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Tattoos as Inked Narratives of Identity: A Comprehensive Forensic Anthropological Review

الأوشام كحكايات محفورة للهوية: دراسة مرجعية شاملة في الأنثروبولوجيا الجنائية

J. S. Sehrawat* and Shubham Thaku
Department of Anthropology, Panjab University, Chandigarh, India

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Abstract

Tattoos are excellent identifiers of unidentified persons encountered in forensic anthropological scenarios as the former are a form of secret language written under the skin that may become silent witness to certain unsolved mysteries. Diverse communities have practiced tattooing for centuries, representing as a marker of their identity, spirituality, traditions, beliefs and cultural heritage. Anthropologically, tattoos generally symbolize togetherness, unity, and kinship. They can prove to be valuable adjunct even in challenging situations where facial identification of an individual isn't possible due to the destruction of the victim's face by the criminal. Present review aims to provide an in-depth information about these inked narratives and, advocates for preparing a catalogue of common tattoo marks and envisions an expedited and accurate human identification process using them in mass-disaster scenarios. The improved technologies of visualization, documentation and classification of tattoo marks can help in generating a comprehensive database to assist law enforcement agencies in identification of unidentified decedents.

Keywords: forensic sciences, tattoos, identification, forensic anthropology, motivations, biometric tools

المستخلص

تُعد الأوشام محددات هوية ممتازة للأشخاص مجهولي الهوية الذين يتم التعامل معهم في سيناريوهات الأنثروبولوجيا الجنائية؛ إذ تُمثل الأوشام لغة سرية مكتوبة تحت الجلد، قد تتحول إلى شاهد صامت على ألغاز معينة لم يتم حلها إلى وقتنا الحالي.

لقد مارست مجتمعات متنوعة الوشم لعدة قرون، باعتباره مؤشراً على هويتهم، وروحانياتهم، وتقاليدهم، ومعتقداتهم، وتراثهم الثقافي.

ومن الناحية الأنثروبولوجية، ترمز الأوشام عموماً إلى التآزر والوحدة والقرابة. ويمكن أن تثبت قيمتها كعامل مساعد حتى في الحالات الصعبة التي لا يمكن فيها التعرف على ملامح وجه الفرد بسبب تشوهه المتعمد من قبل المجرم.

تهدف المراجعة الحالية إلى تقديم معلومات متعمقة حول هذه «السرود المحبورة» (Inked Narratives)، وتدعو إلى إعداد كتالوج لعلامات الوشم الشائعة، وتستشرف عملية تحديد هوية بشرية سريعة ودقيقة باستخدام هذه الأوشام في سيناريوهات الكوارث الجماعية.

وإن تحسين تقنيات التصوير، والتوثيق، وتصنيف علامات الوشم يمكن أن يسهم في إنشاء قاعدة بيانات شاملة لمساعدة وكالات إنفاذ القانون في تحديد هوية الرفات المجهول.

الكلمات المفتاحية: علوم الأدلة الجنائية، الأوشام، تحديد الهوية، الأنثروبولوجيا الجنائية، الدوافع، أدوات القياس الحيوي

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* Corresponding Author: JS Sehrawat
Email: jagminder@pu.ac.in
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1. Introduction

Since times immemorial, humans have manifested their sentiments and thoughts or ideas in diverse ways; especially artistic forms such as verbal, musical, visual, dance, and other abstract forms [1]. The term "tattoo" has been derived from the Polynesian word 'ta tau' which means 'to mark'. Tattooing is considered an age-old sacred art form or custom known to humans, wherein an indelible mark, figure, or pattern of ink or pigment (having some specific individual, cultural or magical significance) is inserted under the skin. The art of tattooing, deeply rooted across different cultures, has been a global phenomenon throughout human history, serving purposes ranging from ritualistic to decorative, and reflecting Piombino the rich tapestry of human expression across civilizations. Ötzi, the Iceman displayed therapeutic or symbolic tattoos dating back to 3300 BCE [2, 3, 4], ancient Egyptians practiced tattooing, as did Polynesians where tattoos conveyed social and spiritual significance [5]. Ancient Chinese used tattoos for punishment and medicinal purposes [6], while Scythians in Central Asia adorned themselves with tattoos for social status [7].

