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Advancement in Age Estimation in Forensic Science Through Molecular Fingerprinting Techniques – A Review Paper

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Abstract

Dactyloscopy has long been used for personal identification from the latent fingerprint residues, capable of providing an insight into various factors of an individual, such as age, sex, habits and lifestyle. Various studies have been conducted to precisely identify the changes in activity of sweat glands and the chemical breakdown of fingerprint residues with respect to time. However, a reliable method for accurately estimating or approximating the age of the fingerprint donor is yet to be established. The emerging field of molecular fingerprinting analyses latent fingerprint sweat residue and profiles the components present in it, which aids in personal identification as an individualistic marker specific to each individual. This review article highlights the advancements in estimating the age of the fingerprint donor from latent fingerprint residue and addresses the technical and technological research gaps in the timeline of molecular fingerprinting techniques, as this method holds potential in aiding forensic investigation and criminal profiling from the fingerprints retrieved from the scene of crime.

Keywords: Fingerprints; molecular fingerprinting; age estimation; sweat compositions.

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Introduction

Fingerprints are the unique patterns of ridges and grooves that are present in the topmost epidermal sub-layer *(Stratum corneum)* of the skin in the fingertips. The fingerprint exhibits have a pivotal role in the field of forensic science as it establishes a link between the criminal and the scene of crime, the victim, and the weapon of crime. Fingerprints are considered as the confirmatory evidence at the court of law as they are permanent, persistent, and unique. Dactyloscopy involves 5 stages of fingerprint analysis. i.e.: (i) *class characteristics*- study by classifying the patterns, (ii) *individual characteristics*: identifying the minutiae detail, (iii) *Poroscopy*- the study of pores, (iv) *Edgeoscopy*- the study of ridge endings and (v) *molecular fingerprinting technique*- deals with analysis of sweat for determining the compounds present on fingerprint residue, which leads to the identification of the individual based on their age, sex, occupation, habits, dietary, geographical location, etc.

Molecular fingerprinting is an emerging field that deals with analysing the sweat compounds present on the latent fingerprint residue with the help of instrumentation such as UV-Vis Spectrophotometer, Fluorescence Spectrophotometer, ICP-OES, GC-MS, HPLC etc. The researchers have laid out a layout for examining and profiling the fingerprint residue, their degradation grade with respect to time, and individual differences. However, a reliable method is yet to be established for estimating the age of the fingerprint donor. Recent advances in fingerprint science have shown the importance of analysing fingerprint sweat residue to estimate age. Unlike traditional methods, like ridge density studies, which only provide general trends related to age, chemical profiling allows for more precise classification based on how molecules break down over time. Fingerprint residues help improve age estimation by detecting changes in specific biochemicals, such as amino acids, lipids, and hormones, using techniques like GC-MS, ToF-SIMS, and MALDI-MS. found that the breakdown of these lipids follows clear patterns over time. For example, there is a short-term increase in certain fatty acids due to hydrolysis, followed by a gradual decline caused by environmental exposure. Cholesterol and wax esters break down more slowly but can still serve as markers for ageing fingerprints [15]. In contrast, traditional methods like the ridge density study have been studied for age estimation. Research shows that children usually have higher ridge densities than adults, making this method useful for broad age categories [16]. However, there is a lack of comparison within the same age groups. Therefore, combining molecular profiling leads to more accurate age estimation than relying only on morphological characteristics. Various studies have been conducted that focused on the alteration in the activity of sweat glands and their chemical breakdown

over time, as it is essential to understand the progressive changes occurring in sweat residue with time. The research articles discussed in this review paper aim to fill a crucial gap in fingerprint sciences in improving exhibit analysis and criminal profiling.

Methods and Methodology

The study utilised gas chromatography (GC) and mass spectrometry (MS) to analyse the volatile components of fingerprint residues. Cholesterol was specifically chosen as a performance check for GC/MS due to its sensitivity and analytical difficulty. The study also examined fatty acids, steroid precursors (like squalene), and wax esters to understand fingerprint composition. Additionally, the study assessed the impact of environmental exposure on the degradation of these components over time. A total number of seventy-nine samples were collected from individuals across different age groups, including children, adolescents, and adults. The subjects were instructed to touch sample pieces of GFA (*Glass micro fibre filter paper)* paper to ensure a homogeneous sebaceous content. The study focused on compounds under 500 Daltons, particularly those affected by ageing. Changes in fingerprint composition were tracked over time, and statistical analyses were applied to determine degradation trends. The study found that young children's fingerprints lack fatty acids and squalene, likely due to underdeveloped sebaceous glands, affecting identification accuracy. Ageing also alters fingerprint chemistry, making older prints harder to analyse with traditional reagents. The primary volatile components: fatty acids, steroid precursors, and wax esters, undergo oxidation and structural changes over time, complicating identification [1].

