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Ink Dating—Comparative Examination of Inks on Documents using Optical and Chemical Methods

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Comparison of inks on the same or multiple documents is one of the ink dating approaches that determines and compares the physical and optical characteristics (including ink line morphology defects) and chemical composition of writing inks on documents. In this work, writing samples produced by 400 ballpoint pens (200 new and 200 used pens) were examined under the microscope, and the relative frequency of occurrence of various morphology defects, including certain reproducible ink line morphology defects that can be used for the purposes of relative ink dating, was determined. Also, the paper outlines typical case situations in which a comparative examination of inks on documents using optical and chemical methods is used for dating purposes.

Introduction

There are four major approaches (each approach is a group of methods) used for dating inks on documents[1]:

1. Ink Aging Approach—Ink aging methods that measure aging processes that occur in ink on documents.

2. Ink Availability Approach—Analytical methods that analyze the chemical composition of inks on a contested document with the aim to determine whether these inks (as well as other materials used to produce the document—paper, inkjet printing ink, toner, stamp pad ink, *etc*.) were commercially available on or prior to the date appearing on the document. For example, if the questioned document's date precedes the manufacturing date for the ink used to sign the document, it is established that the document could not have been signed on the date it bears.

3. Ink Comparison Approach

3.1. Intra-comparison of various written entries in a file or document—The examination's purpose is to assess whether the entries being compared were produced with the ink of the same composition or with different inks (pens). Such intra-comparisons of inks may reveal that the questioned entries were not written contemporaneously with the other entries in the file or document.

3.2. Comparison of multiple questioned entries dated over a long period of time—The examination's purpose is to assess whether the use of various inks on the document(s) fits a pattern that is either consistent with the dates appearing on the document(s) or indicates preparation "at one time" (during a short period of time).

3.3. Comparison of the contested document to other similar documents from the same time frame—If other similar documents from the same source and pertinent time frame are available for comparison with the contested document, then:

- presence of the same printing defects on the contested document and comparison documents (or the same patterns of trash

[1]There are some other approaches that may provide a forensic document examiner with information of considerable value for dating documents. For example, the examinations of watermarks (they might include dating codes) in paper, staple holes, punch holes, and tears might reveal a document's history and its relationship with other documents. Also, the examination of a document prepared on a letterhead stationary might show that the address or telephone numbers were different at the time that corresponds to the date appearing on the document.

marks or incidental marks on photocopies or laser prints) may yield valuable information concerning the dating of the contested document.

- The physical (optical) and chemical examinations of writing inks, as well as other materials used in the production of documents (paper, inkjet printing ink, toner, typewriter ribbon ink, carbon paper ink, stamp pad ink, etc.), can provide important information as to when a contested document was made.

4. The order of execution of certain elements of a document

4.1. Writing ink sequencing—Examining intersections (areas where two or more pen lines cross) to determine the order of writing (it may prove that a particular entry was added at a later time).

4.2. Sequencing of indented impressions and writings—Examining intersections (areas where the visible ink lines cross the indentations) may determine the order of writing and thus prove that a particular entry was added at a later time.

4.3. Paper folds—It is often possible to determine whether an ink line that intersects a paper fold was written before or after the paper was folded.

4.4. Offset marks—When two pieces of paper are pressed together, marks such as writing (and printing) may be transferred from one to another. When the writing on the reverse side of a sheet of paper in a bound ledger intersects with the writing on the front side of the sheet of paper, ink may be transferred from the front page onto an underlying page. Such transfers will occur only when inks are freshly applied. For example, if transfers of ink are found on several pages of a diary, it indicates that the corresponding entries on the diary were made in a single sitting, not over a longer period as suggested by the dates.

4.5. Ink and Toner Intersections—When a signature (or a handwritten notation) intersects a printed text on a document, a forensic document examiner may be asked which came first, the text or the signature (handwritten notation). The answer to that question may determine whether the document has been altered (by adding certain information). It should be noted that sequence of execution may be determined even when lines of the text and signature (handwritten notation) do not intersect. For example, a forensic document examiner can determine whether the stray toner particles (they are present on any laser-printed and photocopied documents but invisible to the naked eye) are below or above ballpoint pen ink writing [1].

