the second generation [9]. Though some studies were conducted to evaluate the effect of writing instruments on characteristics of the original writings, no exhaustive study has been made to find out the extent to which the effect of the writing instrument could be felt on the line quality features of handwriting in multi-generation photocopies up-to the fifth generation. The present study was, therefore, undertaken to find out the effect of writing instruments on the reproduction of line quality morphology of handwriting in multi-generation photocopies.

2. Materials and Methods

2.1 Collection of Samples

As many as 34 different writing instruments were used for the preparation of the original handwriting samples (Table-1). Two handwriting samples were collected with each pen on the standard A4-size paper. Thus, a total of 68 handwriting samples were prepared. These samples were then photocopied, using four digital photocopiers (Canon IR 3300, Canon IR 7095, Konica Minolta bizhub 423 and, Xerox WC 5755) up to five generations to study the morphological features of photocopies. First-generation photocopy (G-1) was produced directly from the orig-

Table 1- *List of writing instruments used for the preparation of original handwriting samples.*

Ball Point Pens	1. Reynolds Fine carbure (blue, black, red) 2. Roritoliquiglide (blue, black, red) 3. Cello Butter flow (blue, black, red) 4. Linc (blue, black, red, green) 5. Parker ball pen (blue)
Roller Ball Point Pens	6. Rorito Greet personal touch roller ball pen. (Blue). 7. Luxor Pilot H- techpoint (blue, black, red) 8. Flair Quicker roller pen (0.7) (blue)
Gel Pens	9. Rorito Racer max gel (blue, black, red Green). 10. Linc executive Gel (0.5) (blue, black, red Green)
Nib Ink Pens	11. Hauser Ink Pen (nib) 12. Parker ink pen (nib)
Glitter Gel Pen	13. Linc shine Glitter gel pen (black, violet)
Fibre Tip Pens	14. Cello ultra-fine permanent marker fiber tip 15. Koressmoothline+ multimarker pen
Lead Pencil	16. Apsara regal gold pencil

inal sample (O-1); the second-generation copy (G-2) was prepared by a reproduction of the first-generation photocopy (G-1). Likewise, third-generation (G-3), fourth-generation (G-4), and fifth-generation (G-5) photocopy samples were subsequently produced from the earlier generations.Thus, a total of 1360 (68 x 5x 4) photocopy samples were available for the study.

2.2 Sample Analysis Procedure

All the samples were visually analyzed using Stereomicroscope [Magnus MSZ-TR with camera & projector attachment, Magcam DC 5, 5.1 MP 1/2.5" CMOS Sensor].

3. Results

The findings of the study are presented here according to the types of handwriting instrument used:

3.1 Ballpoint Pen

Common line quality defects of ball point pens, such as pen skipping, ink goopings/ blobs, striations, and deposition of ink traces along the line of writing stroke, were observed in the originals and the photocopies. Pen skips and ink goopings were found to appear as hesitation points, while, in some photocopies, pen skips appeared like pen lifts at the curving of writing strokes (Figure-1). The presence of natural pen skip defects in stroke-line along with ink gooping at the curving of strokes could often be differentiated from the hesitations of simulated strokes in early generation copies (G1 and G2).

Ink gooping could be identified in G1 and G2; but, after G2, their shapes changed due to what appeared as hesitation or pen pause in G3 to G5. Further, ink blobs at initial strokes could also be identified in several photocopy generations (Fig.2). Sometimes, ball point pen needs priming at the beginning of a stroke, and consequently it leaves an un-inked indented portion on the paper surface. This condition could be identified in the original writing, using oblique light and low power microscope, but the same could not be identified in photocopies (Figure-2). Inkless grooves / striations are the specific characteristics of ball point pen writing; such line quality defects caused significant deterioration in photocopy generations (Figure-2).

