

A preliminary study of semi-quantitative, comparative evaluation of split or half fingerprints using Densitometric Image Analysis (DIA) - Inter-analyst differences for split or half fingerprints -

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Abstract: Due to the difficulty of grading visualized fingerprints with previously known evaluation methods for the comparison of split fingerprints, a preliminary study was performed with the densitometric image analysis (DIA) method as a potential quantitative and supplementary evaluation method. Each image of inked split fingerprints was divided into 4 zones for analysis. Weekly intra- and inter- analysis by two analysts with three whole fingerprints that were constructed by combining inked split fingerprints showed that the average area values and the ranges of difference fluctuation were not significantly different between strong fingerprints and strong-weak pairs, while they were different in weak fingerprints and weak-weak pairs. In the case of weak fingerprints, the exact acquisition of ridges was difficult and this seemed to influence the results. An additional study is needed for the improved reliability using DIA method with weak fingerprints such as 8 zones division rather than 4 zones. In addition, the analysis results performed by several analysts at different times should be used to improve the reliability of the analysis method further. Based on the above result, it can be judged that utilizing the DIA method as a secondary evaluation method of the existing scoring system would be effective with the additional studies especially on weak fingerprints.

Key words: latent fingerprint, split fingerprints, densitometric image analysis, semi-quantitative evaluation method

1. Introduction

Various kinds of evidence can be found in crime scenes and be effective to find crime-related facts when they are collected after appropriate verification. Among them, the fingerprint and substance containing DNA are at the center, through which crime-related

individuals can be identified.¹ The fact that the ridge pattern of the fingerprint of each person is different and has a characteristic that they never change in their lifetime are well known.² Thus, they are known to have a function for individual identification. In addition, it has a universal characteristic that can be classified broadly into three categories (Arch, Loop,

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and Whirl); it has been systematically organized and implemented as an efficient individual identification method. It has widely been accepted throughout the world as an indispensable means in Forensic Science.^{2,3}

Fingerprints found in crime scenes are primarily latent fingerprints, and it is necessary to develop them to be visualized and observed by the naked eye through optimal chemical and physical treatment based on the conditions of them.^{4,5} The selection of the technique of development process is determined by several elements and differs depending on the conditions (dry and wet), colors, properties (porous, non-porous, and semi-porous), and texture (roughness and softness) of the surface on which latent fingerprints are deposited.⁶

Generally, there are various development methods, depending on the two basic categories of porous and non-porous surfaces on which fingerprints remain. In addition, for the selection of the optimum development method, it is necessary to validate relative superiority of the degree of their visualization through various experiments.⁷ Yet, since it is difficult to secure sample fingerprints in the same kind and condition, as for the validation of development methods, usually, split or half fingerprints from the division of sample whole fingerprints in half are developed with different methods for the left and right and recombined, and then, the results are compared.⁸ Quantitative scoring methods are then used for their comparison. They are used broadly according to three quantifying methods, and each has somewhat different purposes and has merits and demerits.⁹⁻¹²

First, McLaren's method compares split or half fingerprints, which were developed on the left and right with different methods and evaluates each method and quantifies them by giving a 0 point when there is no difference between the left and right, +1 for somewhat excellent and +2 for more excellent, or -1 and -2. Evaluations by the naked eye are important, as there may be a difference between evaluators.⁹

The method by the Center for Applied Science & Technology (CAST) gives a score of 0 to 4 for the whole fingerprint, which quantifies that by the part

of the clear ridge detail to the whole fingerprint with about 1/3 as a unit.¹⁰ Moreover, as a revised version of this, the fingerprints are quantified with 1/3 as a unit according to the degree of continuity of ridges.¹¹ Both methods mentioned above give points by judging them by the naked eye, according to the clarity and continuity of the ridges, which can be applied to the whole fingerprint; however, they also have problems that they are not objective according to subjective observations by the individual's naked eye and that the width of scoring steps is narrow. In additional method, as for the evaluators, they usually mark target fingerprints as +, -, and \pm by the naked eye and usually according to the 2-level clarity of the ridges (Whether minute features can be observed).¹² According to a recent study, with the method of giving 0-4 points, the scores given to individual visualized fingerprints showed a median grade in about 67 % of evaluators, and the scores were within 1 point in about 99 %. Thus, it was suggested that even a rather small number of evaluators could make dependable and reliable evaluations.¹³ But, since this absolute scoring method has a very narrow width (0-4), it requires more analysis, and is very likely susceptible to human error. Results would likely rely on the experiences of individual analysts, and require supplementary comparative evaluation, a novel and highly reliable method, which can supplement the lack of the scoring systems