Different portions of the body are ornamented with tattoos, temporarily or permanently, across different cultures to indicate their gender, occupation, social status, spiritual or cultural affiliation, fear, love, achievements etc. [1, 8]. In India, diverse tribal communities have practiced tattooing for centuries, using it as a marker of their identity, spirituality, and cultural heritage, connecting individuals to their ancestral beliefs and traditions. Additionally, tattoos also serve as a form of storytelling, preserving folklore and the tribal history. Despite modern influences, the continuation of tribal tattooing in India underscores the resilience of indigenous cultures and their commitment to preserving unique expressions of identity [9]. Given the widespread use of tattoos in modern times (particularly by the youth), it becomes crucial to understand the cultural, evolutionary, and historical aspects of tattooing practices. Tattoos can help identify unknown deceased individuals to provide insights into their social, cultural, ethnic or geographic backgrounds [10]. In the present era of globalization and universalization, the identity of specific tattoo style or design can no longer be traced to certain specific population or ethnic groups as the tradition has percolated down to all societies.

Present review article aims to provide an in-depth anthropological information about these body modifications i.e., tattoos (motivations, styles & designs, pigments and techniques used, classification, cultural identity/symbolism), with special emphasis on their forensic anthropological significance [11]. The major aim and objective of this review was to discuss the motivations, styles & designs, pigments and techniques used, the classification, cultural identity/symbolism etc., of the tattooing and investigate how these inked narratives can be used in forensic identifications.

Part I: Tattoos as Cultural Narratives: History, Techniques, Symbolism and Classification

Brief History of the Art of Tattooing

The history of tattooing can be traced back to ancient times, evolving across different periods and civilizations to continually reinvent itself. Archaeological discoveries of skin-puncturing tools and pigment reserves dating to approximately 3300 BC, from the Upper Palaeolithic period in Europe, represent the earliest evidence of tattooing practices [2, 3, 4]. Descriptions and discoveries of tattooed mummies from ancient Egypt further confirm the antiquity of this art form. Across the world, numerous indigenous cultures have long practiced tattooing as an integral part of their

traditions. In the Polynesian islands, particularly among the Māori of New Zealand, tattoos served diverse cultural, spiritual, and social purposes. Similarly, Southeast Asian ethnic groups developed intricate tattoo designs and motifs imbued with deep cultural and religious symbolism [12].

The practice reached western societies through encounters with indigenous peoples during the eras of exploration and colonization, where it gradually evolved into an art form of personal expression and body adornment. Historically, tattoos have also been employed for various utilitarian or symbolic purposes — to identify slaves and criminals, to denote honor or bravery, or to covertly mark members of prohibited religious sects. During the medieval period, European crusaders and pilgrims to the Holy Land commonly tattooed Christian emblems on their bodies as symbols of faith and devotion.

In the 20th and 21st centuries, tattooing experienced a global revival, emerging as a mainstream medium of art and self-expression. Today, tattoos have become an integral element of popular culture, embraced by people from all walks of life and expressed through diverse styles and techniques. The art of tattooing has been interpreted as a rite of passage, a means of personal and cultural expression, and a symbol of social status, achievement, or group affiliation. The present review aims to explore the multifaceted significance of tattoos and to examine their dual role as both cultural markers and forensic identifiers.

Techniques of Tattooing

The techniques and pigments involved in tattooing vary widely according to the traditional and modern practices associated with it. Modern tattooing techniques use a tattoo machine having a mechanized needle used to inoculate the pigment into the skin in controlled quantities for impregnating a desired pattern. The tattooing process involves the dispersion of pigment/s in both the epidermal (outer) and dermal (inner) layers of skin; pigment in outer layer is shed due to desquamation while it is absorbed and held on by the cells of inner layer. The machine generally injects the tattoo inks in the dermis layer at the rate of about 1mg of ink per centimeter square of the tattooed area. The indigenous amateur tattooing techniques involve a variety of traditional tools and techniques, considering the deep cultural significance and identity attached to the technique; the techniques vary from simple hand-poking methods for hammering ink to the rubbing of pigments into the cuts. The traditional methods, often, employ sharp tools like different types of thorns or sharpened sticks to create tattoos. In the hammering ink method, a small hammer is used to embed ink into the skin, helping the tattoos become more visible over time. Some groups have a distinct approach of tattooing wherein they create cuts in the skin and rub pigments or soot to form tattoos. Though such methods pose a higher risks of infection, the same is viewed as a rite of passage among the members of a specific community [13, 14, 15, 16].