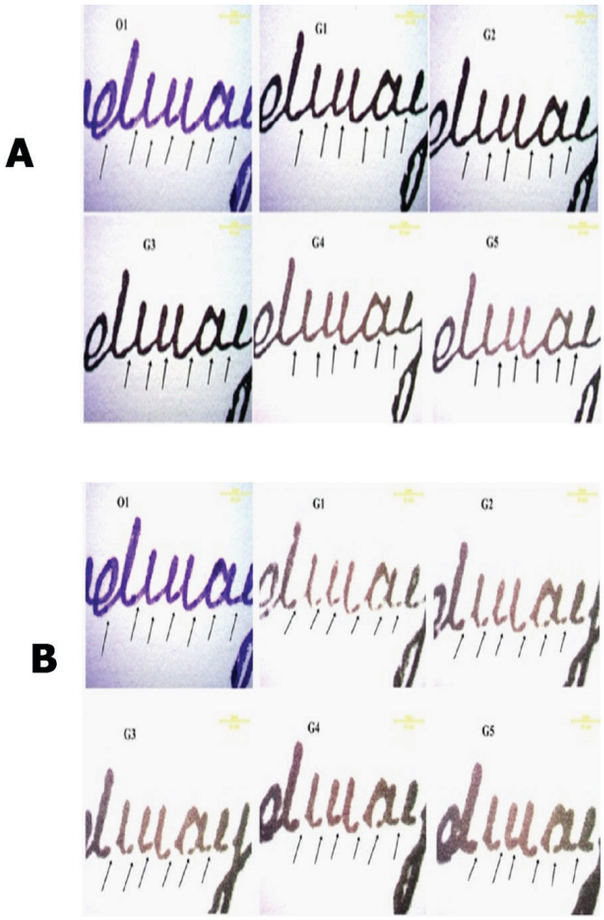

Figure 1- *Regular ink goopings and pen skips at the curving of lower strokes in original (O-1); these defects are seen as regular hesitations in G1 to G5 (upper part marked as A). Lower part (B) of figure showing these features as pen lifts in G1 to G5 [Linc ball point pen]. (10X magnification).*

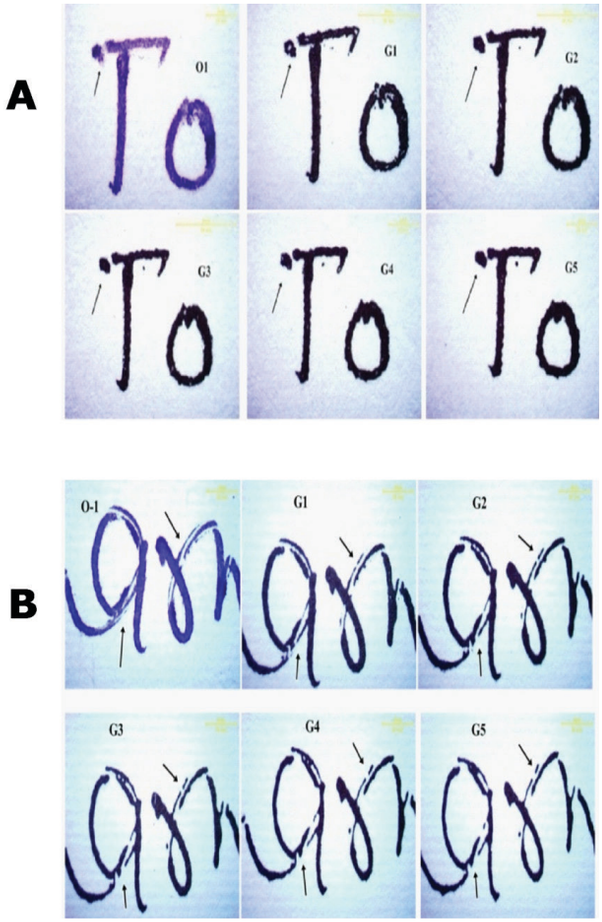

Figure 2- *Upper part (A) showing ink-less start and ink blob at the initial of upper stroke of letter "T" in O-1, it shows as separate blob in photocopy generations G1 to G5 [Linc ball point pen]. Lower part (B) illustrates the strokes-line of letters 'a' and 'r'' written with ball point pen 'Parker' showing inkless groove/ prominent striations as seen in the originals; they have been subsequently degraded in photocopies. (10X magnification).*

3.2 Roller Ball Pen

Writing strokes produced with these pens were usually free from ink goops, skipping and striations. Slight bleeding of ink into the fibers of paper and ink flow-back at the ending of strokes were seen in the original handwriting. However, these features did not reproduced well in the photocopies G1 to G5. Further, the line contours were found slightly rough in the photocopies because of a slight ink-line bleeding in the original strokes in O-1 (Figure-3).

