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# Preliminary Insights into 3D Cheiloscopy for Forensic Applications: A Pilot Study

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**Abstract:** Background: Cheiloscopy, a forensic technique based on the uniqueness of labial traces, has traditionally relied on analog methods. While simple, these methods present significant limitations in terms of precision and reproducibility. The introduction of 3D technology, specifically high-resolution optical scanners, represents a pivotal advancement in overcoming these challenges. Objective: This pilot study aimed to explore the feasibility and potential advantages of 3D cheiloscopy in forensic science by analyzing its precision and repeatability compared to traditional analog methods. Methods: Two participants were selected as a pilot sample, and their lip impressions were captured using both analog techniques and a high-resolution intraoral scanner (Medit i700). A total of 40 samples were collected, equally distributed among operators with varying levels of experience. Surface deviation analysis was performed to compare the methods. Results: The 3D models demonstrated greater uniformity and resolution compared to the analog impressions, which were more prone to errors caused by material quality or operator pressure. Surface deviation analysis showed an average similarity of 70%, with a standard deviation of 0.229 mm. The digital methods also significantly reduced operator-dependent variability. Conclusions: This pilot study highlights the potential of 3D cheiloscopy to improve precision and standardization in forensic applications. While the small sample size limits the generalizability of the findings, the results provide a foundation for further research with larger and more diverse datasets. Future studies should explore the capability of 3D cheiloscopy to accurately match individuals and further validate its applicability in forensic and clinical contexts.

**Keywords:** 3D cheiloscopy; forensic analysis; digital forensic techniques

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## 1. Introduction

Cheiloscopy, derived from the Greek words keilos (lips) and skopein (to observe), is a forensic identification technique based on the uniqueness of the patterns present in the labial vermilion, much like fingerprints [1]. The distinctive folds and grooves in this region form a unique "lip print" that can be used for individual identification [2]. First introduced in the 20th century, cheiloscopy has since been employed in various forensic applications, including crime scene investigations and post-mortem identification [3]. However, its practical application has been historically constrained by the limitations of lip print collection and analysis methods [4].

Traditional cheiloscopy relies on lipstick and adhesive tape to transfer lip impressions onto a physical medium. These analog techniques, being simple and accessible, have been widely used due to their ease of application [1]. Typically, a layer of lipstick is applied to the subject's lips, and the impressions of the upper and lower lips are captured on strips of transparent adhesive tape, then transferred to blank cards for analysis. The prints are subsequently examined for unique features and compared with latent lip prints recovered from crime scenes using powders or other lifting techniques. However, despite their widespread use, the reliability of these methods has been questioned, because this process is inherently complex and subjective, as there is no standardized database for systematic matching [2,5]. Additionally, factors such as pressure variation, lipstick type, and adhesive tape handling can affect the quality of the impressions, making consistent results difficult to achieve [4,6].

Although these analog approaches remain prevalent due to their practicality and low cost, their limitations underscore the need for more precise and reproducible methods. Previous research has highlighted the importance of developing a standardized database for comparison, which would significantly enhance the utility of cheiloscopy in forensic investigations [7,8].

Another challenge lies in the numerous classification systems used to categorize lip prints [9]. While these systems aim to organize and interpret lip print patterns, they are often overly didactic and fail to capture the full complexity of lip morphology, limiting their forensic applicability. Moreover, inconsistencies in lip print classification, particularly regarding sex determination, further hinder the reliability of cheiloscopy [10]. While some studies suggest sex-based differences in lip print patterns, findings remain highly discordant, with no universally accepted correlation between lip characteristics and biological sex [1,7,11]. This variability complicates the role of cheiloscopy as a forensic tool, emphasizing the need for standardized and objective methodologies.

In contrast, other forensic identification techniques, such as fingerprint analysis and dental profiling, have benefited from advancements in digital and 3D technologies, improving precision, reproducibility, and data management [12,13]. Cheiloscopy, however, has been slower to adopt similar innovations, remaining reliant on traditional analog methods that are less effective in complex forensic scenarios.

The advent of 3D imaging technology presents a transformative opportunity for cheiloscopy. High-resolution optical scanners, such as intraoral devices, enable the capture of detailed three-dimensional representations of the lips, addressing many of the limitations of traditional methods. This approach minimizes operator dependence, reduces artifacts, and improves long-term data storage. Furthermore, 3D cheiloscopy facilitates advanced digital manipulation and interdisciplinary collaboration by enabling the sharing of standardized digital models [14]. By enhancing systematic matching and reducing human error, this technology offers the potential for a robust, standardized digital database for lip print analysis.