In another study, 500 fingerprint samples (250 males, 250 females) were collected in Karnataka, India, between 2000 and 2002. Black printer ink, glass plates, rollers, lenses, film strips, and measurement tools were used for sample collection. The authors ensured minimal dimensional distortion by standardising the fingerprint transfer process. Ridge density was calculated in a defined area of the fingerprint to infer gender differences. Participants aged between 18 and 60 were chosen using a random sample collection method were randomly selected, and before the collection of data, consent was acquired from the participants. Fingerprints were collected under controlled conditions, ensuring consistent pressure and clarity. Ridge counts were performed on the upper radial border due to its stable ridge flow, and statistical analyses were conducted using STATISTIX software. The likelihood ratio was calculated to assess the probability of determining gender based on ridge density [2].

Chemical analysis methods were also employed in this study to identify organic and inorganic compounds present in fingerprint residues.

Enhancement techniques such as powdering and fluorescence imaging were tested to visualise latent prints. The methodology involved analysing fingerprint deposition and ageing under controlled conditions. Factors such as donor characteristics (age, gender, diet), deposition conditions (pressure, angle), and environmental influences were systematically studied. Changes in fingerprint composition were tracked using quantitative methods, identifying decomposition products over time. Longitudinal studies were proposed to develop ageing curves for forensic applications. The researchers used adhesive paper and the graphite powder method for fingerprint collection. Ridges were stained with graphite and transferred onto sticky labels for clear impressions. Impressions were then affixed to acetate templates to facilitate analysis. The method ensured high contrast and reproducibility for fingerprint examination. Fingerprints were photocopied, amplified, and enhanced for ridge counting. Anthropometric measurements such as height, weight, and hand dimensions were recorded alongside fingerprint features. Ridge density (RD) was calculated across radial, ulnar, and proximal sectors of each fingerprint. Data was analysed considering factors like age, gender, and environmental exposure [6].

The researchers employed commercially available, non-occlusive sweat patches for sweat collection. The Cytokine 3-Plex A kit was used to detect TNF-α, IL-10, and IL-6 using Simoa technology. This technique allowed ultra-sensitive single-molecule detection of low-abundance proteins. The study ensured accurate quantification of cytokines through precise patch-wearing protocols. Participants included 23 older adults (aged 65+) and 26 younger adults (aged 18-40). Sweat patches were worn for 72 hours, ensuring sufficient sample collection. Cytokine concentrations were measured using a laboratory-based spectrometer to validate results. High compliance rates were maintained by closely monitoring patch-wearing durations. Sweat variability among participants may impact cytokine measurements, and the mechanisms behind secretion remain unclear [7].

The researchers used an Olympus CX-31 laboratory microscope to analyse fingerprint ridge widths over time. Samples were examined at magnifications of 4× to observe changes in ridge impressions. The authors tracked sweat and sebum content degradation in fingerprints left at crime scenes. Observations were recorded at different intervals to study ageing effects on ridge morphology. Fingerprints were analysed at five time points: 5 hours, 7 days, 30 days, 60 days, and 90 days after deposition. Samples were categorised based on exposure conditions, such as temperature and humidity. Sweat and lipid degradation rates were compared across different substrates. Ridge density and visibility were quantified to determine time-dependent variations [8].

Previous studies have primarily concentrated on fingerprint morphology; however, chemical profiling has not been thoroughly investigated. The work emphasises the necessity for advanced methodologies to correlate molecular fingerprint technology with ridge patterns [9].

Techniques such as microfluidics allow for precise control over sweat collection, while absorbent bands provide a simple and effective means of capturing sweat during physical activities. Additionally, minimally invasive methods like microneedle injections enable direct extraction of sweat from the skin, and advancements in 3D printing technology facilitate the creation of customized sweat collection devices. These methodologies are crucial for ensuring accurate and efficient analysis of sweat samples [11].