This paper considers a combined use of microscopic and chemical examinations in the frame of the *Ink Comparison Approach*—the third out of the four ink dating approaches listed above. In particular, this paper reports the incidence of certain morphology defects observed under the microscope in writing samples produced by ballpoint pens, and it is a continuation of multiple similar studies, such as the studies conducted by Black [2], Poulin [3], Hung and Leung [4], Lewis [5], and Haywood [6]. The presence of morphology defects in ink strokes may be of considerable value for determining the relative time of writing of entries on documents. As follows from results of this study, if peculiar morphology defects are present in ink strokes, then the microscopic examination, coupled with chemical examinations, may establish whether the same or different pens were used to write certain notations.

Methods and Materials

New Ballpoint Pens (100 black and 100 blue ballpoint pens):

- *Black ballpoint pens*—Avery (number of pens tested—1), Bic (7), Caran d'Ache (3), Cartier (2), Cross (3), Dunhill (1), Dupont (2), Eversharp (1), Faber-Castel (1), Filofax (1), Fisher (6), Hauser (1), Lamy (4), Maped (1), Milan (1), MMF Industries (1), Montblanc (2), Montegrappa (1), Papermate (3), Parker (3), Pelikan (1), Penatia (1), Pentel (5), Pilot (10), Preventa (1), Private Reserve (1), Rotring (1), Schmidt (2), Schneider (1), Sheaffer (3), Snowhite (1), Stabilo (1), Staples (3), Stypen (1), Sun-Star (1), Tombow (3), TUL (1), Uniball Jetstream (2), Uni-ball Power Tank (2), Uni Clifter (1), Visconti (2), Waterman (3), WH Smith (1), Yard-O-Led (2), Zebra (5).
- *Blue ballpoint pens*—Aurora (1), AIHAO (2), Bic (4), Biefa (1), Burberry (1), Caran d'Ache (2), Cartier (2), Cross (3), Dunhill (1), Dupont (2), Faber-Castel (1), Fisher (10), Lamy (4), Maped (1), MMF Industries (1), Montblanc (3), Montegrappa (2), Papermate (4), Parker (2), Pelikan (1), Pentel (7), Pilot (9), Preventa (1), Private Reserve (1), Schmidt

(2), Schneider (1), Sheaffer (2), Snowhite (1), Stabilo (1), Sun-Star (2), Tombow (2), TUL (2), Uni-ball Jetstream (2), Uni-ball Power Tank (1), Uni Clifter (2), Visconti (2), Waterman (3), WH Smith (1), Yard-O-Led (2), Zebra (8).

Used Ballpoint Pens—100 black and 100 blue used ballpoint pens were chosen from the ink library of this author. About half of these pens were promotional pens the makes and models of which could not be determined.

Paper—Over 80% of writing samples in this study were prepared on HP Office paper (92 brightness, 20 lb weight, manufactured in USA) and OfficeMax Multi Purpose paper (96, 20 lb, USA). About 20% of writing samples were prepared on paper samples of various types.

Methodology and Instruments—Writing samples were prepared (over a span of several years) using each of the above 400 pens and consisted of repetitions of the overlapping numerals "0," as well as horizontal and diagonal strokes, ovals, and handwritten notations that relate to the make and model of the pen and/or ink cartridge. Each writing sample occupied 10 to 20% of a letter-sized sheet of white paper. The writing samples were examined macro- and microscopically using 4X, 10X and 20x magnifying glasses, a Dino-Lite digital microscope with magnifications 10X to 50X, and a Zarbeco MiScope-2MP digital microscope with magnifications 40X and 140X. Photomicrographs were taken to record striations and other morphology defects in ballpoint pen strokes, and the incidence of such defects was evaluated for the writing samples produced by the 200 new and 200 used ballpoint pens.

Results

The relative frequency of occurrence of various morphological defects, such as simple striations[2], elaborate striations[3], skips[4], and "starving"[5], which were observed under the microscope in strokes produced by new and used ballpoint pens, are shown in Tables 1 and 2.

Other ballpoint ink line morphological defects, such as "inkless start," "goops"[6], and "strings"[7], were also examined. Though the used pens created significantly more goops and strings in their writing samples than the new pens tested, it was noted that the incidence of goops and strings in ink lines produced by both used and new pens

Black **Ballpoint Ink Pen**	**Number of Pens**	**Ink Line Morphological Defects**			
		Simple Striations	**Elaborate Striations**	**Short Gaps (Skips)**	**Long Gaps (Starving)**
New BP	100	13	0	26	2
Used BP	100	91	7	77	18

Table 1. Incidence of various morphological defects in strokes produced by new and used black ballpoint pens.