Densitometric Image Analysis (hereafter, "DIA") has primarily been used in biological and biochemical analysis, and semi-quantitatively analyzes the intensity of the density of each band, which appear as a result of the separation of protein and DNA. DIA utilizes electrophoresis and/or the area of the part on Thin-Layer Chromatography (TLC) image of chemically separated organic matter.¹⁴⁻¹⁶ Since the density of fingerprint ridge's line contrasted to the background can be calculated in the form of the image density value, the DIA method could be used for the analysis of fingerprints. They are composed with the generation of peaks contrasted to the background. The selection of peaks is set against the background and the area value of each of selected peak is calculated. A clear

and strong line contrasted with the background shows a high area value, while the line with weak density shows a low area value. It was reported that it would be possible to make a semi-quantitative comparative evaluation by comparing the area values of the peaks of the fingerprint ridges for the purpose of fingerprints with DIA method.¹⁷

Recently, a reported study of the variables generated from the analysis of whole fingerprint with DIA method showed the potential variables generated from the acquisition angles of ridge lines with analysis line, thickness of acquired ridges, and the number of zones in which the part of whole fingerprint acquired for the ridges etc. In particular, the importance of the acquisition angle of 90° was reported.¹⁷ However, to apply DIA method for the analysis of fingerprints, it is necessary to validate the reliability through the validation of the use, especially in applying it to the comparison and evaluation of split or half fingerprints.

Thus, this study attempted to validate the reliability of the DIA method as a semi-quantitative and comparative evaluation method by comparing the difference between analysts, which may occur in applying the DIA method for the comparison and analysis of the left and right of split or half fingerprints. Moreover, the reproducibility of the analysis result of the difference according to the time determined

and compared with the existing scoring method that analyzed fingerprints by the naked eye.¹⁸

2. Experiment Method

2.1. Materials and general method

For sample fingerprints, three consecutive fingerprints were identically pressured in the form of depletion series on a sheet of A4 paper (Double-A), using an ink fingerprint pad (JS-32435), and for each, divided fingerprints roughly in half were used. They were photographed with a digital camera (NIKON 5300) equipped with a macro lens (Nikon AF Micro Nikkor 60 mm f/2.8D, Japan), and they were edited, using Adobe Photoshop® CS6 (Adobe Systems Inc., USA), e.g., calibration and insertion of a standard line. In the evaluation of the results of the development of fingerprints, the area value of the peak of each ridge calculated was obtained with the DIA program, CP Atlas 2.0 (Lazarsoftware, USA),¹⁹ and the result was summarized and displayed in a graph, using Excel 2016 (Microsoft, USA).

2.2. Fingerprint sample

The fingerprint used in this experiment is that of the thumb of a man in his mid-20s, and three sample fingerprints were prepared with the finger (right

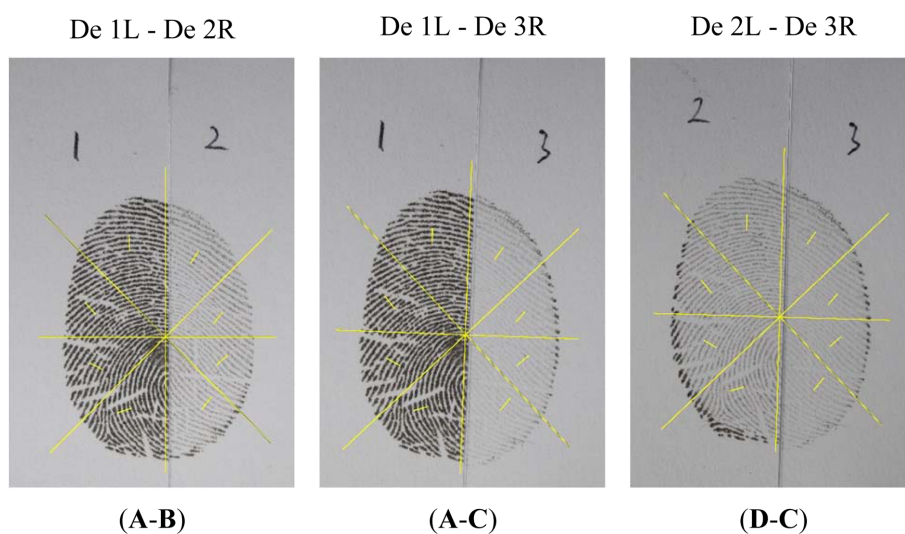


Fig. 1. Images of combined whole fingerprints for densitometric image analysis with standard line.