This pilot study aimed to explore the feasibility and advantages of applying 3D technology to cheiloscopy. Specifically, it evaluated the precision, repeatability, and potential for standardization of 3D cheiloscopy in comparison to traditional analog methods. By addressing these aspects, this research sought to establish a foundation for future studies and forensic applications of 3D cheiloscopy. The findings could contribute to the development of a standardized lip print database, ultimately improving the accuracy and reliability of forensic lip print analysis.

## 2. Materials and Methods

This preliminary experimental study aimed to compare two different methodologies for acquiring lip morphology, one analog and one digital, evaluating their reliability and repeatability.

### 2.1. Selection of Subjects

Two female participants were selected based on specific inclusion and exclusion criteria and enrolled in the study after providing written informed consent:

Inclusion criteria:

- Lips free of active lesions or inflammation;
- No previous allergic reactions to lipstick or other cosmetics;
- Stable and confirmed general health condition;
- Clear indication of the subject's sex for potential future analysis of sex-based morphological differences.

Exclusion criteria:

- Lack of informed consent from participants;
- Presence of active lesions (cold sores or keratitis) or lip surgery;
- Congenital malformations that could alter the labial morphology, such as cleft lip.

Ethical approval for the study was obtained from the Ethics Committee of the University of Palermo Policlinico "Paolo Giaccone" (Minutes No. 04/2024, Session of 8 February 2024).

### 2.2. Acquisition Protocols

Labial morphologies were acquired in a single session using two different methodologies to evaluate their precision, repeatability, and operator dependence. For the analog method, a standardized liquid lipstick (NYX Professional Makeup, Los Angeles, CA, USA) was applied in a homogeneous layer using disposable brushes, ensuring uniform coverage. The subject was asked to rub their lips together to ensure an even distribution of the lipstick. The resulting lip prints were then transferred to transparent adhesive tape and stored on white paper sheets for subsequent digitization (Figure 1).

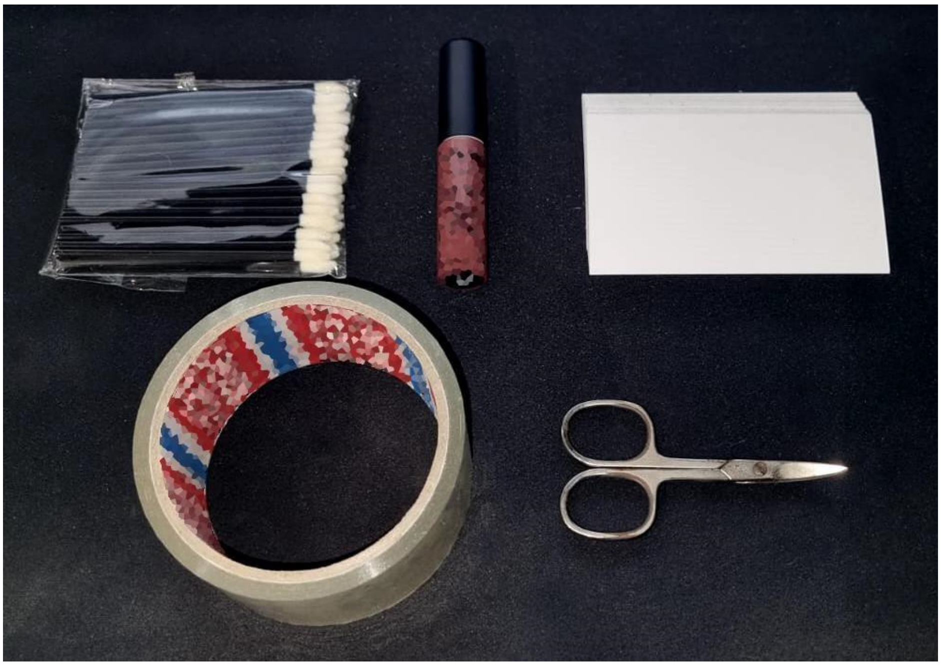

**Figure 1.** Tools used for analog lip prints capture.

In contrast, the digital method involved direct scanning of the lips using high-resolution 3D intraoral optical scanners. Two intraoral scanners were utilized in this study: the IS 3600 from Dexis (Quakertown, PA, USA) and the i900 from Medit (Seoul, Republic of Korea), which captured the labial surface without the need for any intermediate steps, such as lipstick application. This allowed for direct acquisition of the lip morphology without the influence of external substances (Figure 2).


**Figure 2.** Tools used for digital lip prints capture. (Images from https://www.medit.com/it/medit-i900-intraoral-scanner/ and https://dexis.com/it-it/dexis-is-3600 (accessed on 2 February 2025)).