Blue **Ballpoint Ink Pen**	**Number of Pens**	**Ink Line Morphological Defects**			
		Simple Striations	**Elaborate Striations**	**Short Gaps (Skips)**	**Long Gaps (Starving)**
New BP	100	14	0	29	3
Used BP	100	93	4	65	22

Table 2. Incidence of various morphological defects in strokes produced by new and used blue ballpoint pens.

[2]*E.g.*, one or two thin "white" (void) lines within the confines of the written line.
[3]Complex patterns of non-inked and inked areas within the confines of the written line.
[4]Self-recoverable temporary *short* breaks (no/negligible deposition of ink) in an otherwise continuous ink line.
[5]A self-recoverable *long* break (no/negligible deposition of ink) in an otherwise continuous ink line (*e.g.*, due to inadequate flow of ink to the writing surface).
[6]A small dot-like deposit of ink, especially at points of redirection, such as in loops and connecting strokes.
[7]A portion of ink from goop still clinging to the pen tip which strings along the ink line and remains connected until the tension becomes too great and the "string" breaks, rebounding back on the paper in a thin thread of ink (a typical example of a "string" is shown in Figure 2).

was also strongly dependant on the angle of the pen relative to the writing surface. Thus, many of the tested pens that had not exhibited any goops in their writing samples began showing goops (sometimes both goops and strings) when the pens were held at acute angles in relationship to the paper during the writing process.

Discussion

It is well known in the fields of both ink/pen industry and forensic document examination that, due to normal wear and tear, *used* ballpoint pens typically produce more defects in the written lines than *new* pens. Some specific factors that may contribute to a malfunction of a used pen include *1)* the formation of burrs on the ball housing, *2)* gradual clogging of the ball housing (during the act of writing) with fibers and other components of the paper and/or materials present on the surface of the paper, and *3)* excessive wear and tear (*e.g.*, the tip of a ballpoint pen may be damaged either by forcing it against a hard surface or by rough handling).

As shown in Tables 1 and 2 above, the overwhelming majority of the used ballpoint pens examined, 91% of black and 93% of blue pens, exhibited striations, while only 13% of the examined 200 new pens produced striations in their writing samples. None of the new black or blue pens showed elaborate striations, while 7% of the used black pens and 4% of the used blue pens produced elaborate striations in their ink stokes (see Figures 1 – 3).

Figure 1. Elaborate striations reproducibly exhibited in the writing samples prepared with a used Bic® (Sweden, 1992) medium point blue ballpoint pen (photographed at 40x).

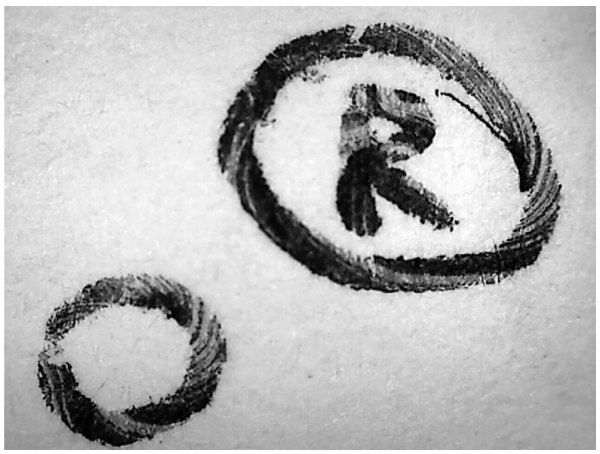

Figure 2. Elaborate striations reproducibly exhibited in the writing samples prepared with a used Bellagio® (Las Vegas, NV) medium point black ballpoint pen (photographed at 40x).

Figure 3. Elaborate striations reproducibly exhibited in the writing samples prepared with a used pharmaceutical company (Michigan, 2010) medium point black ballpoint pen (photographed at 40x).

It is interesting to note that similar patterns of elaborate striations shown in Figures 2 and 3 were produced by two different black ballpoint pens that contain the inks of different chemical compositions (determined by the chemical analyses of these two inks). This indicates that, without the chemical analysis of the ink used to produce written notations or signatures, even the presence of a complex pattern of burr striations (unless the striation pattern can be considered unique) might not be sufficient for a definitive individualization of the pen, *i.e.*, for establishing that a single pen was used to produce all the written notations or signatures.

Figure 4. Multiple skips (gaps) reproducibly exhibited in the writing samples prepared with a used gift medium point blue-violet ballpoint pen (photographed at 40x). The image clearly shows a high level of malfunctioning of the pen that is not typically observed in ballpoint ink writing. In this study, such a peculiar pattern of alternating skips and areas of heavy deposits of ink was shown by only one out of the 400 pens tested.