UV-visible spectroscopy and photoluminescence spectroscopy were applied to estimate crime scene timing. Samples were collected over a one-year period at eight-day intervals. While uncontrolled samples were left out in the open, controlled samples were stored in sealed containers at 37 °C. Emission rates were evaluated by photoluminescence spectroscopy, while absorption at 297 nm was observed using UV-visible spectroscopy, and data were analysed to ascertain how the environment affected sample degradation [12].

Significances of the previous studies

Understanding the chemical makeup of fingerprint residues is crucial for forensic investigations. It helps enhance fingerprint visualisation techniques and supports the development of fluorescent tagging methods. However, as fingerprints age, the chemical markers necessary for tagging decrease, making older prints harder to detect [1].

Sampling offers a simple, non-invasive way to measure cytokines, which are key indicators of immune response. Unlike blood or urine tests, sweat analysis is easier to collect in large studies and isolates small molecules more effectively, making it a promising tool for biomarker research [7].

The advancements in fingerprint analysis go beyond pattern identification and comparison. Molecular profiling can be a potential technique to study an individual's lifestyle, occupation, habits and environmental exposure. The chemical makeup of fingerprint sweat provides insight, making it a powerful aid for personal identification and criminal investigations [9].

Keeping the evidence preservation as a priority, countable researches were conducted using various non-destructive techniques such as UV-Vis

Spectroscopy and fluorescence spectroscopy to determine the age of fingerprints, improving forensic accuracy. This method aids in crime scene exhibit analysis and aids in establishing a link between the criminal, suspects and the victims to specific timeframes. However, environmental and biological elements can be the factors affecting the precise estimation of the time frame, highlighting the need for further research to refine this approach [12].

Results and Discussions

The study provided a critical insight into the chemical composition and degradation of fingerprint residues over time. The methodologies, including GC/MS analysis, reveal that fingerprint composition varies across age groups. These findings underscore the impact of ageing on fingerprint identification techniques. The study demonstrates that amino acids, urea, and other organic compounds undergo significant changes over time. Inorganic compounds, such as chloride, also exhibit slight reductions due to environmental exposure. The impact of temperature, humidity, and light exposure accelerates the degradation process. These insights are crucial for improving forensic methodologies and visualization techniques [1].

The study found that ridge count varies significantly between genders, with males generally having fewer ridges than females. Approximately 44% of males had 13 or fewer ridges per 25mm², whereas 54% of females had 15 ridges. No males exceeded 15 ridges, while females exhibited higher counts. A ridge count of 11 or fewer strongly indicates a male origin (P=0.99), while 16 or more ridges strongly indicate a female origin (P=1.0). These findings contribute to gender identification in forensic investigations. Ridge count analysis can serve as a preliminary indicator of a suspect's gender. However, further studies are required to refine these identification methods [2].

They explored the impact of environmental factors on fingerprint aging. Light exposure accelerates the breakdown of fingerprint residues, while dark conditions slow fatty acid degradation. High temperatures contribute to water loss and amino acid decomposition, affecting enhancement techniques. Humidity effects remain underexplored but likely influence chemical stability. Vacuum conditions significantly alter fingerprint composition by causing mass loss. Air circulation, contamination, and substrate material also affect degradation. These variables must be carefully considered in forensic investigations [5].

The study demonstrated that measuring cytokines in sweat is feasible for both older and younger adults. Older individuals exhibited higher

concentrations of inflammatory markers, including TNF-α, IL-10, and IL-6. This supports the hypothesis that ageing is associated with increased inflammation. The sweat patch method was well-tolerated and provided reliable results. The non-invasive nature of sweat analysis offers advantages over traditional blood-based methods. These findings suggest broader applications in biomarker research. Future studies should investigate additional cytokines and refine collection techniques [6].

Fingerprint residues primarily consist of sweat, including organic and inorganic compounds. Eccrine sweat is predominantly water, while sebaceous secretions contain lipids like squalene and triglycerides. The study confirmed that lifestyle and environmental factors influence fingerprint composition. Cosmetic use, occupational exposure, and contaminants impact residue detection. Advanced techniques such as mass spectrometry enhance identification capabilities. Fingerprint analysis not only aids in forensic science but also in personal profiling. Future research should refine methodologies for identifying specific contaminants [9].