3.3. Gel Pen

Original writing strokes produced by these pens were relatively dark and smooth as compared to that of other pens. Usually, features like ink blobs/ goopings, pen skips, striations and extra traces of ink along the strokes' line were not present in the original writing produced by gel pens; and, consequently, those were not observed in the photocopies. Line quality of writings produced by these pens was generally good enough for identification, as compared to the other pen writings (Fig. 3). However, exceptionally, heavy accumulation of ink at the curving of strokes was observed in handwriting pro-

Figure 3- *Part (A) showing slight ink bleeding in original line (O-1) in roller ballpoint pen writing [Luxor Pilot H-techpoint 0.5 blue ink pen]; slight irregularity is seen in line contours in photocopies G1 to G5 as a result of ink bleeding in original strokes. Part (B) showing smooth line edges in gel pen writings in the original (O-1) and in photocopy generations G1 to G5 [Rorsto Racer max gel]. (10X magnification).*

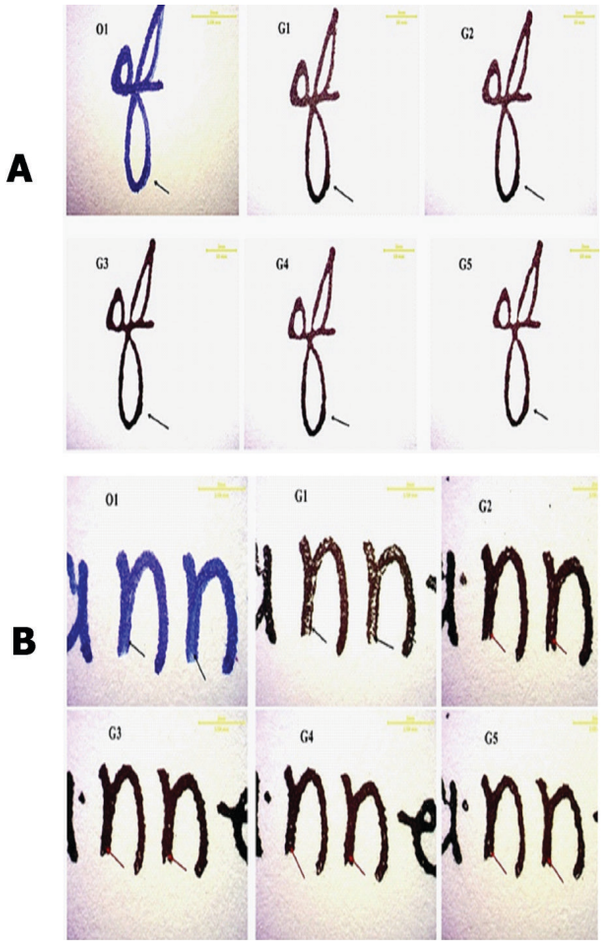

Figure 4- *Part (A) showing over accumulation of ink at lower ascending stroke of letter 'f ' written with "Link Executive gel 0.5". This looked like a pen pause in G1 to G5. Part (B) showing tracking effect in original (O-1) written with "Linc gel blue pen". In G1, it appeared as striation; however, in further generations, this defect could not be properly identified [magnification 10X].*

duced by Linc Executive gel 0.5 pen, which could not be reproduced with sufficient clarity in photocopies G1 to G5 (Figure-4).

Gel pen ink line, in some cases, could be distinguished from the other writing instruments by the presence of 'tracking effect' along the outer edges of ink stroke; the probable reason for this effect is that the ink is being pushed by the ball to outer edges of the strokes [6]. This tracking effect was observed in the handwriting written with 'Linc gel blue pen' in the original which appeared as striation in G1. However, in further generations, this defect could not be reproduced with sufficient clarity (Figure-4).