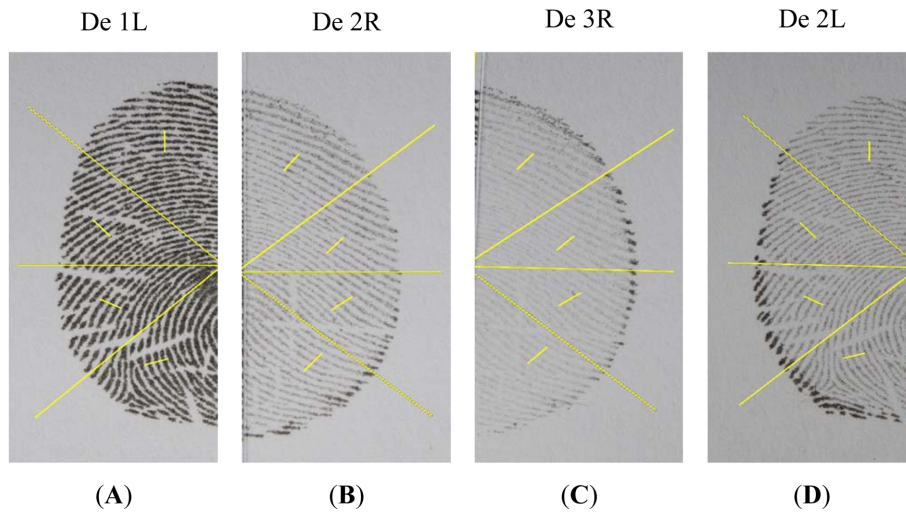


Fig. 2. Images of half fingerprints with standard line for the combination to generate whole fingerprints as in Fig. 1.

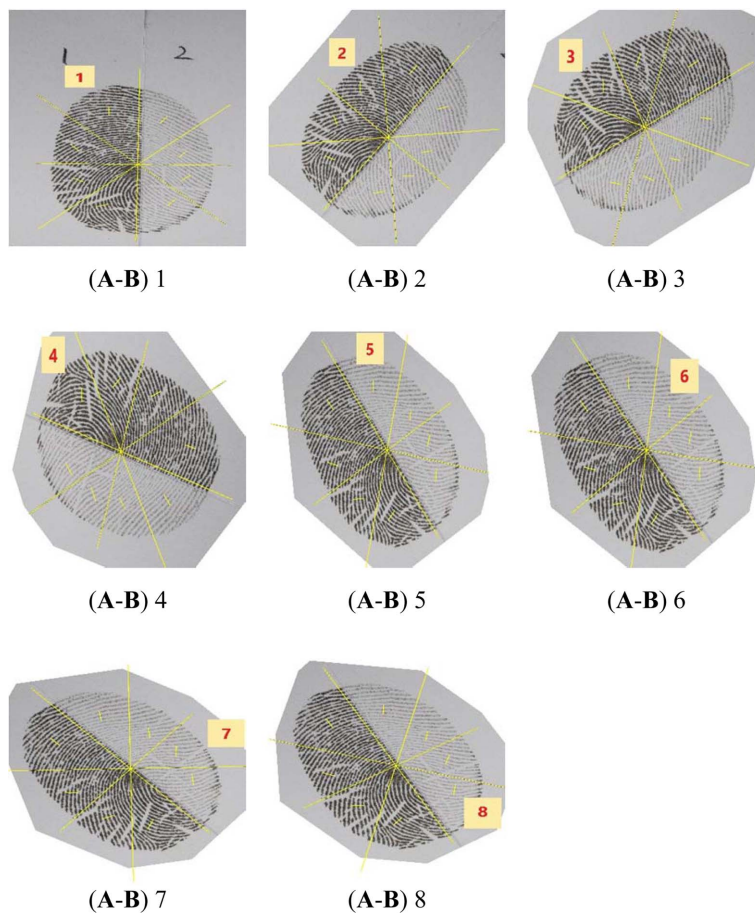


Fig. 3. Rotated images of combined split fingerprints for analysis to obtain the 90-degree acquisition of ridges with analysis line within the zone.

