Aksaray University
Journal of Science and Engineering
e-ISSN: 2587-1277

http://asujse.aksaray.edu.tr

Aksaray J. Sci. Eng.
Volume **6,** Issue **1,** pp. **27-41.**
doi: 10.29002/asujse.1035557
Available online at DergiPark

Research Article

The Role of Silica Nanoparticle in Fingerprint Visualization Studies

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▪*Received Date:* Dec11, 2022 ▪*Revised Date:* Mar 14, 2022 ▪*Accepted Date:* Mar 24, 2022 ▪*Published Online:* Apr 24, 2022

Abstract

Fingerprints are the most important evidence that allows the criminal to be profiled in a crime scene investigation. A fingerprint is considered evidence due to its unique characteristics. Fingerprints are not visible and therefore need to be visualized after being recovered from the scene. Many methods are used for visualization purposes. The most commonly used methods are dusting, Ninhydrin, DFO, Super Glue, etc. the methods are not. In addition to these methods, other chemicals, physical and optical methods have recently been uncovered. Due to technological developments affecting the field of Forensic Sciences, new dimensions have also been introduced to fingerprint studies. The use of nanoparticles has gained momentum, especially in fingerprint visualization studies. In the use of nanoparticles, silica nanoparticles are used in studies.

Objective: this study, it was aimed to determine the level of use of silica nanoparticles in fingerprint visualization studies. Based on the data obtained for this purpose, which silica nanoparticle is most used, which method is most used in silica nanoparticle synthesis, what are the dimensions of the resulting molecules, which technique is most preferred for visualization, etc. it is aimed to provide researchers with up-to-date information by determining the parameters?

Method: In this study, the systematic literature review was preferred to collect research data. The level of use of silica nanoparticles has been investigated in fingerprint visualization studies between 2016 and 2020. Data collection was obtained through scientific studies. Parameters such as silica nanoparticle molecules, synthesis methods, absorbent values, surface types used, imaging types were compared in the obtained publications.

Keywords

Crime Scene Investigation, Fingerprint, Fingerprint Visualization, Silica Nanoparticles

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1. INTRODUCTION

The most important part of forensic investigations is the Crime Scene Investigation. Based on the findings obtained during the crime scene investigation, the crime scene is being rebuilt. If the collected findings are related to the incident, these findings are called evidence. It is necessary to identify the person or persons who may have something to do with the incident through the evidence and to resolve the incident pattern. The most important biological element in identifying people is fingerprints. The fingerprint consists of a mixture of water, amino acids, proteins, fatty acids, lipids, and inorganic salts. Because of these structural forms, fingerprints exhibit both hydrophilic and hydrophobic properties. It is not possible to see his fingerprints at the scene with the naked eye. For this reason, fingerprints need to be visualized. There are different methods used to visualize fingerprints. The most commonly used method is dusting. Powders used for dusting are categorized into 4 groups: normal powder, metallic powder, thermoplastic powder, and luminescent powders [1].

Developing and visualizing fingerprints plays a very important role in judicial investigations. In cases where optical enhancement is insufficient, chemical enhancements are used. Chemical development relies on the use of chemicals that target specific functional groups on biomolecules in the blood, such as amino acids and proteins. There are chemicals used for chemical development. Amido contains chemicals such as Black, Purple acid, protein dyes [2].

The development of fingerprint ridges and glowing fingerprint images can be achieved using nanomaterials. Recently, the use of nanoparticles has been available in fingerprint visualization studies. Nanoparticles can physically bind by chemical reaction to amino acids, fatty acids, and other water-soluble molecules contained in the fingerprint. At the same time, nanomaterials exhibit photoluminescence properties. Thanks to these features, clear images of fingerprints can be obtained. Nanoparticles used in fingerprint visualization include gold, silver, titanium dioxide, zinc oxide, and silica nanoparticles Dec. December yesilite nanophosphores vary in particle size from 300 to 500 nm and emit a red-green fluorescence under ultraviolet (UV) light. Silica nanoparticles are suitable for fingerprint visualization due to their optical transparency, small particle size, large surface area, and high surface absorbency. Silica materials often increase surface functionalization with hydrophobic and/or hydrophilic groups to provide better affinity. They then provide fingerprint visualization with paints or fluorescence labels [3].