Pigments Used for Tattooing

The survivability of tattoo pigments deep in the dermal layer make them significantly valuable for identification of the victims of mass fatality incidents. Carbon black is the most widely used pigment for creating black tattoos which acts as a base for shading and outlining the tattoos. The black pigments are typically made from carbon, and iron oxides, and sometimes may even include titanium dioxide. In contrast, colored pigments are categorized as organic or inorganic pigments. Contemporary tattoos often include heavy metals such as titanium, barium, aluminium, and copper.

The increased use of these organic pigments is associated with their ability to provide a wide range of hues, bright and vibrant colors. Inorganic pigments may include heavy metals like antimony, arsenic, cadmium, chromium, cobalt, lead, and nickel. These opaque and solid, long-lasting colors are more stable and less likely to cause any allergic reactions to an individual. Traditional tattoos often use pigments such as India ink, pen ink and carbon particles from burnt materials, etc. At times, soot and ash are mixed with substances like animal fat, urine, or breast milk to enhance application and reduce inflammation. Certain plant-based inks are also created by burning sap collected from specific trees or mixing green sap with soot [13, 14, 15, 16, 17]. Also, if laser removal methods are undertaken for tattoo removal, different types of lasers are used for targeting specific colorants without damaging the surrounding skin. Although, this may often take multiple sessions for effective removal. Tattoos are generally considered a permanent form of body art, though over the time, tattoos may fade or blur due to factors such as exposure to sunlight, aging, and body décompositions.

Technical Precision in Pigment Analysis

Certain tattoo pigments may function as an objective marker of identity when the analysis extends beyond their visual appearance. By examining the chemical composition, including trace elements and impurities, tattoo inks can provide valuable information from the forensic perspective. These compositional profiling of tattoo inks may assist in determining their origin or source of inks, thereby enhancing their potential utility in individual identification. Therefore, the chemical characterization of specific tattoo pigments, their additives, and trace impurities may allow forensic experts to develop a chemical fingerprint for a given tattoo ink. This chemical fingerprint may further help in linking a tattoo to a particular ink type or brand, finding the geographical origin or manufacturer of the ink, potentially identify inks used in specific contexts, such as illegal operations, etc. [18, 19] . Since, visual examination of tattoos is often considered to be insufficient and unreliable in terms of forensic identification, tattoos are often recognized as secondary means for human identification. There exists plethora of limitations wherein visual assessment of tattoos is concerned. Thus, deeper visualization is required for improving the detection of tattoos as latent evidence that is generally based on utilization of state of art technology. Not only that, photographic techniques are highly capable and proven method for detection of significant percentage of sampled cover-up tattoos, which would otherwise be undetectable based on visual inspection. Moreover, visual examination is incapable of revealing the chemical composition of tattoo pigments, thereby, necessitating the use of analytical techniques for identification of elemental and molecular characteristics existing beyond the surface of tattoos. Additionally, it has been often observed that the undisclosed and often mixed nature of tattoo inks created compositional complexity, making such techniques essential for accurate determination of pigment structure, concentration and its origin [18, 19, 20]. Therefore, it becomes necessary to employ analytical techniques like Raman Spectroscopy, X-ray fluorescence (XRF), FTIR spectroscopy, SEM-EDS, HPLC/LC-MS/Py-GCMS for the analysis of organic and inorganic dyes used as tattoo inks.

Thus, the comprehensive analytical framework provided by these methods strengthens evidentiary value in forensic identification by devising a chemical fingerprint based on the combination of elemental, structural, and molecular information, which tries to



eliminate the limitations associated with individual techniques and allows for better identification and differentiation of inks.