thumb), using ink for fingerprints on a sheet of A4 paper (Double-A). In other words, three inked whole fingerprints were left in the form of depletion series to leave No. 1, No. 2, and No. 3 (De 1, De 2, and De 3). Then, the three each fingerprints were divided into two, the left and right, respectively (L and R) in the form of split or half fingerprint. They were combined in the form of the whole fingerprint: ‘De 1L (A) – De 2R (B)’, ‘De 1L (A) – De 3R (C)’, and ‘De 2L (D) – De 3R (C)’ as seen in *Fig. 1*. (e.g., *Fig. 1*, A-B) and photographed. Using Photoshop CS6 (Adobe System Inc.), a standard line was inserted to divide them into eight zones equally (*Fig. 1*, standard line), and three ridges were selected in each zone. The combinations of four split or half fingerprints (A, B, C and D) in *Fig. 2* generated three whole fingerprints in *Fig. 1*. In addition, to obtain three ridges with analysis lines from each zone (1-8, *Fig. 3*) and to reduce the deviation by the known variables, the angle was set by the naked eye, rotating clockwise through Photoshop at 90 degrees.¹⁷ For each split or

half fingerprints, 12 ridges were gathered and analyzed by randomly selecting three fingerprint ridges respectively from four zones.

2.3. DIA method

In measuring the area of fingerprint ridges using DIA, the fingerprint image (A-B) was divided into eight zones equally, using Photoshop to take the ridges in the similar position, like *Fig. 4(a)* to apply the DIA program. The analysis procedures of the DIA program were as follows.

Fingerprint images were retrieved in the jpg format. Then, the background type was set to “dark on light.” Three fingerprint ridges to analyze were set with analysis line (*Fig. 4(a)*), and after appointing a baseline to the part corresponding to the valley of the fingerprint ridges, the peaks of the ridges were selected (*Fig. 4(b)*), and the area values were drawn as in pictures (*Fig. 4(c)*). The analysis was conducted, applying the same method to ‘(A-C)’ and ‘(D-C).’

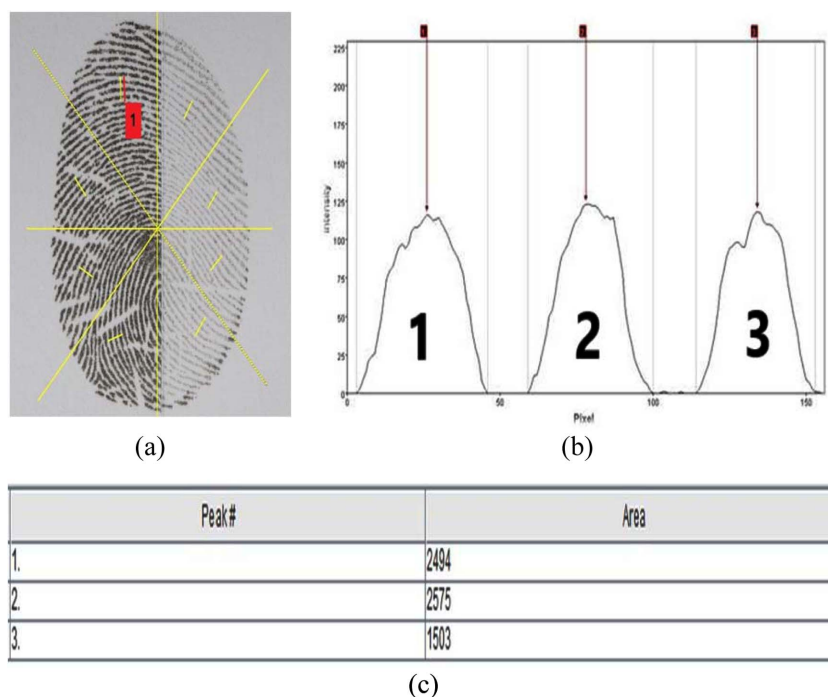


Fig. 4. An example of analysis with combined inked fingerprints with standard and analysis line (a), lane profile after peak selection (b) and analysis results (c) from densitometric image analysis by CP Atlas 2.0.