The data listed in Tables 1 and 2 also shows that old pens exhibited a sufficiently larger quantity of short gaps (71% of pens) and long gaps (20% of pens) in their ink lines (see Figures 4 and 5) than new pens.

It should be noted that both *elaborate striations* (shown by 11 out of the 400 pens tested; see Tables 1 and 2) -- three examples of which are shown in Figures 1 through 3 -- and *peculiar patterns of gaps* (1 out of the 400 pens tested, see Fig .4) were exhibited reproducibly from one writing sample to another prepared with each respective (malfunctioning) pen. Hence it follows that if various writings are compared, *e.g.*, writings purportedly made over a long period of time, and if these writings show a certain peculiar ink line morphology defect(s), then it may be possible for the examiner to individualize the pen that produced all these writings.

It should be stressed, however, that some of the new pens examined also produced not only short

Figure 5. Long gaps present in ink strokes written with a used fine point blue ballpoint pen manufactured in South Korea (photographed at 40x). Though this pen has shown good writing characteristics when preparing multiple writing samples for this study, sometimes it produced long skips (long areas of "starving") like the V-shaped one shown on this image.

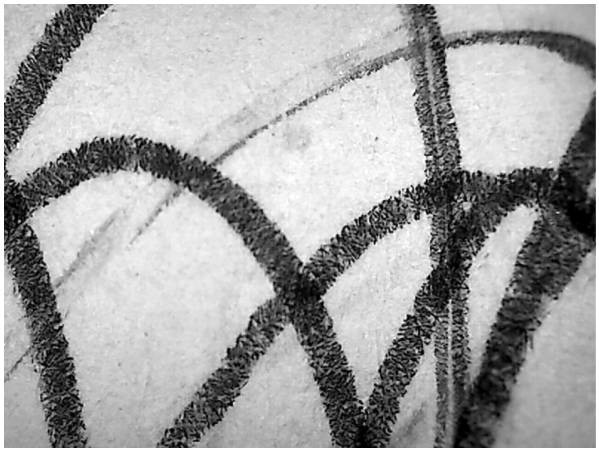

Figure 6. An example of a long gap (a long area of "starving") present in a stroke within a writing sample produced by a new fine point Tombow® (Japan) black ballpoint pen (photographed at 40x).

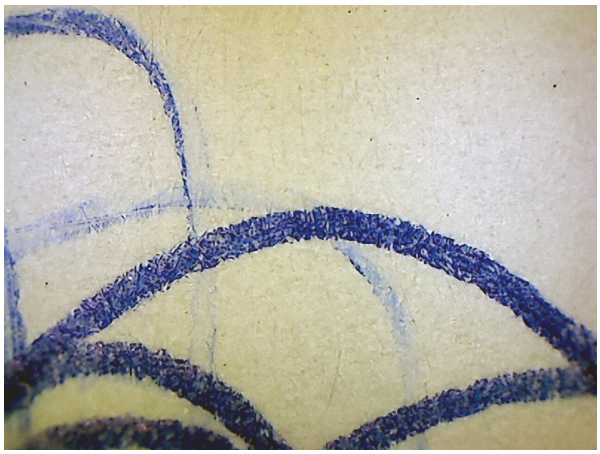

Figure 7. Two long gaps (long areas of "starving") present in ink strokes written by a new, high-end medium point Aurora® (Italy) blue ballpoint pen (photographed at 40x).

gaps (*ca*. 28% of pens) but also long gaps (*ca*. 3% of pens) in their ink lines (see Figures 6 and 7).

The fact that both used and new ballpoint pens may exhibit multiple short and long gaps in their ink strokes should be taken into consideration when conducting a microscopic examination and comparison of written notations and signatures in casework.