### 2.3. Operators Involved

The acquisitions were carried out by two operators, as follows:

- Expert operator: a dentist with experience in the use of intraoral scanners and analog acquisition techniques in the forensic field;
- Neophyte operator: a beginner with minimal training in the field.

Each operator collected 10 samples for each participant with both methodologies for a total of 40 impressions (20 analog and 20 digital) (Figure 3).

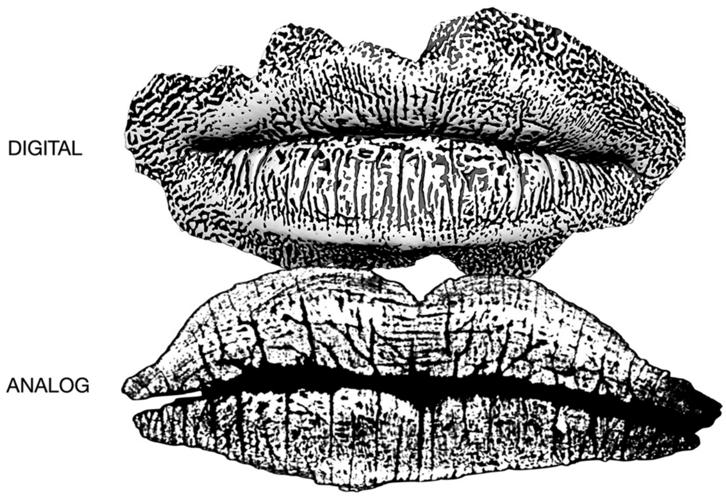


**Figure 3.** Comparison between digital and analog acquisition.

### 2.4. Analysis of the Acquired Data

#### 2.4.1. Analog Acquisitions

- The analog lip prints were digitized using a high-resolution document scanner, allowing direct comparison with the digital samples.
- The prints were analyzed using a transparency overlay method, which required manual alignment of the images. The visual concordance between the samples was assessed by counting the number of captured lip wrinkles, which provided a measure of the macroscopic detail. This method was highly operator-dependent and enabled evaluation of visible differences between the prints.

#### 2.4.2. Digital Acquisitions

- The analysis of the 3D models, resulting from optical scanning, was carried out using MEDIT DESIGN software v2.1.4, which allowed management and analysis of the 3D models. The main phases of the analysis were as follows:
  1. Preliminary alignment: each participant's scans were aligned using landmark matching algorithms;
  2. Cleaning of the model: using software tools, the outside edges of the vermilion, considered potential noise, were eliminated (Figure 4);
  3. Precision alignment: application of a best-fit algorithm to obtain optimal overlap between scans of the same subject;
  4. Surface deviation analysis: the software measured the differences between the superimposed models, providing quantitative values useful for evaluating the repeatability of the scans.

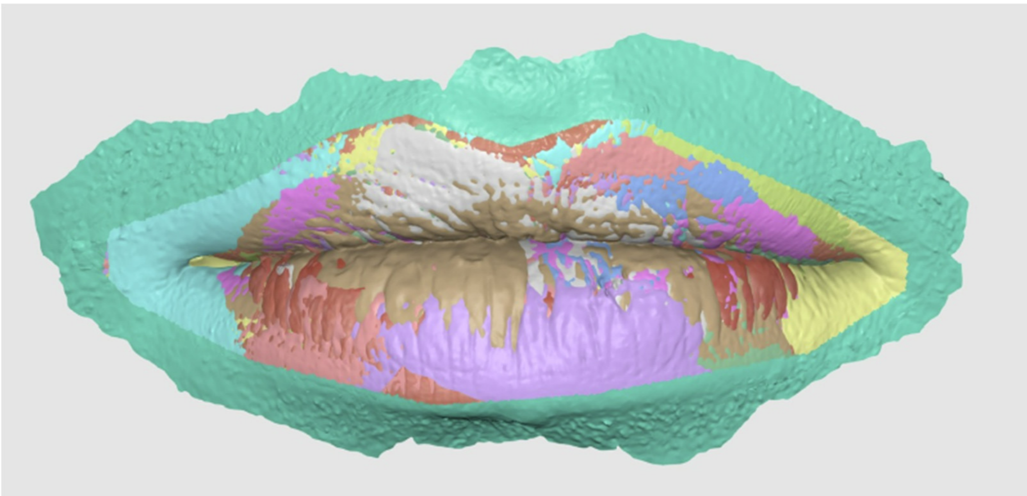

**Figure 4.** Cleaning the model: the vermilion edges were removed using software tools, with each color representing a different 3D lip scan.

Each 3D model was composed of approximately 795,000 triangles, ensuring sufficient resolution to detect complex morphological details, such as micro-furrows and labial curvatures.