3. Results and Discussion

This study aimed to verify the possibility of the use of the DIA method as a part of the development of an analysis method having a supplementary role for the known scoring method previously used in the comparative evaluation of split or half fingerprints developed with different methods on the left and right. To examine the inter-analyst differences and weekly reproducibility of the analysis method, a comparison was made when two analysts evaluated the same images of fingerprints in the same period each week for two weeks.

3.1. Visual evaluation

First, McLaren's method was applied, which is a quantitative scoring known before DIA. In a comparison of split or half fingerprints on the left and right, the score of each fingerprint was measured by giving 0 points when there was no difference between the left and right, +1 for somewhat excellent, and +2 for more excellent, or -1 and -2.⁹

In *Fig. 1 A-B* and *A-C*, **A** had stronger, higher clarity and much higher continuous ridges compared to **B** and **C**, so it was easy to compare and was safe to score 2 points by the naked eye. However, in the comparison of **D-C**, 0 points might be given because small differences exist between **D** and **C**; however, by way of exception, an analyst might make a mistake of giving it 1 or 2 points based on his or her individual criteria.

Consequently, the subjective observation by the individual's naked eye is not objective and may have very different evaluation results due to analyst-specific uniqueness.

For this reason, this study would objectively validate the criteria and quantify them through DIA, a quantitative evaluation method.

3.2. Comparison of the results of analysts' weekly analysis

To use the DIA method in the comparative evaluation of split or half fingerprints, it is necessary to validate the method through validation. The

preceding experiment was a study of the impact of variables on the operation of the DIA method, which reported general variables.¹⁷

However, the analysis results have not been validated if the same analyst analyzed at different times and if different analysts analyzed the same sample fingerprint. Thus, proactively, the result of one analyst's analysis, using the DIA program (CP Atlas 2.0) in three different times (for two weeks; Day 1, Week 1, and Week 2) was compared. In addition, to obtain more objectivity and reliability compared to one analyst's one-time experiment, comparisons were attempted, showing the results of experiments three times per week in a graph by adding one experimenter (Analyst 1) (*Fig. 6, 7*).

3.2.1. Comparison of the results of Analyst 1's weekly analysis

Weekly analysis results by Analyst 1 are shown in *Fig. 5*. The highest area value was 2462, and the lowest area value was 2237 for **A** from the weekly analysis of whole fingerprints in *Fig. 1* three times with DIA program totaling six times. The difference was 225, which was about 10 % of their average value, 2345. For **C**, evaluated as a weak fingerprint, the highest area value was 181, and the lowest area value was 120. The difference was 61, which was about 38 % of their average value, 159. To compare this with **A**, the degree of change in the strong fingerprint was better than that in the weak fingerprint. Additional studies are required to reduce the range of fluctuation especially designed to apply for the analysis of weak fingerprints. In **B** (De 2R) and **D** (De 2L) from dividing 'De 2' equally, the highest area value was 480, and the lowest area value was 441 for **B**. The difference was 39, which was 9 % of their average value, 461. In **D**, the highest area value was 496, and the lowest area value was 366. The difference was 130, which was about 29 % of their average value, 449. In the graph of the results by Analyst 1's weekly analysis (Day 1, Day 7, and Day 14, *Fig. 5*), there was a small difference in the area value found in numbers from the image of each split or half fingerprint, but there was no clear difference