At the elemental characteristic level, techniques like X-ray fluorescence (XRF), Scanning Electron Microscopy- Energy Dispersive X-ray Spectroscopy (SEM-EDS) exists that provide information about the elemental composition and spatial distribution of constituents present within the tattoo pigments [18, 21]. XRF is a non-destructive technique that determines the elemental composition of a sample by measuring characteristic fluorescent X-rays emitted when atoms, excited by an incident X-ray beam, undergo electronic transitions, with advances forms like synchrotron XRF enabling high-resolution analysis at the nanoscale. The XRF based chemical fingerprint is based on the wide range of inorganic elements present in tattoo inks such as lead, copper, iron, titanium, aluminium, strontium, bromine, calcium, zinc, arsenic, cadmium, chromium, nickel and their relative concentrations. Furthermore, it is also useful in quantification of these elements in parts per million (ppm) levels, mapping the distribution of elements found within the tattoo pigments and even in biological tissues providing insights into their fate after tattooing, revealing the presence of specific pigments, i.e., ingredient levels analysis of the pigments. This analytical technique holds a significant evidentiary value in forensics as it enables the differentiation of tattoo inks based on variations in composition and concentration, which can assist in distinguishing between manufacturers or batches and support potential source attribution. Additionally, it allows for the quantification of specific elements, facilitating the assessment of compliance with regulatory standards for harmful substances. Despite of all this, the utility of XRF is limited by its incapability in detection of organic compounds, nor does it differentiate between chemical forms or oxidation state of elements. Additionally, its sensitivity may vary depending on the sample matrix, which can influence quantification accuracy, although this can be managed by complementary techniques [19, 21, 22, 23].

SEM-EDS is a powerful combination of two techniques that is also used for detection of inorganic components present in tattoo inks. The working principle of SEM technique operates by scanning a focused beam of electron beam across the sample surface, generating signals such as secondary electrons for high resolution topographical imaging and backscattered electrons for compositional contrast based on atomic number. While the EDS functions by detecting the characteristic X-rays emitted when atoms, excited by an electron beam, undergo electronic transitions, enabling the identification and relative quantification of elements based on their unique energy signatures. Furthermore, SEM-EDS is useful for characterizing the elemental composition and morphology of tattoo pigments, including particle, shape, size and distribution of the elements used. Thus, this feature enables generating characteristic differentiation between the tattoo inks based on their unique elemental profiles and it also aids in the detection of trace contaminations present within the inks. Therefore, making this technique highly valuable in forensic investigations due to its ability for providing high resolution morphological and elemental information which may further aid the characterisation of tattoo pigments, including their micro-topography and chemical composition. Thereby, the integrated use of SEM-EDS facilitates differentiation between ink types and brands, and it also aids in determination of their origin, thereby strengthening its application in forensic identification. Moreover, in the absence of a unified international database, studies employing

techniques such as SEM-EDS contributes to the development of scientific repositories of elemental profiles of tattoos inks and pigments, thereby supporting comparative and forensic analyses. While there are certain advantages attached to this combination of techniques, it is pertinent to acknowledge the limitations associated with this technique. Since, this technique is limited to surface or near surface analysis and requires samples to be stable under high vacuum conditions, but some samples may require conductive coating that may affect the results generated by it. Furthermore, it is mainly limited to elemental analysis, lacking the ability to identify organic molecular structures, and may face challenges in precise quantification due to matrix and geometric effects [18, 19].

At the structural characteristic level, techniques like Fourier-transform infrared (FTIR) and Raman spectroscopy analyse the vibrational models of molecules, revealing the specific chemical bonds and functional groups existing in the tattoo pigments. Therefore, the spectral so obtained helps in providing a molecular structure [19]. They offer distinct advantages and are highly relevant in forensic science, particularly for analysing substances like tattoo inks. FTIR works fundamentally by measuring the absorption of infrared radiations by molecular bonds, producing a characteristic spectrum based on vibrational frequencies so produced that serve as a molecular fingerprint of the sample processed. it is particularly useful for the partial identification and classification of pigments, while also enabling the analysis of their physicochemical properties. This technique works effectively towards detection of contaminations present in the sample beyond the 5-10% mark. It is a highly advanced technique that is capable of analyzing mixtures of pigments present in the tattoo inks, with combination of multiple wavelengths that aids the accuracy and reliability in identification of pigments. More advanced version of this technique such as Synchrotron FTIR micro-spectroscopy are capable of undertaking tasks like histological mapping of the biochemical changes in body tissues in response to tattoo pigments or other alterations. Therefore, this technique offers a significant advantage in forensic analysis due to various attributes attached to it such as its rapid, non-destructive nature as well as its ability to analyze complex matrices with minimal sample preparation. Thereby, providing valuable insights into the physicochemical characterization of substances which in combination with chemometric modelling, enables rapid, accurate and cost-effective analysis suitable for routine applications. But there are certain inhibitions attached to the application of this technique in analysis of tattoo inks. This technique showcases limited sensitivity towards detection of substances present in very low concentrations. Hence, rendering it useless and harmful in analyzing samples involving trace amount of contaminations in tattoo inks, which may remain undetected despite posing as a potential biological or toxicological threat. Thereby requiring other complementary analytical techniques for accurate interpretation of tattoo inks [21, 24].