Moret and colleagues created silicon oxide nanoparticles synthesized with the carboxyethylsilanetriol sodium salt and 3-triethoxycylyl propylsuccinic anhydride to detect fingerprints. By using these particles, the detectability of natural fingerprints has been demonstrated on various non-porous surfaces such as glass, plastic, and stainless steel [2].

2. LITERATURE RESEARCH

2.1. Crime Scene Investigation and Finding Types

The crime scene is the place where the crime was committed. Along with the place where the crime was committed, it is a dynamic region that includes the arrival direction, the surrounding areas where evidence can be found, and the escape direction [4].

There are some pre-treatments to be done at the scene. The first response at the scene begins with the first team arriving at the scene. If the offending action continues, the first team takes measures to eliminate or prevent this situation. If the incident is over upon arrival at the scene, necessary interventions should be made for the person or persons affected by the incident. Afterward, the relevant superiors and units are informed about the incident. The first team at the scene ensures the protection of the scene by taking the necessary safety precautions. Strips are drawn to assign personnel to control the entrance and exit of the crime scene and to prevent irrelevant persons from entering the scene. Incident places that need to be protected are categorized into 3 groups. These; indoor crime scenes, open area crime scenes, and underwater crime scenes [5].

Documenting the crime scene and collecting physical evidence is an important aspect of forensic investigation. Crime scene investigation should be done meticulously. Maintaining the integrity of the physical evidence obtained is essential to ensure the outcome of the forensic investigation. crime scene investigation; It includes procedures for the first arrival at the crime scene, securing the crime scene, documenting the crime scene, recognizing physical evidence, collecting physical evidence, packaging evidence, examining physical evidence [6].

The crime scene is documented in detail with photographs, sketches, and notes. With the documentation of the crime scene, a permanent record of the crime scene is created. There are 4 steps in the documentation phase of the crime scene investigation. These steps are; It consists of note-taking, photographing, drawings, and video recording. With crime scene documentation; Detailed notes were taken at the crime scene, videotaping of the crime scene, photographing, and measurements provide a detailed formation of the crime scene [7].

Photographs taken at the scene; can clearly show the scene of the crime, the direction from which the criminal came to the crime scene, the way of entry, exit, and escape. Photographs taken at the crime scene are categorized into 3 groups. These; overview photos, photography of evidence, and close-up photos of evidence (see Figs. 1, 2, 3). In general view shots, the crime scene is shot from different angles. photographing evidence; is the framing of findings that may be related to the event. The gap between photographing the evidence and the overview and close-up photography is closing. Close-up photography is the demonstration of detailed aspects of the evidence. Close-up photographs provide documentation of items such as bloodstains, firearm remains bruises, and biological stains [8].

Figure 1. General view shots [9]

Figure 2. Photographing the evidence [9]

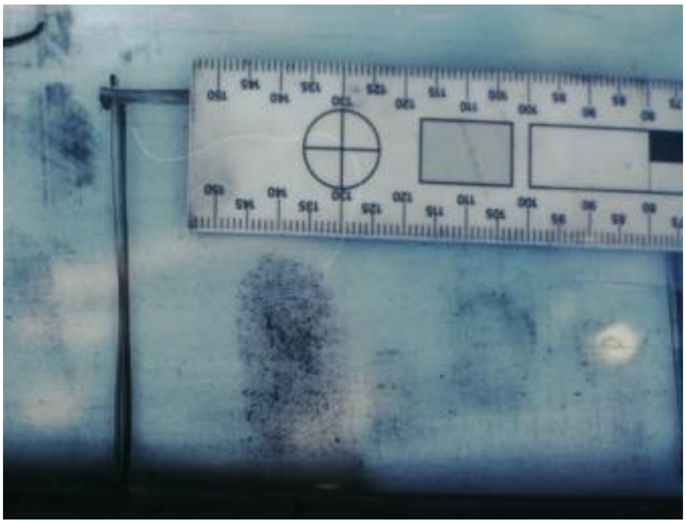

Figure 3. Close-up photos of the evidence [9]