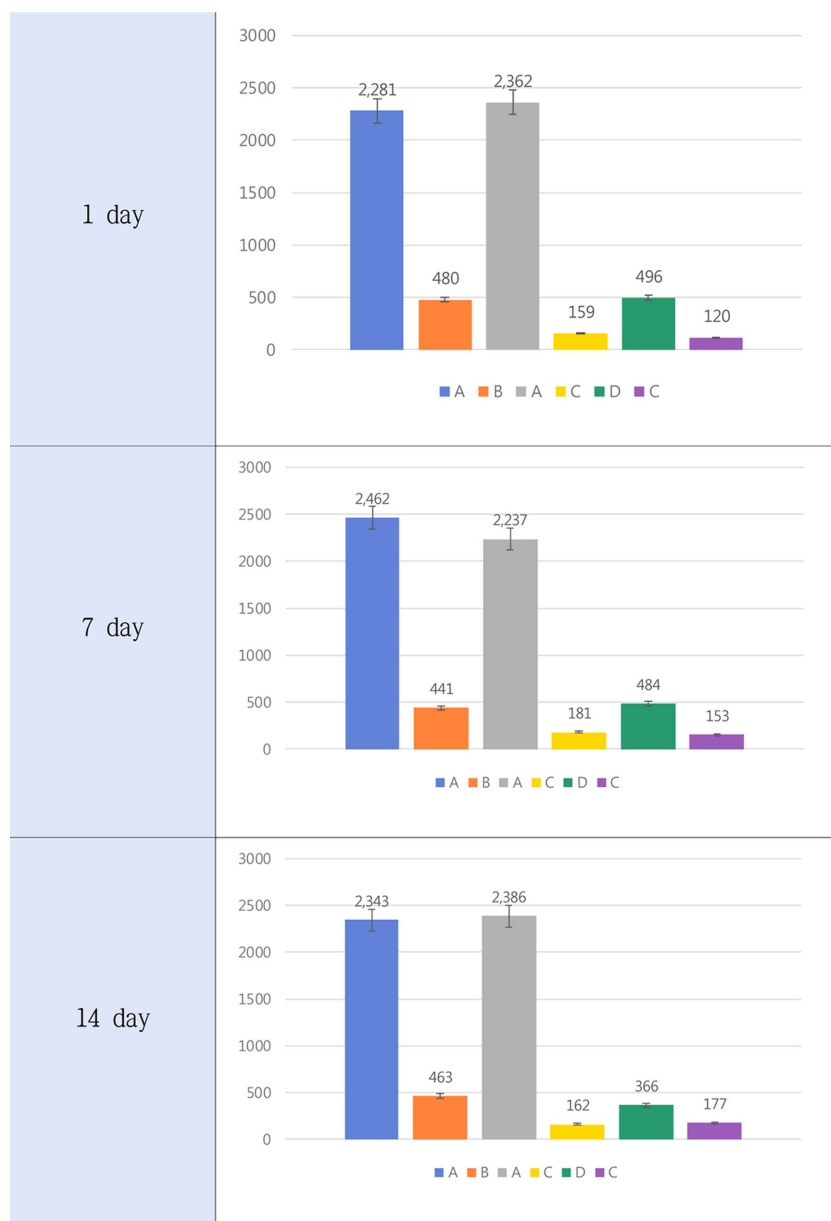


Fig. 5. Comparison of average area values after densitometric image analysis by analyst 1 at one-week intervals for 2 weeks.

by the naked eye.

In pair **A-B**, a combination of a relatively stronger fingerprint and a weaker fingerprint, the difference in the area value between **A** and **B** was 1801 (Day 1), 2021 (Day 7), and 1880 (Day 14), and the average value of the differences was 1900 by Analyst 1. The range of fluctuation was 5.2 % (Day 1), 6.3 % (Day

7), and 1 % (Day 14), so the range of weekly fluctuation was about 1 – 6 %. This showed that the difference was relatively smaller, and the analysis was consistent when the same analyst evaluated the difference between the left and the right on different days (Table 1).

However, in pair **D-C**, a combination of two weak



Fig. 6. Comparison of average area values after densitometric image analysis by analyst 2 at one-week intervals for 2 weeks.

fingerprints, the difference in the area value between **D** and **C** was 376 (Day 1), 331 (Day 7), and 189 (Day 14). The average value of the difference between the left and the right was 299, and the range of fluctuation was 25.8 % (Day 1), 10.7 % (Day 7), and 36.8 % (Day 14). The range of weekly fluctuation was about 11-37 %.

To compare the difference between **A-B** and **D-C**, the difference in the range of fluctuations was much greater in **D-C**. The difference in the range of the weekly fluctuation in each of them was small, and

the analysis was consistent as a whole. These results demonstrated similar previous research results for weak fingerprints. Therefore additional research should be conducted, e.g. the subdivision of analysis zones or the increase of reliability by statistical treatment of the results of several analysts' analysis to increase the reliability of the analysis.¹⁷

3.2.2. Comparison of the results of Analyst 2's weekly analysis

A method with high reliability should have

statistically acceptable difference between the analysts who use the method. To examine the inter-analyst difference, Analyst 2 performed an analysis using the same method by Analyst 1 with the same fingerprint image sample. Fig. 6 shows the result of the weekly analysis of three whole fingerprints presented in Fig. 1 by Analyst 2 with DIA. After six

evaluations of **A**, a strong fingerprint, the highest area value was 2694, and the lowest area value was 2279. The difference was 415, which was 16 % of their average value, 2521. In **C**, evaluated as a weak fingerprint, the highest area value was 306, and the lowest area value was 209. The difference was 97, which was 40 % of their average value, 245. To