3.4 Glitter-based Gel Pen

Glitter-based Gel Ink contains a mixture of fluorescent colours and metallic sparkles. Glitter-based gel pens usually have thick writing points. Handwriting strokes produced by these pens resembled the strokes as produced by heavy tipped fiber pens in photocopies. Hence, their initial and terminal strokes

are generally thick, and, consequently, the direction of pen movements in letter formations could niether be studied from the originals nor from the photocopies. Characteristic small voids appeared in the ink-line of photocopy at places corresponding to the fluorescent / metallic sparkles of the originals (Figure-5).

3.5 Fountain / Nib Pens

Handwriting produced by the 'nib pen' shows unique line quality features such as feathering, nib marks and indentations, as well as variations in pen pressure and shading resulting from splitting of the nibs at certain points in the process of writing. Prominent feathering found in the original strokes (O-1) could not be identified in photocopies produced in the first generation copiers. In some cases, this feature was converted into over-toner projections or dents online edges.

Regular sharp changes in the width of descending strokes were observed in original writing samples O-1 produced by the 'Parker' nib pen. This feature was normally identifiable in photocopies of early generation, G1 and G2 but, in higher generations this feature could not be identified due to darkening of lines (Figure-5). Such nib marks were not observed in the original handwriting samples O-1 produced by the 'Hauser' nib pen; handwriting strokes produced by this pen showed a morphological resemblance with the gel pen writing strokes. Therefore, in such cases, clear differentiation between gel pen and nib pen writing strokes could not be in the photocopies.

3.6 Fiber Tip or Felt Tip Pens

Writing produced by the thick-point fiber tip pen could not be reproduced with sufficient clarity in photocopies; consequently, line quality features were not found good enough for forensic analysis. Due to the regularity and uniformity of thickness in

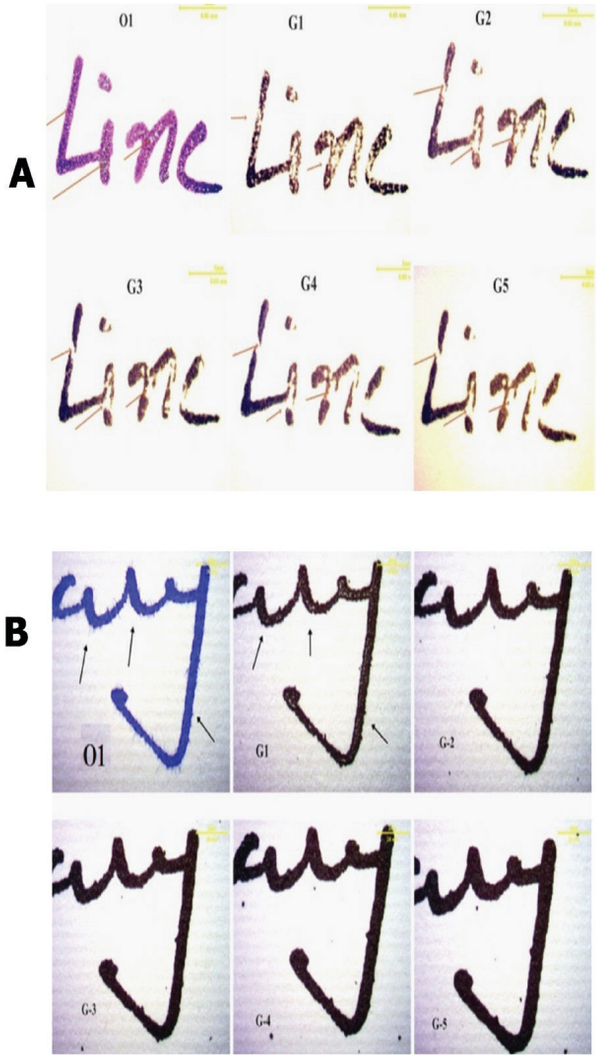

Figure 5- *Part (A), showing line quality in O-1, produced with "Linc shine Glitter gel pen". The fluorescent areas of the original image have been reduced as blank spots in the photocopies. Part (B) showing regular changes in thickness in descending strokes in nib pen writing. This feature could be seen in G1 and G2, in further generations, its identifying detail has been lost due to darkening of line. [Parker nib pen] [magnification 10X].*

writing strokes produced by such wide tipped pens, the direction of pen movement could not be identified in the photocopies. The formation of small-sized letters such as 'e', 'o', 'a'; and loop structure in letters 'g' and 'l' were not clearly identifiable in the photocopies (Figure-6).