All kinds of traces, signs, and materials in the scene that will lead to the solution of the incident are called findings. Results; Transient findings are categorized as conditional findings, pattern findings, transfer findings, medical findings, electronic findings, and related findings. By their nature, they are findings that can easily change or disappear. Some physiological and physical forms such as odor, color or hardness, drying of blood can be given as examples of these findings. Conditional finding; It is generally created by a series of actions. Like transient findings, they can be lost if not immediately documented or observed at the scene. Smoke or fire, the condition of the victim's body are examples of these findings. Pattern findings are forms of marks such as indentations, scratches, or breaks. Bullet trajectory patterns, clothing or substance patterns, tire or brake traces, bullet dust or debris traces, blood traces or stain patterns, fire-burn traces are examples of this type of finding. Transfer findings; occur through physical contact between persons, objects, or persons-objects. The most common examples are; blood, fingerprints, hair, bodily fluids, drugs, and chemicals. Such findings are forensic evidence studied in forensic laboratories. Medical findings; injury of the victim, suspect or witness, type and extent of injuries, location and condition of a wound, number and size of the wound. It is also a type of find, including the type of medical equipment on the person's home or car, the date of the prescription. Electronic findings; These are the findings obtained from digital equipment such as cell phone records of the person, e-mail messages, documents recovered from the suspect's computer hard drive, video recordings of a bank security camera. Related findings are; Examples are certain items found at the crime scene during an investigation, the suspect's vehicle, wallet, the victim's ring or watch, other items found at the crime scene, receipts, tickets, and business cards that can be used as evidence to link the victim or suspect to a particular incident [10].

2.2. General Characteristics of Fingerprints and Fingerprint Identification Methods

On the inside of the fingertips and the palms, there are lines in different patterns lined up at regular intervals. These lines are called papillae. Sodium chloride crystals are frequently seen in the ridge regions corresponding to the pores on the ridges of the papillae. On the other hand, fingerprints rich in sebum form large irregularly drawn ridges depending on the degree of contamination on the fingers [11].

Fingerprints have their characteristics. One of these features is the dissimilarity of fingerprints. Everyone's fingerprint is unique. Because of this feature, fingerprints are individual. The reason why fingerprints are used as evidence in forensic investigations is that the fingerprints of no two individuals are not alike. Galton calculated that the probability of two fingerprints being alike is 1 in 64 billion. Another feature is that fingerprints are immutable and unchangeable. The patterns of human fingerprints begin before birth and remain unchanged until they die. Another feature of fingerprints is that they can be classified. Fingerprints in general; are categorized as the lasso, helix et al. According to a study, it was determined that 60-65% of fingerprints are lasso, 30-35% are spiral, and 5% are arcs [12].

The first scientific studies on fingerprint classification were made by Galton. Galton divided fingerprints into 3 main groups. Later, Henry multiplied these groups and revised Galton's classification. Hungry introduced the concept of "core" and "delta" points for fingerprints [13].

There is no core and delta formation in belt fingerprints. The ring fingerprint has one or two cores and two delta structures. Loop fingerprint and belt arc systems have only one core and delta. The tent belt fingerprint extends along the line connecting the core and delta points. Left and right loop fingerprints differ from each other according to the slope of the line around the core point [14]. In a loop fingerprint, one or more papillary lines begin on one side of the finger, arching at the center and ending where it started [15]. Arc fingerprints; it is classified as simple arc, right curved arc, and left curved arc [16].

Techniques such as iodine vapor, ninhydrin DFO, Super Glue, Sudan Black, Amido Black, Stick Side, SPR are used for fingerprint development. Iodine vapor is used for fingerprint visualization on oily, dry, and moist surfaces. While DFO and Ninhydrin are used on bloody and dry surfaces, Thermanin is used on thermal surfaces. It is also used in silver nitrate on dry surfaces [17].

Iodine vapor; The evaporated iodine interacts with the fingerprints, making the fingerprints visible. The document whose fingerprint is to be visualized is exposed to steam. The trace appearance is obtained as brown. The traces created tend to disappear in a short time. For this reason, photography is applied [18].