### 2.5. Classification of Usable vs. Non-Usable Prints

In terms of determining which prints were usable, impressions were considered non-usable if they exhibited certain flaws, such as the following:

- Excessive smudging or blurred edges, which would distort the integrity of the lip morphology;

- Lack of detail, where large areas of the print were missing features such as wrinkles or micro-furrows;
- Overload of lipstick, which could lead to the print being overly saturated with color, masking fine details and preventing accurate analysis.

*2.6. Comparison Between Methods*

- Repeatability: The precision of the results was compared between the two operators and the two methodologies. For the analog impressions, the visual concordance between the samples was evaluated, while for the 3D scans, the average value of the surface deviation was analyzed (Figures 5 and 6).

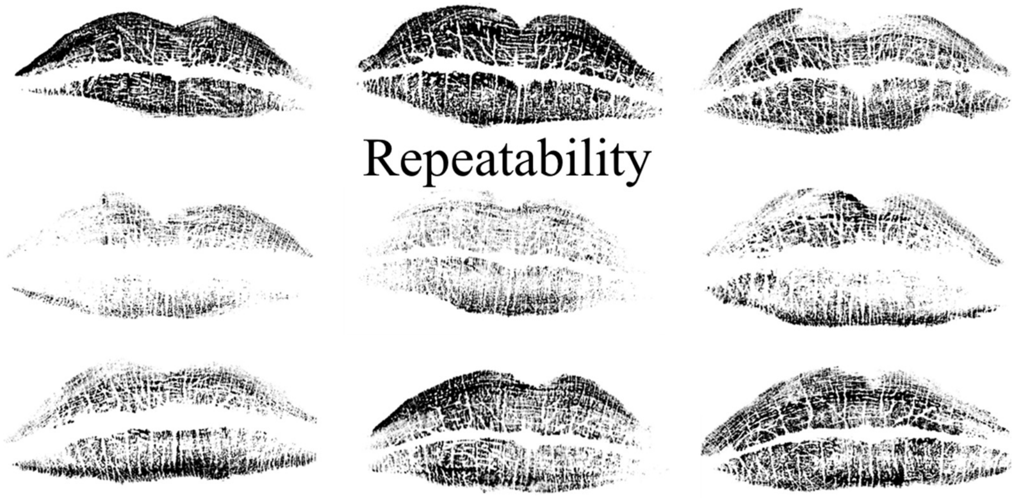


**Figure 5.** Low repeatability of analog prints.

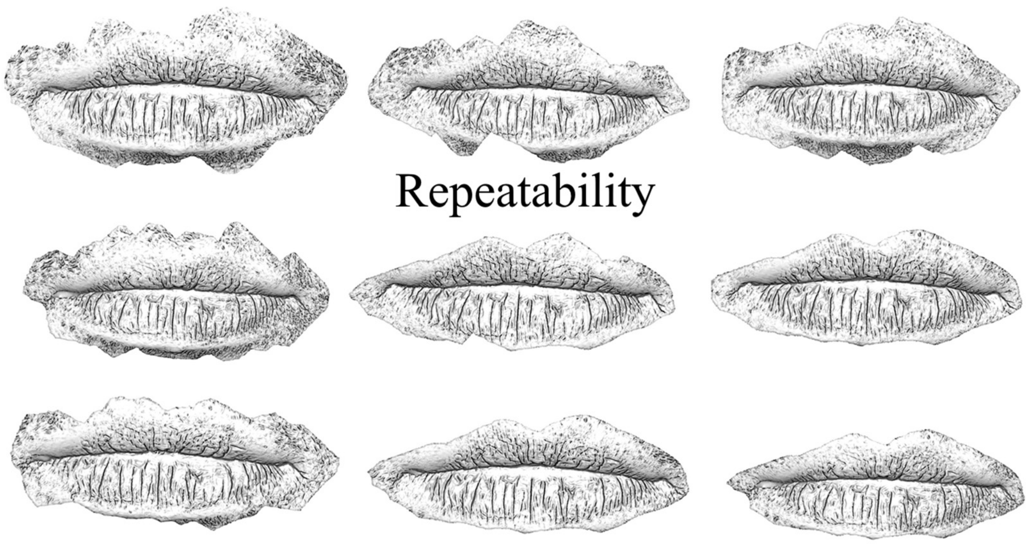


**Figure 6.** High repeatability of analog prints.

- Efficiency: the time required for data acquisition and analysis was recorded for each methodology.
- Data quality: the 3D scans showed higher resolution and less variability than the analog impressions, which were more prone to errors resulting from the pressure of the tape or the amount of applied lipstick.