Class and Individual Characteristics of the Pen

All the ink line morphological defects listed in Tables 1 and 2 above can typically be found in ballpoint ink writing, and thus such defects are class characteristics of ballpoint pens. However, depending on the level of pen malfunction, any of these class characteristics may develop into an individual characteristic of the pen. In other words, though a typical malfunctioning of a ballpoint pen resulting in the presence of striations and/or gaps in ink strokes is a **class** characteristic, a more serious pen malfunction, *depending on the degree to which a particular defect occurs*, might lead to written lines showing peculiar features (*performance characteristics*), which, in combination, may well become an **individual** characteristic of the pen. It is well known in the field of forensic document examination that if the entries being compared show peculiar written line characteristics that are caused by a defect(s) of a writing instrument, such a writing instrument can be identified (individualized) as the one that was used to produce the entries compared. Thus, Lindblom, referring to multiple scientific publications that describe the studies of burr striations in ink strokes in order to identify ballpoint pens, concludes that, *"Very fine burr striations may occur at times in a pattern distinctive enough to individualize the pen"* [7]. Also, the Scientific Working Group for Forensic Document Examination (SWGDOC) "Standard for Test Methods for Forensic Writing Ink Comparison" recognizes that a forensic document examiner can conduct an "*examination of the ink line to individualize the writing instrument that produced it based on its performance characteristics*" [8].

Case Example

In a civil case, the key issue was whether 15 documents, each bearing a printed text and two signatures (further referred to as Signature "1" and Signature "2"), were or were not produced during a period of time of over 11 years—from July 1996 to December 2007. This author used thin-layer chromatography (TLC) and gas chromatography-mass spectrometry (GC-MS) to chemically analyze the inks used to produce the signatures on the documents. The results of the chemical examination showed that on all 15 documents Signature "1" was produced using blue ballpoint ink of the same formulation (ink "*1*"). The ink "*1*" had quite a complex chemical composition (numerous components detected by TLC and GC-MS formed a complex "chemical finger-

Figure 8. A fragment of Signature "1" on a document purportedly produced and signed in 2007 (photographed at 40x).

[8]ASTM International Standard E1658-08 "Standard Terminology for Expressing Conclusions of Forensic Document Examiners" recommends (in section 4.1) the terms "*probable*" and "*highly probable*," as well as some others, to express qualified opinions. As used here, in accordance with the language of the ASTM standard, the term "*probably*" means that the evidence (virtually the same peculiar ink line morphology defects present in all the signatures compared) contained in 15 Signatures "1" points rather strongly toward all the 15 signatures having been written by the same pen. As an acceptable alternative to this qualified conclusion, using the Bayesian approach and a degree of confidence similar to that expressed by the term "*probably*" in section 4.1 of the ASTM E1658-08, one may reformulate this conclusion as follows: the evidence provides strong support for the proposition that the same pen was used to produce all the 15 Signatures "1" and weak support for the proposition that multiple pens were used to produce the 15 Signatures "1."

Figure 9. A fragment of Signature "1" on a document purportedly produced and signed in 1996 (photographed at 40x).

print"), which warranted a conclusion that all 15 Signatures "1" were most probably produced by the ink that came from the same manufacturing batch. Besides, all 15 Signatures "1" had ink line morphology defects that under the microscope looked like similar patterns of alternating long gaps (long areas of "starving") and segments of heavy deposits of ink within the strokes (see Figures 8 and 9). This indicated that all 15 signatures were probably[8] written using the same pen.

Besides, it was determined that another blue ballpoint ink (ink "2") that was used to produce most of Signatures "2" on the 15 documents was also of the same formulation and most probably of the same manufacturing batch.

The use of the ink of the very same composition (the same manufacturing batch), not to mention the use of the same pen, over purportedly extended time periods of over eleven (11) years strongly indicates that the respective signatures have been made contemporaneously. More so, the use of the same two inks by two (2) different individuals in significantly different time periods is strongly indicative that the respective signatures have been made contemporaneously.

Based on the results of that examination, this author concluded that it was highly probable that all the 15 documents were signed contemporaneously—within a short period of time, not within a period of time over 11 years as purported.[9]

This case examination shows the capabilities of the combined use of the chemical analysis and microscopic examination of ballpoint inks on documents in determining whether the use of various inks on the documents fits a pattern that is either consistent with the dates appearing on the documents or indicates preparation within a short time frame.

Conclusion

This paper discusses the relative frequency of occurrence of certain ink line morphology defects observed under the microscope in writing samples produced by ballpoint pens. The presence of such defects in ink strokes may be of considerable value for determining the relative time of the production of a document or specific entries on a document(s) by reference to other entries or documents.

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[9]Using the Bayesian approach and a degree of confidence similar to that expressed by the term "*highly probable*" in section 4.1 of the ASTM E1658-08, this conclusion could be reformulated as follows: the combined results of this examination provide *1)* very strong support for the proposition that all 15 documents were signed contemporaneously—within a short time frame, and *2)* virtually no support for the proposition that the 15 documents were signed within a period of time over 11 years as purported.

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