Ninhydrin; is used to detect ammonia or primary amines. As a result of the reaction with amines, they form a dark blue or purple product. Ninhydrin aqueous solution is yellow. In 1954, ninhydrin was proven as an important reagent in the detection of fingerprints with porous surfaces [19]. It reacts with the compounds formed as a result of the breakdown of amino acids and amino acid components in the fingerprint [20].

DFO; 1,8-Diazafluoren-9-one belongs to the large molecule class that contains nitrogen and oxygen in its structure. This compound was first synthesized in 1950 and used in forensic investigations to detect hidden fingerprints in the late eighties. DFO reacts with amino acids found in natural secretions under green light, which is highly fluorescent at room temperature, to produce a red-colored complex [21].

Super Glue; Super adhesives (cyanoacrylate esters) are used by many police forces to develop fingerprints on various surfaces such as plastics, metals, photographic film, records, plastic tape, and glass surfaces. The product suspected of bearing fingerprints is placed in a chamber in which commercial Superglue is placed. Superglue from the tube creates cyanoacrylate ester vapor inside the chamber, which selectively polymerizes on fingerprint backs. A hard, white-colored polymeric material emerges [22]. It creates vapors that interact with some of the eccrine components of the latent fingerprint residues and polymerize, giving them a white color. This hard, white polymer is known as polycyanoacrylate [23].

2.3. New Technique in Fingerprint Visualization: Nanoparticles

There is a wide range of materials used to develop fingerprints from various surfaces in fingerprint visualization studies [24]. These materials also include nanocrystals [25]. Various dyes, nanostructured zinc oxide, monovalent CO-doped $SrTiO_3:Pr^{3+}$ nanostructures, microstructured fluorescent powders, nanophosphors can be given as examples of such materials [26].

Lanthanide-based nanoparticles are of great interest in fingerprint visualization studies due to their unique optical properties. Among the many known solid optical materials, Y_2O_3 (Yttrium Oxide Nanosalt) is among the most popular due to its strong red emission and high quantum yield. Nanoparticles are used as an optical contrast material for hidden fingerprint detection on different surfaces (Fig. 4)[27].

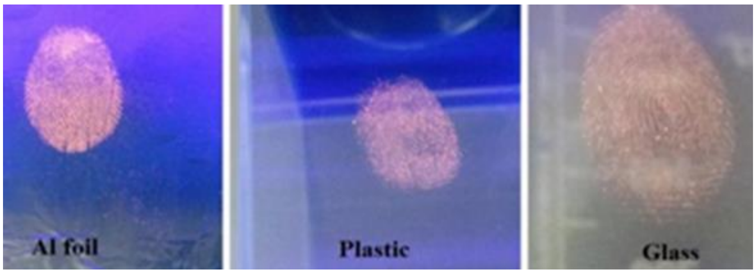

Figure 4. High contrast fingerprint visualization with Y_2O_3: Eu nanoparticle[27]

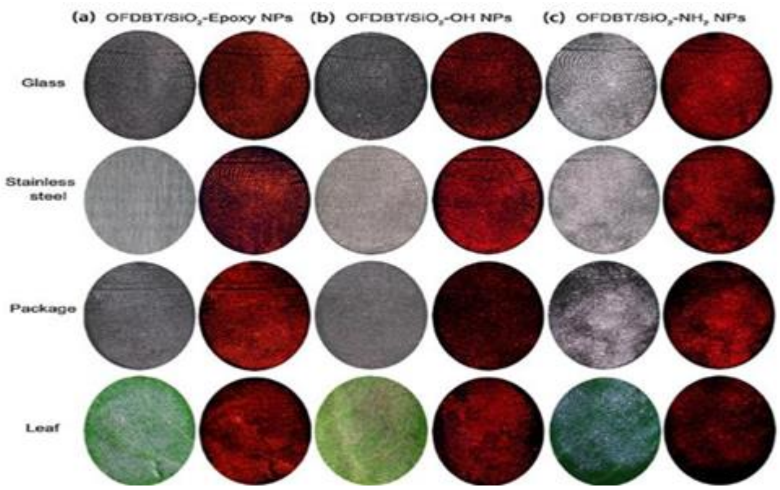

Figure 5. Fingerprint images visualized with nanoparticles [28]