Writing produced by the fine fiber tip pen was found good enough for analysis in G1 and G2. However, the

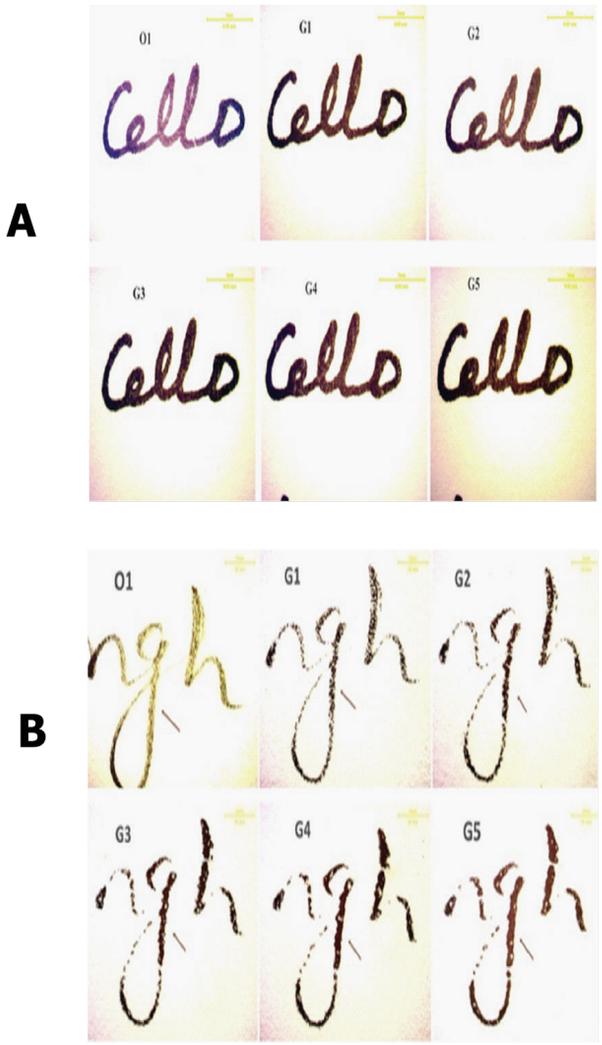

Figure 6- *Part (A), Showing the original word 'Cello' written with thick fiber tip pen (O-1); direction of writing movement could not be identified due to thick strokes, both in the original, as well as in photocopies G1 to G5. Part (B) showing dots pattern of graphite deposition in O-1 in strokes of letters 'g'and 'h' produced by lead pencil. In G1, graphite deposition is observed as toner dots pattern; but in further generations, it appeared as large and dark dots (magnification 10X).*

morphology of strokes was found to be similar to the writing produced by the roller ball point pens.

3.7 Lead Pencil

Presence of 'segregated toner dots' pattern corresponding to graphite particle distribution in the original pencil writing was found at higher magnification in photocopies of early generations G1 and G2 (Figure-6). In further generations beyond G2, this pattern had almost disappeared.

Overall line quality in photocopies of lead pencil writing was found to be poor compared with those of the ink pen writing; however, the reproduction quality of first-generation photocopy G1 also depends on the intensity of graphite deposition in writing line of the original. Further, it has also been observed that the sensitivity of photocopiers to detect and reproduce the original pencil writings was relatively poor as compared with that of the ink writings.

4. Discussion

Referring to the quality of strokes produced by the earlier ball-pens, Conway [5] states that personal individuality is not reflected in ball-pen writing to the extent that it is in the line of the conventional fountain pen. He had, therefore, cautioned the examiners to keep in mind that it is not always possible to differentiate with certainty between the writing characteristics produced by a faulty ball pen from those due to faulty movement of the forger. In author's opinion, the ball-pen provides shelter for the forger. Obviously, the photocopier reproduction of writings produced by such low-quality ball-pens further makes the task of document examiners difficult. However, with the advancement in technology, the quality of ball-pens as well as the photocopiers has substantially improved to the extent that examiners can safely differentiate between the ball-pen writings of different writers both from the originals as well as their good quality photocopies.