Another technique working towards the detection of structural characteristics of tattoo pigments is Raman Spectroscopy, which is particularly useful in identification of elements like carbon and some inorganic compounds that may pose as a challenging task for Infrared radiation. This technique is based on the inelastic scattering of monochromatic light, where a small fraction of incident photons undergoes energy shifts due to molecular vibrations, producing a characteristic spectral pattern that serves as a molecular fingerprint of the substance. Therefore, it is often employed for the molecular level identification and

characterisation of tattoo pigments, that aids the process of detection of specific compounds such as phthalocyanines, azo pigments, and carbon-based materials, including harmful or legally restricted chemicals present in tattoo inks. Its non-destructive and in-situ analytical properties allows for minimal sample preparation at the same time facilitating the differentiation of structurally or visually similar inks, thereby aiding the forensic investigations. As far as its application in forensics is concerned from the evidentiary standpoint, its characteristic features as a powerful, non-destructive tool for in-situ chemical characterization of modern tattoo pigments, especially valuable in assessment of organic compounds. Thereby, enabling it for identification of specific pigments, including regulated or potentially harmful substances present in tattoo inks. This technique is capable of differentiating between visually similar inks, while also supporting the characterization of unique entities such as coal tattoos, thereby enhancing its applicability in forensic contexts. This technique is also associated with certain limitations, such as presence of fluorescence in samples or impurities that may interfere with the weaker Raman signal, thereby making the analysis a difficult task. While comparison of pigments with highly similar structures becomes an undaunting task when solely undertaken using Raman spectra. Although, this technique works perfectly well for molecular structural analysis, it is not suitable for assessment of elemental composition [23, 24].

Finally at the molecular characteristic level techniques like HPLC, LC-MS, Py-GC/MS works highly effectively towards molecular characterisation by offering high specificity and sensitivity in forensic investigations, particularly for complex organic substances present in tattoo inks. While High-performance liquid chromatography (HPLC) and Liquid Chromatography (LC) works for separation and analysis of complex mixtures of organic compounds, enabling their resolution into individual components and subsequent identification based on characteristic mass-to-charge ratio and fragmentation patterns. On the other hand, Pyrolysis-gas chromatography/mass spectrometry (Py-GC/MS) generate characteristic fragment patterns by decomposing pigments at high temperatures for identification of parent organic compounds, even in complex matrices or when the original pigment is difficult to analyse directly. HPLC and LC-MS are primarily useful for identification of soluble pigments present in tattoo inks. LC-MS is based on the powerful combination of two techniques, i.e., the amalgamation of separation power of liquid chromatography with the identification capability of mass spectrometry, making it particularly useful in characterizing specific compounds, though its application becomes limited in case of pigments with poor solubility. Py-GC/MS works effectively towards identification of insoluble pigments and polymers in tattoo inks. Its working principle is based on thermal degradation of substance into characteristic fragments, which then undergo analysis. Although, this method passes through the solubility test as it requires no sample purification and is also capable of predicting potentially toxic degradation products that might arise from laser removal or sunlight exposure. But its limitation lies in case of pigments that lack specific cleavage sites. These analytical techniques offer essential evidentiary and forensic value for tattoo inks. Hence, these techniques enable comprehensive characterisation of tattoo inks by identifying a wide range of organic pigments, polymers, and their degradation products, thereby generating detailed chemical fingerprints of the same. Furthermore, these techniques also show regulatory compliance, supporting the detection of prohibited or harmful agents, thereby, aiding the

health risk assessment and contributing towards the indirect source behind tracing ink products [22].

Ultimately, the collective application of complementary analytical techniques is capable of generating a multi-dimensional fingerprint of tattoo inks, based on the integrative groundwork of elemental, molecular, and compositional data for enhancing their accuracy and reliability. Therefore, by overcoming the individual methodological fallacies and enabling cross-validation approach towards the results incurred. Hence, this strengthens the differentiation pattern, source attribution and detection of impurities or degradation of products, which in turn enhances the evidentiary value attached to tattoo analysis in forensic investigations.