Silica nanoparticles (Si-NPs) are promising fluorescent nanoparticles due to their high fluorescence, strong visualization ability, good biocompatibility, and favorable low toxicity capabilities (Fig. 5). These special properties make Si-Nps have potential application prospects in fluorescent sensors, bio-labeling, and medical imaging. Currently, fluorescent powders are explored as powerful tools for the visualization of hidden fingerprints and show good contrast, sensitivity, and accuracy. Tang et al. showed in their study that Si-NPs exhibited 4 different fluorescence colors (Fig. 6). In particular, Si-NPS A provided a unique advantage as it could be distinguished in different excitations with different fluorescent color conversions [29].

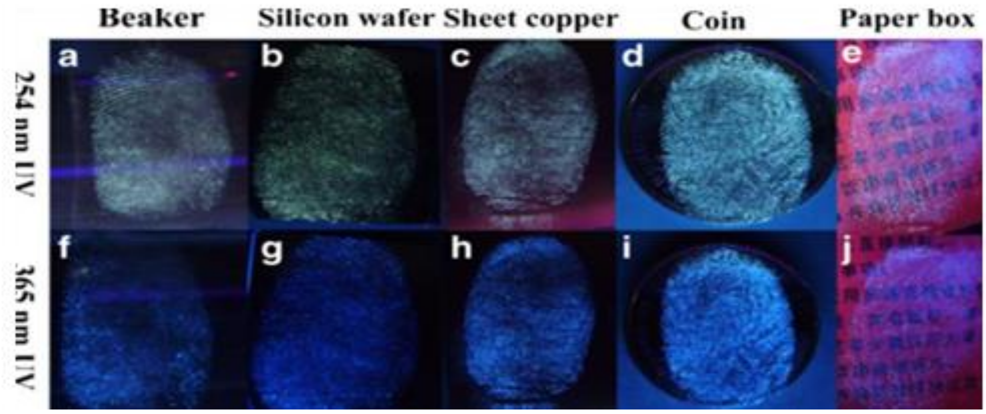

Figure 6. Fingerprint visualization with silica nanoparticles [29]

3. RESULTS AND DISCUSSION

For the research, 19 studies involving the use of silica nanoparticles in fingerprint visualization between the years 2016-2020 were examined. The findings of the study are indicated in the tables (Table 1).

Table 1. Number and percentage of studies in the last 5 years

Number of fingerprint visualization studies	Preferred number of studies	Percentage
1540	19	1%

Scientific studies between 2016 and 2020 were preferred for the research. Out of 1540 publications belonging to fingerprint visualization studies, 19 publications suitable for our research were selected. The total number of publications, the number of preferred publications, and their percentage in the total number of publications are given in Table 2.

Table 2. Number of publications and percentages for the last 5 years

Publication year	Number of publications	Percentage
2016	1	5%
2017	5	26%
2018	5	26%
2019	4	21%
2020	4	21%
Total	19	100%

The 19 publications preferred for research were classified based on years. Year-based ranking and a total percentage of publications are shown in Table 4. Looking at the information of 19 preferred studies, it is seen that silica nanoparticles with different properties and different sizes are used. Different synthesis methods were preferred for the synthesis of silica nanoparticle molecules used in the studies. In addition, the preferred imaging techniques for fingerprint visualization differed from each other in the studies.

Table 3. Silica nanoparticle types preferred in studies

SNP Type	Number	Percentage
MSN's	3	11%
SiO_2	5	18%
Fluorescent carbon-doped	1	4%
FSNP	2	7%
Functional silicon oxide	1	4%
Si-CNs	1	4%
SPNX	1	4%
Black Nano Silica	1	4%
Of/ SiO_2NPs	1	4%
ZnO-SiO_2	1	4%
F-SiNPs	1	4%
Si-NPs	6	21%
FLSNPs	1	4%
OFDBT/ SiO_2	3	11%
Total	28	100%

The preferred silica nanoparticle types in the studies were classified as the most preferred and the least preferred (Table 3). The synthesis types preferred in the studies are divided into percentage distribution as the most preferred and least preferred (Table 4).