The present study also reveals that the nature of writing instrument affects the line quality of strokes, not only in the original, but also in photocopies. Ball point writing often shows some irregularity in photocopy generations. Presence of inkless starts with blob at the beginning of strokes could give a ten-

tative idea of the nature of writing instrument used in the original; the same could also be detected in photocopies of earlier generations (G1 or G2). Directional skips may occur after an abrupt change in the direction of the line [1]. Therefore, the presence of skipping in original handwriting often indicates the type of pen used as well as the direction of pen movements. Such condition/ defect could not be reproduced with sufficient clarity in the photocopies. Modern fountain pens now have very fine quality non-flexible nib points. They do not produce bifurcated line as in the past and produce a handwriting line similar to the writing instrument with a single writing tip [3].

The results of the present study revealed that ink feathering was not reproduced with clarity in the photocopies. Thick fiber point or felt tip point pens have little effect on action of the writer but examiner may find difficulty in establishing the pen movement [10]. Pen movement identification was found difficult in photocopies corresponding to heavy point fiber tip pens. In fiber tip writing with light pen pressure and rapid execution, ink lines will sometimes have a streaked or brush stroke appearance [5]. The results of the present study also support the earlier findings that striation/ blank streaked strokes could be present in the original writing and the same could also be identified in average quality first-generation photocopies.

Pencil writing line shows graphite particle deposition [4]. It has been observed that replica of graphite dots was seen on photocopied strokes as irregular toner dots in first-generation photocopies; in higher generations, this defect could cause further distortion in the writing strokes. Therefore, the presence of irregular, scattered toner dots pattern can help to differentiate between the ink-pen and graphite pencil writings from a photocopy. However, it needs to be further established whether the toner dots pattern is an effect of image processing of photocopier, or a replica of graphite particles of the original. Scott [7] has reported that in good-quality photocopy, a tentative determination of the type of writing instrument is possible on the basis of some line quality characteristics of writing instruments, such as the presence of gooping and striations indicating that the original was prepared with normal ballpoint pen. The descriptive results of the present study also support the earlier findings that it is usually possible to determine the type of writing instrument used to prepare the original, by microscopic examination of first- and second-generation photocopies.

5. Conclusion

Results of the present study reveal that the nature of the writing instrument affects the line quality of strokes, not only in the original but also in their photocopies. The present study supports earlier findings that it is usually possible to determine the type of writing instrument used to prepare the original by a microscopic examination of the first- and second-generation photocopies; however, it is sometimes difficult to differentiate the modern fountain pen writing from the roller pen writing because both use aqueous inks. Obviously, such differentiation cannot be made from their photocopies. Further, the study also supports earlier findings that writing instrument features like striation/blank streaked strokes, which were present in the original writing, could also be identified from the average quality first-generation photocopies.

It has been concluded that the evidence of skipping may indicate the type of pen used. However, the direction of pen movements which could be studied from the original handwriting could not be revealed with sufficient clarity from any generation of the photocopier reproduction. It has also been concluded that the overall quality of photocopies

of writings produced by the gel pen category was better than that of the other writing instruments. Therefore, the type of writing instrument could be determined from their first and second generation photocopies. The study also concludes that the evidence of ink feathering that was sometimes present in the original handwriting could not be reproduced with sufficient clarity in the photocopies. Further, it has been concluded that some of the photocopiers were not sensitive enough to detect and reproduce the original lead-pencil writings with clarity. Hence, their quality of reproduction was relatively poor, even in their first generation, as compared to that of the ink-writings. However, if the intensity of graphite-deposition from lead-pencil writings happens to be legible and good enough for detection, its first generation photocopier reproduction will normally be good enough for identification.

It is hoped that the results of the present study will be of great practical importance to the document examiners while handling questioned document cases involving multi-generation photocopies. Further research with a greater number of existing and new categories of writing instruments, as well as photocopiers, will undoubtedly enhance the utility of this study.

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