### 2.7. Statistical Analysis

To evaluate operator-dependent variability and methodological consistency, lip wrinkle counts obtained from analog and digital cheiloscopy were analyzed descriptively.

For each operator (expert and novice), the mean, standard deviation (SD), and coefficient of variation (CV) were calculated to assess intra-operator consistency. Inter-operator variability was quantified by computing the absolute difference in mean wrinkle counts between the operators for both analog and digital methods.

Surface deviation metrics (e.g., average similarity, standard deviation, and variance) from the 3D scans were derived using MEDIT DESIGN software [13,14], following mesh alignment and noise removal. All analyses were performed using R (v4.4.2), with a focus on descriptive statistics due to the exploratory nature of the pilot study.

## 3. Results

In this pilot study, although a quantitative wrinkle count was performed, the primary focus was on assessing the repeatability of the methodologies and the level of detail captured. Given the exploratory nature of the research, numerical data were not the main objective. Our analysis highlighted that the analog impressions were often incomplete to varying degrees, influenced by both the operator and the acquisition method (Figure 5). In contrast, the digital impressions consistently provided complete and analyzable data, regardless of the operator (Figure 6). This finding underscores the greater reliability and standardization offered by 3D cheiloscopy compared to traditional analog techniques.

A significant difference emerged in terms of the homogeneity and level of detail between the analog lip prints and the digital scans. The analog impressions obtained by the two operators were not always legible and, when they were, sometimes displayed different morphologies due to variables such as the pressure applied by the adhesive tape or inconsistencies in lipstick application. Out of a total of 20 analog samples, only 12 were deemed usable, eight acquired by the expert and only four by the neophyte operator.

The digital scans, however, showed significant uniformity across both the patients and the operators, with slight differences observed mainly in the areas outside the perimeter border of the vermilion. However, once these discrepant areas were eliminated, the resulting 3D models presented substantially overlapping morphologies. These data suggest an important greater repeatability in the collection of information using 3D technology compared to traditional methods.

To assess potential inconsistencies, the analog data were subjected to a manual wrinkle count and classified according to the Suzuki and Tsuchihashi classification. The same classification was applied to the digital scans, but with an additional step: alongside the manual wrinkle counting, a surface curvature analysis of the 3D meshes was performed (Figure 7). This analysis highlighted the main visible wrinkles, providing an additional dimension of detail that is difficult to achieve with traditional methods. The Suzuki and Tsuchihashi classification was easier to apply in the digital models due to the higher level of detail available.

Finally, the meshes obtained from optical scans were aligned using MEDIT DESIGN software to conduct a surface deviation analysis, evaluating similarities and differences between the various samples [13,14]. Each scan, after noise removal, contained approximately 795,000 triangles. The surface deviation analysis showed an average similarity of 70% between scans of the same participant, regardless of the operator. Additionally, the data presented a standard deviation of 0.229 mm and a variance of 0.052 mm.

In our study, we focused on a descriptive analysis of the data to evaluate the consistency and reliability of the two operators (an expert and a novice) in counting lip wrinkles using both the analog and digital methods:

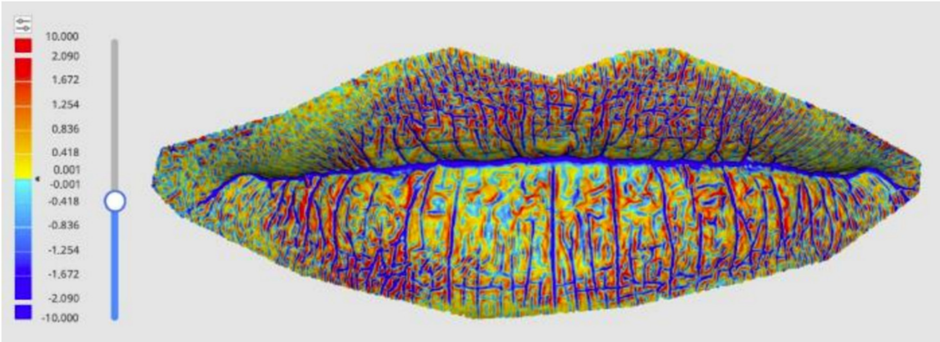


**Figure 7.** Curvature analysis.

## *3.1. Analog Method*

### 3.1.1. Descriptive Analysis

- Operator 1 (expert):

  Mean = 42.6, standard deviation = 6.35.
  Coefficient of variation (CV) = 14.9%.

- Operator 2 (novice):

  Mean = 31.2, standard deviation = 6.96.
  Coefficient of variation (CV) = 22.3%.