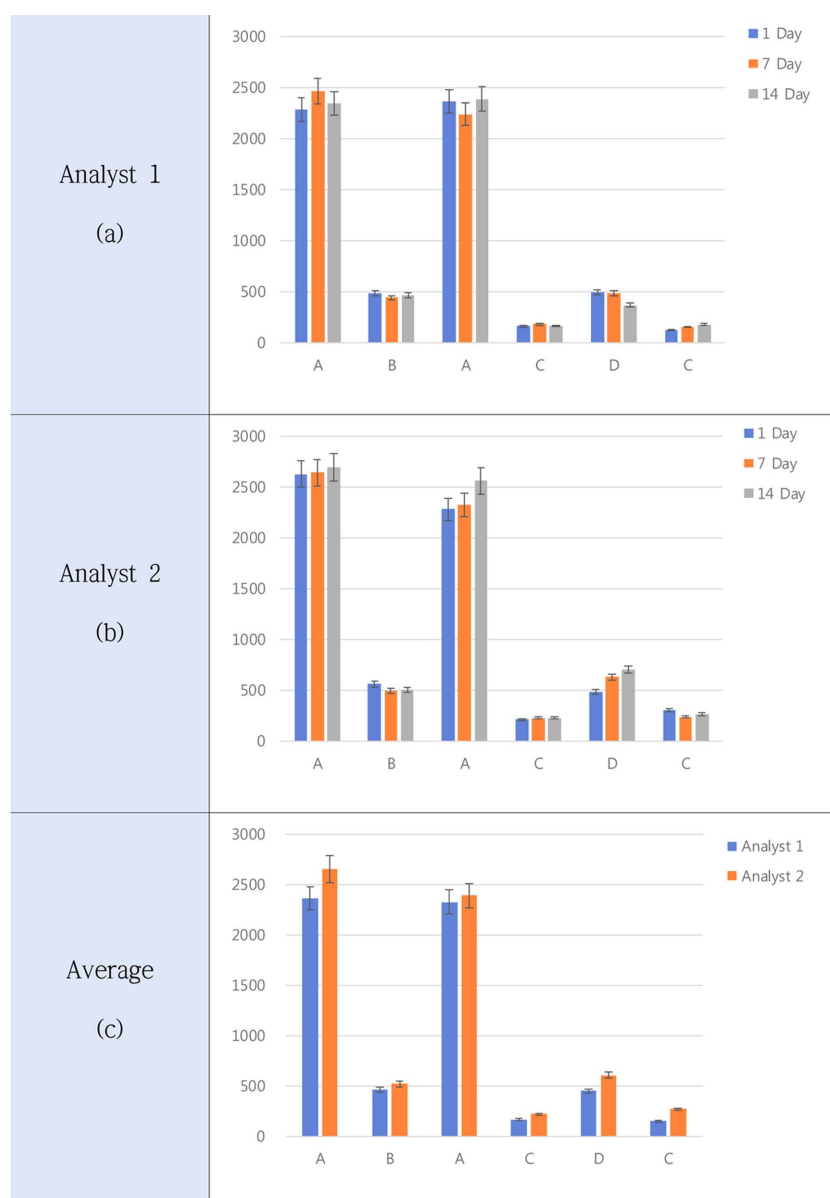


Fig. 7. Comparison of average area values after densitometric image analysis by analyst 1 and 2 at one-week intervals for 2 weeks.

compare this with **A**, the degree of fluctuation of strong fingerprints was better than that of weak fingerprints as shown in the analysis by Analyst 1. In **B** (De 2R) and **D** (De 2L) from dividing 'De 2' equally, for **B**, the highest area value was 561, and the lowest area value was 495. The difference was 66, which was 13 % of their average value, 518. In **D**, the highest area value was 705, and the lowest area value was 485. The difference was 220, which was 36 % of their average value, 607 (Fig. 6). In **A-B** pair by Analyst 2, the difference in the area value between **A** and **B** was 2065 (Day 1), 2146 (Day 7), and 2195 (Day 14). The average value of the difference between the left and the right was 2135, and the range of fluctuation was 3.3 % (Day 1), 0.5 % (Day 7), and 2.8 % (Day 14). The range of weekly fluctuation was about 1-3 %. This is a result similar to that of the analysis by Analyst 1, which shows that the difference is relatively small and the analysis was consistent (Table 1). In pair **D-C**, the difference in the area value between **D** and **C** was 179 (Day 1), 395 (Day 7), and 439 (Day 14). The average value of the difference between the left and the right was 338. The range of fluctuation was 47 % (Day 1), 16.9 %

(Day 7), and 29.9 % (Day 14). The range of weekly fluctuation was about 17 – 47 %.