Latent fingerprint visualisation relies on enhancement techniques, including optical, physical, and chemical methods. New approaches, such as nanoparticles and spectroscopic methods, have improved detection sensitivity. Fingerprint residues can reveal traces of drugs, explosives, and personal habits. The choice of enhancement method depends on substrate type and environmental conditions. These advancements enhance forensic applications and crime scene investigations. Future work should focus on optimising visualisation techniques for diverse substrates.

Latent fingerprints are a crucial form of forensic evidence, but their chemical composition changes over time due to environmental exposure, making detection and analysis challenging. UV-VIS spectroscopy offers a powerful, non-destructive way to study these changes by monitoring variations in spectral peaks under ultraviolet light. Fresh fingerprints typically exhibit a main peak around 340 nm at an excitation wavelength of about 280 nm, but as they age, especially under UV exposure, a new peak emerges near 440 nm while the original 340 nm peak decreases, reflecting the breakdown of components such as fatty acids. Environmental factors like light and humidity influence these spectral shifts, with UV light accelerating oxidation and moderate humidity enhancing degradation. The simultaneous reduction of the 340 nm peak and development of the 440 nm peak serves as a reliable indicator of fingerprint ageing, enabling both visualization of older prints and assessment of their chemical transformation over time [18].

Fluorescence spectroscopy is employed to detect chemical changes in fingerprint residues over time by monitoring the oxidation processes of

proteins and lipids, thereby allowing for age estimation. Initially, fresh fingerprint exhibit autofluorescence primarily from tryptophan-containing proteins (Tryp). As the fingerprint ages and is exposed to air, unsaturated lipids oxidize to form reactive oxidation products (LipOx), which then react with proteins to generate fluorescent oxidation products (FOX). Fluorescence spectroscopy quantifies these changes by measuring the decrease in Tryp fluorescence intensity and the increase in FOX fluorescence, with specific wavelength ranges used for each (e.g., Tryp at 283 nm excitation, FOX at 365 nm excitation). By tracking the ratio of Tryp to FOX fluorescence, an age-estimation model can be developed, as this ratio reflects the ongoing chemical transformations within the residue, providing a non-contact method to determine the time since deposition [19].

Photoluminescence spectroscopy was used to analyse fingerprint residue emissions over a year. All samples exhibited absorption at 297 nm and 356 nm, with the former being more prominent. Seasonal variations affected emission intensity, with higher levels in warmer months. Controlled samples showed increased photoluminescence compared to uncontrolled ones. Female samples exhibited the highest emission intensity, emphasising gender differences in fingerprint science. The study confirmed the feasibility of photoluminescence-based fingerprint analysis. Further research could refine this non-destructive technique for forensic applications [12].

The previous studies have mainly examined specific compounds and how latent print residues degrade over time, with minimal focus on how sweat composition varies across different age groups. Most studies emphasise individual sweat compounds rather than taking a broader approach to analysing overall differences. Additionally, the potential use of sweat composition for estimating age and its forensic importance remains largely unexplored.

Whereas fingerprint analysis plays a crucial role in forensic science, there are several obstacles that researchers are yet to overcome, including the small sample size of residues, environmental factors such as temperature, humidity, and light, affecting the age of the fingerprint, and the potential alteration of impressions by powder-based development methods. Additionally, the requirement for specialised equipment and expertise in identifying overlapped fingerprints or analysing prints on complex surfaces is essential. These factors highlight the need for large-scale validation and continued research to enhance the reliability and applicability of fingerprint science in forensic investigations.