The average difference between the two operators was 11.4 wrinkles, indicating a significant discrepancy in their counts.

### 3.1.2. Intra-Operator Consistency

Operator 1 (expert) showed greater consistency in their counts, with a lower CV (14.9%).

Operator 2 (novice) showed more variability, with a higher CV (22.3%).

## *3.2. Digital Method*

### 3.2.1. Descriptive Analysis

- Operator 1 (expert):

  Mean = 66.89, standard deviation = 0.93.
  Coefficient of variation (CV) = 1.39%.

- Operator 2 (novice):

  Mean = 66.20, standard deviation = 0.92.
  Coefficient of variation (CV) = 1.39%.

### 3.2.2. Intra-Operator Consistency

Both operators showed excellent consistency in the digital method, with very low CVs (1.39% for both).

The average difference between the two operators was 0.69 wrinkles, indicating much better agreement compared to the analog method.

### 3.2.3. Comparison Between Analog and Digital Methods

- Analog Method:

  High operator dependency, with significant differences between the expert and novice operators (average difference = 11.4 wrinkles).

  Operator 1 (expert) was more consistent (CV = 14.9%) than Operator 2 (novice, CV = 22.3%).

- Digital Method:

  Low operator dependency, with minimal differences between the expert and novice operators (average difference = 0.69 wrinkles).

  Both operators showed excellent consistency (CV = 1.39% for both).

The observed differences in the means, variability, and CVs highlight the operator dependency of the analog method and the superior reliability of the digital method.

These findings align with previous literature, confirming that 3D technology provides a more precise and repeatable alternative to analog methods, significantly reducing operator-dependent variability [15]. The preliminary data suggest that 3D cheiloscopy represents a promising advancement in the collection and analysis of lip impressions, offering substantial improvements in standardization and reliability.

The operator-dependent variability and technical performance metrics are summarized in Tables 1 and 2.

**Table 1.** Operator-dependent variability in analog vs. digital cheiloscopy.

| Method | Operator | Mean Wrinkle Count | Standard Deviation | Coefficient of Variation (%) |
|---|---|---|---|---|
| Analog | Expert | 42.6 | 6.35 | 14.9 |
| Analog | Novice | 31.2 | 6.96 | 22.3 |
| Digital | Expert | 66.89 | 0.93 | 1.39 |
| Digital | Novice | 66.20 | 0.92 | 1.39 |

**Table 2.** Reproducibility and technical performance.

| Metric | Analog Method | Digital Method |
|---|---|---|
| Usable prints (%) | 60% (12/20) | 100% |
| Surface deviation (SD) | N/A | 0.229 mm |
| Variance | N/A | 0.052 $mm^2$ |
| Operator variability | High (CV: 14.9–22.3%) | Low (CV: 1.39%) |

## 4. Discussion

Cheiloscopy has long been considered a potentially useful forensic identification method; however, its practical applicability has been limited by a lack of standardization and high operator-dependent variability [16]. While analog techniques, such as lipstick impressions transferred to adhesive surfaces, are simple and cost-effective [5], our findings align with previous studies demonstrating their significant reproducibility and reliability issues [2,7]. For instance, analog lip prints in our study were often incomplete or distorted, with a usability rate of only 60%, consistent with literature reporting high exclusion rates due to poor imprint quality [7,17]. In contrast, 3D cheiloscopy provided 100% usable impressions with minimal inter-operator variability, underscoring its potential to overcome the limitations of traditional methods.

### *4.1. Limitations of Analog Methods vs. Advantages of 3D Standardization*

Our analysis demonstrates that digital cheiloscopy achieves significantly higher repeatability than traditional analog methods, a finding consistent with recent studies advocating digital tools to improve forensic data quality [13,15]. Unlike analog techniques, where variability arises from methodological challenges such as pressure inconsistencies during impression transfer, material degradation, and operator-dependent handling, 3D scanning eliminates these sources of error by directly capturing the lip surface topography.

This approach preserves intricate morphological details, such as groove branching and depth, with minimal human intervention. Quantitative validation via surface deviation analysis revealed a 70% average similarity between repeated 3D scans, with a standard deviation of 0.229 mm, confirming superior reproducibility. These results underscore that digital methods enhance not only analytical accuracy but also enable the development of standardized, long-term forensic databases for reliable comparative analyses.

### *4.2. Challenges in Sex Determination and Lip Print Classification*

A critical challenge in cheiloscopy lies in the classification of lip prints, particularly for sex determination, a task complicated by the inherent subjectivity of analog methods. While the Suzuki and Tsuchihashi classification system has been widely adopted [16,18], its reliability is undermined by ambiguities in pattern definitions and inter-observer variability, as highlighted in prior critiques [19–21]. Our findings corroborate these limitations: analog prints frequently exhibited overlapping vertical and branched grooves, complicating unambiguous categorization. This variability was most pronounced in sex-based analyses, where subtle morphological differences (e.g., groove density and curvature gradients) proved inconsistently detectable via visual inspection alone.