Table 4. Silica nanoparticle synthesis type preferred in studies

SNP synthesis type	Number	Percentage
Chemical	5	19%
Stober	7	26%
APTES	2	7%
Amphiphilic	1	4%
APTMS	2	7%
Folic Acid	1	4%
BET	2	7%
Inverse Micro Emulsion	2	7%
Sodium Citrate	1	4%
TEOS Hydrolysis	1	4%
Reverse Miçelle Method	1	4%
S-T mix	1	4%
Thermochemical Processes	1	4%
Total	27	100%

The imaging techniques preferred in the studies were classified based on the percentage distribution. This classification is specified in Table 5. The surface types used in the studies were classified by percentage distribution and the results are given in Table 6.

Table 5. Preferred imaging methods and percentages in studies

Scanning types	Number	Percentage
Sem	11	24%
Tem	11	24%
Uv	9	20%
Light	5	11%
Hrtem	1	2%
Fesem	1	2%
Xrd	1	2%
Ft- ır	1	2%
Xps	1	2%
Pl	1	2%
SLM	1	2%
DLS	2	4%
Spektrofluometric	1	2%
Total	46	100%

Table 6. Preferred surface types and percentages in studies

Surface types	Number	Percentage
Paper and Derivatives	18	24%
Pine	9	12%
Steel	4	5%
Wooden	3	4%
Silicon	2	3%
Copper	4	5%
Plastic	5	7%
Acrylic	1	1%
Aluminum	5	7%
Polyurethane and Derivatives	4	5%
Marble	3	4%
Band	3	4%
Tile	1	1%
Petri Dish	2	3%
Nano Carbon	1	1%
Methylene Blue	1	1%
Sodium Acetate	1	1%
Metals and Derivatives	3	4%
CSS	1	1%
Beaker	1	1%
Fresh Leaf	1	1%
Measuring Cylinder	1	1%
Porcelain	1	1%
Skin	1	1%
Total	76	100%

There are scientific studies in the field of fingerprint visualization. Especially recently, visualization techniques have been developed and new techniques have been introduced. Fingerprint data, which helps to reveal the individual identity, has been supported by nanotechnology studies. Especially in this field, the use of silica nanoparticles has reached remarkable dimensions. Such studies are gaining importance day by day to shed light on criminal events in a short time and justice to be carried out correctly. The results of some studies in the literature are given below.

Alsolmy et al. (2018) [30] synthesized 7 different approaches for the development of fingerprints of fluorescein isocyanate encapsulated silica nanoparticles (F-Snp). The suitability of each synthesis route for incorporating the fluorophore selected for the study into the silica matrix and its effectiveness in fingerprint detection were investigated. A systematic investigation of various factors affecting the development of wet fingerprints on 3 different non-porous surfaces is presented for the study. Nanometer-sized particles are loaded into the F-Sinps matrix to increase the contrast of the enhanced fingerprints against the surrounding background while improving the resolution of the enhanced fingerprints. According to the results obtained, it has been shown that the developed silica nanoparticles are effective in detecting the functional groups that have the potential to react with the most abundant components in the fingerprint residue. It has been observed that the most important factor affecting this application is the hydrophobic structure of the F-SiNps surface.

Silica enhancers are used to enhance hidden fingerprints; It is strategically beneficial due to its precision structure, low cost, high surface contrast, and easy adjustment of surface areas. Divya et al. (2018) researched the regulation of the amplification of silica enhancers in their study. They synthesized a series of functionalized silica enhancers with varying degrees of surface hydrophobicity and hydrophilicity and studied the development of latent fingerprints using the dusting method. The results showed that SiO2-4 and SiO2-5, the long alkyl chain functionalized silica boosters, were superior to the other hydrophilic SiO2-1 and the less amphiphilic SiO2-2-SiO2-3. They stated that the obtained SiO2-6 showed extremely good results for the development of hidden fingerprints under ultraviolet light and visible light at a wavelength of 365 nm.