Tattoo Marks as Sacred Ink: Motivations, Style, Symbolism, and Rituals

This practice of intentional insertion of pigment in the skin has been part of the cultures and traditions worldwide. Among the Indian population, the art of tattooing holds significant cultural and social importance, especially among the tribal populations where the art of tattooing is deeply ingrained in their traditions as a form of symbolism to serve multiple purposes like community ideology, spiritual beliefs, social status, role within the community, or specific achievements. However, the concepts of globalization and modernization have re-redefined the meaning and purpose of the practice of tattooing, thus have presented both challenges and opportunities for the preservation of these rich traditions [25, 26, 27, 28].

Motivations Behind Tattooing in Indigenous Societies (Figure 1)

1. Identity: The most common reason for getting a tattoo among indigenous populations is to express identity, where tattoos generally symbolize togetherness, unity, and kinship. Within Indian tribal communities, tattoos play a vital role in reflecting their shared cultural values, beliefs, and histories, thereby reinforcing a sense of collective belonging and unity within each tribe. The diverse forms of body art (in the form of tattoo marks) are often associated with ritualistic practices, nature-inspired motifs, nomadic traditions, rites of passage, ceremonial expressions, or mythological origins. In contrast, within contemporary Western urban cultures, tattooing is typically regarded as an expression of individual identity—serving as a means to distinguish oneself from the larger populace. It allows individuals to convey their unique identities, interests, and personal narratives through body art. [27].
2. Adornments: Tattooing in western culture is often treated as a fashion statement, mostly practiced for decorative purposes, with little or no symbolic significance. For instance, the contemporary female population has an increasing preference for permanent cosmetic tattoos for eyeliner or eyebrows. The ritualistic adornments, sometimes, act as a medium of protection against negative force as the former make them unattractive [10, 27]. The simple geometric tattoos among Baiga tribes of Central India reflect any significant life event such puberty, marriage, etc. [29]. Similarly, Apatani women of Arunachal Pradesh (India) traditionally have a Y-shaped facial tattoo pattern on their forehead and lines on the nose [30].
3. Status and Position: Tattoos may also be employed as a mean of denoting social status and position among their respective groups and every member of a group is generally not

allowed to have a tattoo; specific placement of tattoos holds specific significance. It may also be representative of a person's social status and identity within the group. For instance, Naga (Indian tribal group) tattoos include quite intricate designs including animal motifs and geometric patterns that serve as identity markers, representing a person's achievements and social status within the community. Historically, Naga tribes practiced headhunting, and tattoos were earned through such acts. While headhunting is no longer prevalent, Naga tattoos continue to symbolize power, bravery, and reverence, creating a shared history among the tribes. Within the Singpho tribe of North-eastern India, it was customary for married women to adorn their bodies with tattoos extending from their ankles to their knees, while males were limited to having tattoos just on their limbs; unwed individuals were prohibited from obtaining tattoos. Tattoos can be adorned by those possessing exceptional abilities or high social standing, such as priests or chiefs of clans. Historically, among the Oraon of Jharkhand and Chhattisgarh (India), specific tattoos on individuals might indicate criminal status or certain social roles associated with crime, however, such associations have changed over time. It's crucial to approach these examples with sensitivity and recognize that tattoo practices and their cultural meanings can evolve. Additionally, colonial and historical influences have shaped the perception of tattoos in complex ways. They were often linked to disdain and cultural prohibitions in the past. Western civilization has often linked it to acts of prostitution, homosexuality, and mental impairments. During the colonial period in India, there were instances where the British administration compelled derogatory tattoos on tribal and indigenous communities as a form of identification, punishment, or control. One notable example involves the criminalization of certain tribal groups based on colonial perceptions of criminality. The term "thug" was associated with a specific group of people, and the British administration implemented a practice known as "The Thuggee and Dacoity Suppression Acts" in the early 19th century. This practice not only served as a method of identification but also stigmatized entire communities based on colonial perceptions of criminality. Many innocent individuals were unfairly marked with derogatory tattoos, contributing to cultural stereotyping and prejudice. [27, 31].