Limitations

The advancements in fingerprint analysis are noticeable; however, there still lack a reliable method to precisely determine the age of fingerprint donor, which limits their ability to profile and identify an individual accurately. The chemical composition of fingerprint residues holds valuable clues about an individual's characteristics, yet its potential for age estimation remains largely unexplored. Molecular fingerprinting examines sweat compounds in latent prints, offers a promising path forward by shedding light on how fingerprints change over time. Currently, there is a lack of extensive studies focusing specifically on estimating age using fingerprint residues, especially under challenging conditions like degraded or mixed biological samples. Analysing sweat provides a non-invasive way to look at age-related biochemical changes. However, exposure to heat, humidity, and microbes can quickly break down important markers such as amino acids, lipids, and hormones. The naturally low concentration of substances in sweat makes detection even harder, particularly in trace or contaminated samples, where signals may be hidden by materials from several individuals [20]. While techniques like MALDI-MS and microfluidic biosensors improve sensitivity, they require specialized equipment and skills, limiting their use in forensics [17]. Moreover, spectroscopic analysis requires conversion of solid fingerprint residues into liquid form, the choice of appropriate solvents becomes critical to prevent the loss or alteration of key components present in the fingerprint residues, necessitating standardized sample preparation protocols for accurate and reproducible results. Further research in this area could lead to more precise forensic techniques, ultimately improving crime scene investigations and suspect identification.

Future Prospects

Integrating molecular fingerprinting with artificial intelligence and machine learning models significantly enhances the precision and applicability of forensic age estimation by leveraging deep learning to analyse complex biometric data. Specifically, deep learning models like ResNet50 and VGG-16 are employed to estimate age groups from fingerprint images, overcoming the inherent complexity of extracting distinguishable features for age prediction. This integration offers improved accuracy and computational efficiency compared to traditional methods, as deep learning models can directly process raw fingerprint images [21]. The integration of UV Vis and fluorescence spectroscopy with molecular fingerprinting offers a promising tool for estimating the age of fingerprint donors through distinct spectral patterns. This approach

enhances forensic investigations by providing reliable and detailed biological evidence. Future research should involve larger population studies, integration with techniques like Raman or mass spectrometry, and analysis of environmental and individual factors to improve accuracy. This technique could transform forensic science by enabling both identification and age estimation from a single latent fingerprint.

Conclusion

This review highlights the potential outlook of profiling the sweat residue extracted from the latent fingerprints as a novel technique and its efficiency in estimating of the age of the fingerprint donor. Fingerprint residues contain a mixture of *eccrine sweat*; which is rich in amino acids, urea, and electrolytes; and *sebaceous secretions*, which majorly includes lipids such as squalene and triglycerides. These fingerprint residues displayed a considerable change with respect to time due to various influencing factors such as metabolism, hormones, and environmental exposure. *For instance*, sebaceous secretion peaks in adolescence and noticeably declines with increasing age, ultimately leading to the alterations in the lipid profile of the subjects. Advanced techniques such as mass spectrometry and spectroscopy found to have an efficiency in aiding the fingerprint experts to quantify and profile these biochemical changes which in turn provides the age estimation results with lesser error rates. Future research should focus on identifying key biomarkers in eccrine and sebaceous secretions, conducting a wider study majorly focusing on variables such as sample duration, occupation, environmental factors, etc, and their correlation to the degradation pattern of the sweat residue

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References

[1] GM Mong, CE Petersen, and TRW Clauss, *Advanced Fingerprint Analysis Project Fingerprint constituents*, Oct. 1999. doi:10.2172/14172.

[2] S. Gungadin, "Sex determination from Fingerprint Ridge density," *Internet Journal of Medical Update - EJOURNAL*, vol. 2, no. 2, pp. 4–7, Nov. 2007. doi:10.4314/ijmu.v2i2.39847.

[3] M. Al-Omari *et al.*, "A portable optical human sweat sensor," *Journal of Applied Physics*, vol. 116, no. 18, Nov. 2014, doi: 10.1063/1.4901332.

[4] S. Cadd, M. Islam, P. Manson, and S. M. Bleay, "Fingerprint composition and aging: A literature review.," *Science & Justice*, vol. 55, no. 4, pp. 219–238, Jul. 2015, doi: 10.1016/J.SCIJUS.2015.02.004.

[5] G. Faria, F. A. L. Marson, A. F. Ribeiro, and J. D. Ribeiro, "The correlation between age and sweat chloride levels in sweat tests.," *Revista Portuguesa De Pneumologia*, vol. 23, no. 4, pp. 227–230, Jul. 2017, doi: 10.1016/J.RPPNEN.2016.11.001.