Tang et al. (2020) obtained silica nanoparticles by using S-Tas raw material in their study. By dispersing the obtained silica nanoparticles in different solvents, they formed 4 different silica nanoparticles, Si-NP-A, B, C, D, with different fluorescent emissions. They stated that Si-NP-A can be considered as a promising fluorescent material in the field of covert fingerprint development, due to its dual-emitting properties and superior performance in covert fingerprint visualization.

Looking at the literature studies, it is seen that silica nanoparticle studies have a promising effect on hidden fingerprint visualization.

It was seen that 1% of 1540 publications containing fingerprint visualization studies of the last 5 years were on visualization with silica nanoparticles. When the distribution of the 19 publications examined for this purpose is examined, it is seen that the publication rate, which was 5% in 2016, increased to 26% in 2017 and 2018. The distribution of the rates of publications published after 2016 as 21% and 26% can be evaluated as a result of the increasing attention of such studies. The increasing number of studies in this field is an indication of promising results in fingerprint visualization.

In the studies examined, 14 different silica nanoparticles of very different structures and sizes were preferred. The most preferred silica nanoparticle types in studies; appear as Si-O2, MSNs, Si-NPs, and OFDBT/SiO2. There are many techniques in silica nanoparticle synthesis. The types of synthesis frequently used in studies are Stöber and chemical methods. The most important step after the synthesis step is the visualization step. Fingerprints treated with silica molecules gain visuality with different imaging systems. For this purpose, SEM, TEM, and UV techniques were mostly preferred for visualization in studies. Silica nanoparticles have been used in many surface-type studies to provide fingerprint development. The most preferred primary surfaces are; paper and its derivatives, glass, plastic, and aluminum. Secondary surfaces were determined as steel, wood, silicon, copper, polyurethane and its derivatives, marble, tape, metal, and derivatives with 3%, 4%, 5% slice. It has been observed that the minimum value of the wavelengths applied in the studies varies between 350 nm and the highest value between 540 and 750 nm. The minimum number of fingerprints obtained is 4, while the maximum number of fingerprints obtained is 288.

As a result of these studies, the type of silica nanoparticle used in the imaging of hidden fingerprints, the type of synthesis, the wavelength applied, the type of surface on which the fingerprint will be visualized, and the optical techniques to be preferred for imaging are important. The use of silica nanoparticles in visualization studies is a preferred application in studies in this field due to its ease of application, low toxicity rate, high number of fingerprints obtained, providing clear visualization, and high surface diversity in terms of quality and applicability.

4. CONCLUSION

Chemical, physical and optical techniques are used to visualize hidden fingerprints. Recently, there has been intense interest in the use of nanoparticles for the visualization of hidden fingerprints. Especially silica-based nanoparticles; It is preferred because of their high fluorescence, strong visualization, and low toxicity. In the studies, it has been seen that clearer and sharper fingerprints are obtained thanks to the use of silica nanoparticles. Profiled fingerprints make a great contribution to the detection of criminals.

When the studies on the use of silica nanoparticles for fingerprint visualization are examined, it is seen that silica molecules with different structures and sizes are synthesized. Especially for synthesis, the Stöber method is the most preferred. On the other hand, the choice of the wavelength applied and the optical techniques that will provide the visualization are important. Optical techniques often involve the use of SEM, TEM, and UV. In visualization with silica nanoparticles, the surface variety to obtain fingerprints is high. For this purpose, paper and its derivatives, glass, plastic, and aluminum are mostly preferred. The silica nanoparticle method for visualization of hidden fingerprints has the advantage of being more advantageous compared to other classical methods. Regardless of the surface type, fingerprint visualization is provided from many surfaces.

The visualization of fingerprint evidence, which is important for the resolution of incidents, should continue to be examined with new techniques and methods. The use of silica nanoparticles, which are indicators of technological developments, should be increased gradually. In this thesis, the level of use of silica nanoparticles in fingerprint visualization has been demonstrated. As a result of the examinations, features such as the most preferred surface types in studies, which wavelengths are applied, the techniques used for visualization, the type of synthesis of silica molecules, the dimensions of silica nanoparticles are presented to the scientific world to inform scientists who want to work in this field.

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