4. Therapy: Muslim Maler women living in Punjab were confident that tattoo marks placed on the forehead promoted safe delivery during childbirth [32]. Among some tribal groups, tattoos are also used as an alternative to acupuncture. They look at it from a pseudoscientific lens that provides a sort of medical treatment in some cultures. For instance, the Baiga Tribe believes that the placement of tattoos on specific body parts can cure certain diseases. The Mal Paharia women of Jharkhand believe that tattoos keep their organs healthy and help them function properly. Current research shows that tattoo ink damages skin cells in sunlight and epidermal punctures may allow germs and viruses to penetrate deeper layers and cause skin diseases. Tattoos without proper hygiene can risk infections like hepatitis B and C, TB, and HIV/AIDS [32, 33].

5. Apotropaic: Tattoos have also been used for protective or warding-off purposes as the former are believed to guard against evil, negative forces, or harm, thus apotropaic tattoos are significant for their protective symbolism and spiritual beliefs. Certain symbols or designs of tattoos are believed to ward off certain evil spirits, negative energies, curses, or harm, illness, or other malevolent forces, thus serving as a form of spiritual armor. Among certain tribal communities, specifically designed and symbolized tattoos create a barrier against spiritual and physical threats, providing a layer of defense for the individual. The symbolism embedded in apotropaic tattoos, often, draws inspiration from nature, incorporating animals, plants, and elements that symbolize the protective forces of the natural world. Individuals within these communities may choose apotropaic tattoos not only for their protective qualities but also as a means of personal empowerment. These tattoos serve as a connection with ancestral energies, reinforcing a sense of strength, resilience, and control over one's spiritual well-being. Tattoos of Kolam, a labyrinth symbol drawn at the house door, are believed to protect the body from evil and help people reunite with their ancestors in the hereafter [32, 34].
6. Cosmetic and Medical: Tattoos have been frequently for cosmetic purposes towards enhancing the appearance of eyeliner or lip liner or to conceal birthmarks or scars. They have a rich history that extends over thousands of years, as they have been utilized towards body beautification. The medical applications of tattoos are spread wide in the field of medicine, especially for marking specific anatomical sites in radiotherapy or to indicate areas that need to be carefully re-evaluated during follow-up examinations. Traditional healers in certain ethnic groups in West Africa employ tattoos and scarification as therapeutic instruments, for instance, by creating a fine mark on the forehead to address epilepsy [10]. The ritualistic and cosmetic enhancement via tattooing is often found associated with specific designs or patterns that mark the important life events or transitions contributing to an individual's aesthetic transformations.

   The medical utility of tattoos could range from simple scar camouflage in case of injuries or skin conditions. They may use tattoos as a means to conceal and transform scars aiding the psychological and emotional recovery of individuals. Tattoos are perceived as therapeutic tools, with the process of receiving pain management and contributing to the physical and psychological healing of the individuals. In specific tribal cultures, tattoos on women hold significance in symbolizing menstrual health and fertility, with these markings applied during rituals to convey protective and positive effects on women's reproductive health. Some tribals believe that 'Godna' tattoos keep them fit and that the medicinal herbs used in the ink can heal wounds. 'Baiga' women believe that the tattooing process acts as an acupressure treatment. Many women have tattoo marks of the peepal or acasia tree, which are religiously significant in Hinduism [11].
7. Psychological Issues: There may be certain psychological considerations associated with this symbolic art of tattooing, which can range from preserving memories to



Figure 1- *Motivations behind getting tattoos.*

showcasing cultural influence. Tattoos may be seen as self-expression and originality by younger people but differently by older people, causing intergenerational issues. The geometric tattoos on the face by 'Kondh' tribe of Orissa is believed to allow them to recognize each other in the spirit world. [10]. Stigmatization may still be associated with tattoos in some tribal communities, especially if certain designs or activities were traditionally associated with underprivileged populations. Tattoos serve as an indicator of an individual's personality and can be viewed as narratives that convey the life experiences they have accumulated, persisting throughout time [35].

Symbolism and Belief System Associated With Tribal Tattoos

Tattoos serve as vehicle of spiritual and mythological symbolism, expressing connection to deities, ancestral spirits, and mythical entities. Moreover, tribal tattoos function as markers of rites of passage, denoting critical life milestones and symbolizing personal growth and societal roles. Among indigenous cultures, tattoos serve as powerful expressions of social status, cultural identity, tradition and community affiliations [36, 37, 38]. They encapsulate diverse thematic elements that hold profound meanings for the individuals adorned with them. Totemic tattoos reflect community relations with their natural world, featuring symbols associated with totemic animals, plants, or elements.