To compare **A-B** and **D-C**, the difference in the range of fluctuations was much greater in **D-C** than in **A-B**.

This analysis result has a similar tendency to that of Analyst 1, and it is judged that it is necessary to conduct the additional research discussed above in the analysis of weak split or half fingerprints.

3.2.3. Inter-analyst comparison of analysis results

Fig. 7 and Table 1 show inter-analyst weekly analysis (Day 1, Day 7s, and Day 14s) in graphs, respectively, and a comparison of the weekly average value of the whole weeks.

In **A-B**, the inter-analyst difference was 12 % in **A** and 13 % in **B**. In **A-C**, it was 3 % in **A** and 32% in **C**. In **D-C**, it was 35 % in **D** and 80 % in **C**.

In the above results, it could be found that in **A**, a strong fingerprint, the gradient was the lowest at 3 % – 12 % while it was the highest in **C**, a weak fingerprint.

However, the comparison of the numerical value

Table 1. Comparison of average area values after densitometric image analysis by analyst 1 and 2 at one week intervals for 2 weeks

Analyst	Interval	Fingerprints		
		A / B (Difference)	A / C (Difference)	D / C (Difference)
Analyst 1	1 day	2281 / 480 (1801)	2362 / 159 (2203)	496 / 120 (376)
	7 day	2462 / 441 (2021)	2237 / 181 (2056)	484 / 153 (331)
	14 day	2343 / 463 (1880)	2386 / 162 (2224)	366 / 177 (189)
	Average	2362 / 461 (1901)	2328 / 167 (2161)	449 / 153 (299)
Analyst 2	1 day	2626 / 561 (2065)	2279 / 209 (2070)	485 / 306 (179)
	7 day	2641 / 495 (2146)	2327 / 225 (2102)	631 / 236 (395)
	14 day	2694 / 499 (2195)	2560 / 227 (2333)	705 / 266 (439)
	Average	2654 / 518 (2135)	2389 / 220 (2168)	607 / 269 (338)

of the difference in split or half fingerprint between the left and the right is important for the analysis. The difference in the area value between **A** and **B** was 1901 by Analyst 1, and 2135 by Analyst 2. The average value between the two was 2018, and the range of fluctuations was 5.8%. As for the difference in the area value between **D** and **C**, it was 299 by Analyst 1 and 338 by Analyst 2. The average value between the two was 318, and the range of fluctuation was 6%.

Considering these inter- and intra-analyst weekly differences, to increase the reliability of the DIA method, the averages of the results from the analysis conducted multiple times on different days by different analysts should be used. As for the difference between the left and the right of split or half fingerprints in large quantitative numerical values of the DIA results for comparison, it can be judged that it is a method with high potential as an appropriate method for comparative and quantitative evaluation of split or half fingerprint with small range of fluctuation.

4. Conclusions

Two analysts analyzed images of sample whole fingerprints constructed by combining images of inked split or half fingerprint for two weeks to test the applicability of the DIA method as a supplementary method for the existing scoring method using visual evaluation. The inter- and intra-analyst variability was evaluated. As a result, the following conclusions were drawn.

1. To quantify the range of the fluctuation of the average value of the difference in the area value between the analysts, it was 5.8% in **A-B** and 6% in **D-C**. Since there was not a big difference, and the results of the evaluations were similar, the DIA method could make a great contribution as an evaluation method supplementary for the existing evaluation methods.

2. To sum up the average value and the range of the fluctuation of the area value in the analysis of weak fingerprints, since overall, there are differences, and the results are not even, several analysts must

conduct the analysis multiple times to increase the reliability evaluation of analysis results.

To sum up the above results, DIA is an objective, quantitative evaluation method, shown by numerical values, which is judged to be a method supplementary for the visual scoring method. And yet, additional research is required on a supplementary method that can reduce the difference between additional analysts for weak fingerprints and that can show similar values, even when the analyst conducts another analysis after a certain period.

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