Digital cheiloscopy addresses these challenges by enabling quantitative curvature mapping of 3D lip models, thereby reducing reliance on subjective pattern matching. For instance, digital scans can allow precise measurements of groove angles and branching frequencies, metrics unavailable in analog workflows. Although some studies posit lip prints as potential sex determinants [22], our results emphasize that analog methods, lacking standardized digital protocols. are inherently prone to interpretive inconsistencies. Thus, the transition to 3D methodologies is not merely advantageous but necessary to establish forensic credibility in this domain.

### *4.3. The Introduction of 3D Cheiloscopy: Advantages and Future Prospects*

The introduction of 3D cheiloscopy marks a paradigm shift in forensic identification, moving away from subjective, operator-dependent methods toward objective, technology-driven analysis [23]. Using advanced intraoral scanners, extremely detailed three-dimensional images of the lips can be acquired, ensuring superior precision and significantly reducing the variability resulting from human intervention [19,24].

One of the most significant improvements is the ability of 3D cheiloscopy to eliminate operator-dependent variability [23]. Thanks to the standardization of the acquisition process and the use of digital technologies, this methodology offers greater repeatability and less dependence on the operator [25]. Furthermore, the possibility of obtaining digital models allows for much more detailed analysis compared to analog techniques, which previously did not allow equally precise data manipulation [13].

Besides improving data quality, 3D technology is also less invasive than traditional impression collection [13]. The scanners operate remotely, avoiding direct contact with the skin and thus reducing discomfort for the subject [14]. This is particularly advantageous in clinical and forensic settings, where patient comfort is essential for accurate results [24,26].

Moreover, digitizing lip impressions allows for more efficient and secure data management. 3D scans can be stored in digital format, easily shared, and repeatedly analyzed without loss of quality, improving reproducibility and interdisciplinary collaboration [23,25]. In forensic settings, this data retention capacity is crucial, as it allows lip prints to be accessed at any time without risk of deterioration [27].

A crucial aspect of the adoption of 3D cheiloscopy concerns the choice and optimization of both the software and hardware used [28]. While 3D technology offers enormous advantages, the quality of the results strongly depends on the resolution of the scanners and the precision of the analysis algorithms [23]. The use of devices with insufficient resolution or inadequately calibrated software could compromise the accuracy of the three-dimensional models and the reliability of the analyses [29]. Therefore, careful selection and calibration of technological tools is essential to ensure that the benefits of 3D cheiloscopy can be fully exploited in forensic settings [2].

While this pilot study involved a limited sample of two participants, both the 3D and analog impressions of each participant were systematically compared. This included cross-comparisons between the participants to demonstrate that the lip prints belonged to different individuals. The 3D scans provided quantitative data, such as standard deviation and surface deviation metrics, which allowed for an objective and precise assessment of differences between the individuals.

In contrast, the analog impressions relied solely on visual evaluation, which not only lacked quantitative metrics but also exhibited operator-dependent variability. This difference highlights the limitations of analog methods in ensuring consistent and reliable comparisons, further underscoring the potential of 3D technology to provide standardized and reproducible results.

These findings provide a foundation for further investigations with larger and more diverse datasets. Future research should focus on refining digital lip print classification algorithms and exploring the integration of artificial intelligence to enhance pattern recognition and automate forensic analysis [26,30].

### *4.4. Forensic Applications of 3D Scanning and Lip Print Simulation*

Although the intraoral scanner in this study was used to acquire the direct morphology of the lips rather than lip prints, its potential forensic applications should not be overlooked. Unlike traditional analog methods that require powder or adhesive tape to visualize and transfer lip prints, the scanner directly captures the three-dimensional anatomy of the lips. This could represent an advantage in forensic scenarios, as it eliminates the need for intermediary materials and post-processing while ensuring a more accurate and reproducible acquisition of labial morphology.

Future studies could explore the possibility of generating simulated lip prints from 3D models, either through digital simulations or by 3D printing physical models. These approaches would allow for the controlled study of how labial morphology interacts with different surfaces and materials, replicating forensic conditions more precisely. By using printed models, it would also be possible to directly simulate lip print deposition, facilitating comparative analyses between traditional and digital methodologies.