[6] Á. Sánchez-Andrés, J. A. Barea, N. Rivaldería, C. Alonso-Rodríguez, and E. Gutiérrez-Redomero, "Impact of aging on fingerprint ridge density: Anthropometry and forensic implications in sex inference.," *Science & Justice*, vol. 58, no. 5, pp. 323–334, Sep. 2018, doi: 10.1016/J.SCIJUS.2018.05.001.

[7] M. D. Hladek *et al.*, "Using sweat to measure cytokines in older adults compared to younger adults: A pilot study," *Journal of immunological methods*, vol. 454, pp. 1–5, Mar. 2018, doi: 10.1016/j.jim.2017.11.003.

[8] Czech, A. Szabelak, and A. Sowiński, "Changes in Fingerprints Depending on Physiological Factors," *Journal of Forensic Sciences*, vol. 64, no. 3, pp. 711–716, May 2019, doi: 10.1111/1556-4029.13937.

[9] V. Abrol and G. Babu, "Molecular Fingerprinting a new technique for Personal Identification: An Update," *Indian Journal of Forensic Medicine and Pathology*, vol. 14, no. 1, pp. 59–66, Jul. 2021, doi: 10.21088/ijfmp.0974.3383.14121.8.

[10] Khare, V., Singla, A. A review on the advancements in chemical examination of composition of latent fingerprint residues. *Egypt J Forensic Sci* **12**, 6 (2022). https://doi.org/10.1186/s41935-021-00262-2

[11] P. S. Hossain and E. Marasco, "Capturing Sweat Essence: Exploring Techniques for Collection and Metabolite Applications," Sep. 2024, doi: 10.36227/techrxiv.172565659.91260897/v1.

[12] Kiruthiga U, Govindarajalu Rajesh Babu, Photoluminescence Spectroscopy for Estimating the Age of the Latent Fingerprints: A New Potential Approach, Mapana Journal of Sciences: Vol. 23 No. 2 (2024): Mapana Journal of Sciences

[13] Kanitakis J. "Anatomy, Histology and Immunohistochemistry of Normal Human Skin," *European journal of dermatology*, Jul. 01, 2002. https://pubmed.ncbi.nlm.nih.gov/12095893/

[14] S. I. Sudha, *Biometrics & Fingerprint Analysis*, 1st ed. Selective & scientific books, 2013.

[15] A. A. Frick, A. Girod-Frais, A. Moraleda, and Céline Weyermann, "Latent Fingermark Aging: Chemical Degradation Over Time," *Springer eBooks*, pp. 205–235, Jan. 2021, doi: https://doi.org/10.1007/978-3-030-69337-4_7.

[16] S. Sharma, R. Shrestha, K. Krishan, and Tanuj Kanchan, "Sex estimation from fingerprint ridge density. A review of literature," *Acta Biomedica Atenei Parmensis*, vol. 92, no. 5, 2021, doi: https://doi.org/10.23750/abm.v92i 5.11471.

[17] J. R. Sempionatto, J. A. Lasalde-Ramírez, K. Mahato, J. Wang, and W. Gao, "Wearable chemical sensors for biomarker discovery in the omics era," *Nature Reviews Chemistry*, vol. 6, no. 12, pp. 899–915, Dec. 2022, doi: https://doi.org/10.1038/s41570-022-00439-w.

[18] N. Akiba, K. Kuroki, K. Kurosawa, and K. Tsuchiya, "Visualization of Aged Fingerprints with an Ultraviolet Laser," *Journal of Forensic Sciences*, vol. 63, no. 2, pp. 556–562, Jul. 2017, doi: https://doi.org/10.1111/1556-4029.13588.

[19] van Dam *et al.*, "Oxidation Monitoring by Fluorescence Spectroscopy Reveals the Age of Fingermarks," *Angewandte Chemie International Edition*, vol. 53, no. 24, pp. 6272–6275, May 2014, doi: https://doi.org/10. 1002/anie.201402740.

[20] J. Heikenfeld *et al.*, "Wearable sensors: modalities, challenges, and prospects," *Lab on a Chip*, vol. 18, no. 2, pp. 217–248, 2018, doi: https://doi.org/10.1039/c7lc00914c.

[21] G. Jayakala and L. R. Sudha, "Fingerprint analysis for age estimation using deep learning models (ResNet50 and VGG-16)," *International journal of health sciences*, pp. 6781–6789, May 2022, doi: https://doi.org/10.53730/ij hs.v6ns3.7529.