### *4.5. Future Possibilities: Integration with AI and Machine Learning*

3D technology, combined with artificial intelligence (AI) and machine learning (ML), promises to further revolutionize the analysis of lip prints. AI algorithms trained to recognize specific patterns in 3D scans will be able to identify unique characteristics of the lips with high precision, accelerating the identification process and further reducing operator-dependent errors [10,12]. The possibility of applying AI algorithms for the automatic recognition of lip impressions could also reduce the need for manual interpretations, improving the overall efficiency of the process [31].

### *4.6. Legal and Epistemological Considerations on 3D Cheiloscopy*

#### 4.6.1. A Technological and Epistemological Paradigm Shift

The introduction of 3D technology in cheiloscopy represents a significant step forward compared to traditional methodologies [13]. Three-dimensional scans offer unprecedented precision, reducing the operator's subjective influence and ensuring more reproducible results [30]. This not only improves the accuracy of the analyses, but also redefines the concept of forensic "evidence" [26]. 3D technology allows us to obtain detailed and objective data, which overcomes the limits linked to analog methods, where the operator's experience and the quality of the materials used could significantly influence the reliability of the evidence [28].

#### 4.6.2. Specific Roles and Skills Among Dentists and Medical Examiners

The use of 3D cheiloscopy in the forensic field requires highly specialized skills, where dentists and forensic doctors make complementary contributions [32]. Dentists, thanks to their in-depth training on orofacial morphology and the management of advanced technologies such as the 3D scanner, can precisely detect and analyze lip impressions, identifying unique details [29,33]. Forensic doctors, on the other hand, contextualize this data in the context of judicial investigations, ensuring its validity and integrity as forensic evidence [2]. This interdisciplinary collaboration strengthens the reliability and effectiveness of identification through lip prints [34].

#### 4.6.3. Epistemological Implications and Operational Transformations

The transition from traditional to 3D cheiloscopy is not just a technical evolution but also a change that profoundly affects our conception of identity and scientific truth [35]. Forensic "truth", in fact, turns out to be increasingly related to available technology, which shapes both the scientific method and the legal interpretation of the evidence [36]. 3D cheiloscopy, by reducing variability and ambiguity, offers a clearer and more reliable representation of the evidence, but at the same time requires reflection on the new ethical and legal responsibilities linked to the use of advanced instruments [37–39].

#### 4.6.4. Study Limitations

While this study provides valuable insights into the operator dependency and reliability of analog and digital methods for counting lip wrinkles, it has some limitations:

- Small sample size: The study was conducted on a limited number of lip imprints, which may affect the generalizability of the results. A larger sample size would improve the statistical power and reliability of the findings.
- Exploratory nature: This study was exploratory and primarily descriptive. Advanced statistical analyses, such as intraclass correlation coefficient (ICC) or Bland-Altman analysis, were not performed due to the preliminary nature of the investigation.
- Operator variability: Only two operators were involved in the study, with different levels of experience. Including more operators with varying expertise would provide a more comprehensive evaluation of operator-dependency.
- Methodological constraints: The analog method relies heavily on subjective interpretation, which may introduce bias. Although the digital method showed greater consistency, its implementation requires specialized equipment and software, which may not be universally accessible.
- Lack of ground truth: The study did not include a "ground truth" or reference standard for the exact number of lip wrinkles in each imprint. This limited our ability to assess the absolute accuracy of the methods.

Despite these limitations, our findings highlight important differences between the analog and digital methods and underscore the need for further research with larger sample sizes and more robust statistical analyses.

## 5. Conclusions

3D cheiloscopy offers significant advantages over traditional methods, especially in complex cases like partial or distorted impressions, where analog techniques fall short. The use of 3D technology allows more reliable data, greater standardization and precision in acquisition and advanced manipulation on digital models for deeper analysis.

The transition towards 3D cheiloscopy represents a paradigm shift, not only from a technological point of view, but also for future prospects. With the advancement of portable 3D scanners and the implementation of AI, this technology is likely to become increasingly accessible and integrated into forensic and clinical settings, improving the speed, accuracy, and objectivity of results.

Ultimately, the adoption of 3D technology in cheiloscopy could mark the beginning of a new era, where the identification and analysis of lip prints will be faster, more precise and reliable, paving the way for numerous practical applications in the forensic field, clinical and beyond.

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**Institutional Review Board Statement:** The study was conducted in accordance with the Declaration of Helsinki, and approved by the Ethics Committee of the University of Palermo Policlinico "Paolo Giaccone" (Minutes No. 04/2024, Session of 8 February 2024).

**Informed Consent Statement:** Written informed consent was obtained from all participants involved in the study.

**Data Availability Statement:** The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

**Conflicts of Interest:** The authors declare no conflicts of interest.

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