Taxonomy of Inked Narratives: Understanding the Classification of Tattoos

Tattoos are described as visible and permanent pigmentation present on the secondary skin due to the deliberate or accidental deposition of exogenous pigment within the dermis layer. Therefore, a comprehensive understanding of the diverse forms of tattoos can be categorized into the following classificatory system:

a) Professional and amateur tattoos: The major difference between both classes of decorative

tattoos lies in the mode it is administered. Professional tattoos are courtesy of trained individuals made using a handheld gun that mostly evenly disperses ink in the deep dermal layer. Since, the pigment is deposited deeply in the dermis, making it difficult to remove. With time, the color of the ink fades out due to pigment migration to the deeper dermal layer and reaching the regional lymph nodes. On the other hand, amateur tattoos are often applied at home usually by nonprofessional artists using only a needle and a single ink color. In this case, the deposition of ink is more superficial and variable. These needles deliver Indian ink or carbon that is usually injected at variable depths under the dermal layer. They are often black and may contain ingredients such as charcoal, soot, or pen ink [14, 36].

b) Cosmetic, medical or decorative tattoos: Cosmetic tattoos are often freehand artwork done by cosmetologists to enhance the appearance of body parts, such as areas where makeup is applied, such as eyeliner, lip liner, and eyebrow pencil, or to mask deformities, using permanent makeup tattoos to conceal surgical scars, mastectomy, etc.

Medical tattoos are the ones used to treat a medical condition, communicate medical information, or mark a body part for medical procedures or future review. They are often done by medical personnel to mark radiotherapy fields or port placement sites on the body. They are small gray or blue-black markings made using a sparse quantity of India ink or carbon pigment.

Traumatic tattoos are the result of the deposition of foreign particles into the skin due to mechanical penetration followed by blast injury or physical trauma. They are made due to indentions caused by metal, glass, carbon-containing pigment, etc. Invisible tattoos are also called UV or black-light tattoos and are made with dyes that fluoresce and glow visibly under ultraviolet light [14, 36].

c) Unintentional and intentional tattoos: The unintentional tattoos are accidental and take place with the insertion of pigmented foreign material beneath the skin layer. Occupational tattoos were procured due to the deposition of coal dust in the skin of the hands and faces of coal miners. Besides, the presence of gunshot residue due to close contact discharge of a firearm is more extensively seen in ballistic death cases especially when black powder firearms were used in the past.

At times, intentional tattoos are challenging to determine especially when contemporary tattoos may deviate from the traditional symbolism. The presence of certain tattoos on prisoners, sailors, and ex-servicemen may represent permanent transgression marks placed by authorities, commemorate time in service, and may represent military emblem or protective talisman [14, 36].

d) Permanent or temporary tattoos: Tribes often have unique tattooing practices, with specific designs and meanings that are passed down through generations. Permanent tattoos among tribal communities are often created using traditional methods, such as hand-tapping or stick-and-poke techniques. The motifs and patterns can vary widely, ranging from geometric shapes to representations of animals, plants, or cultural symbols. These tattoos represent a classic example of cultural expression that is deeply intertwined with the tribal way of life.

Although the art of permanent tattoos is more prevalent among the tribal population of India, some

tribes also engage in temporary body art. Temporary tattoos may be created using natural dyes, such as henna, or other materials that are easy to apply and simply fade over time. These temporary adornments are often applied on special occasions, ceremonies, or rituals within the community [14, 36].

Part II: Unveiling Identities through Tattoos: Forensic Perspective

Tattoos are a form of secret language written under the skin that may become silent witness to certain unsolved mysteries. They are not only meant for body adornment but can also serve as a secondary or circumstantial mean of identification in forensic anthropology. It is the unique and permanent nature of tattoos which make them withstand trauma and damage, thus useful in forensic identification. Though tattoos are considered as cultural heritage of certain communities, they may help in identity establishments as regard to the ethnicity, nationality, occupation, religion, travel, language, name of person or relatives/friends/loved ones, drug use, medical conditions, criminal or social gang affiliation, sexual orientation, and socioeconomic status etc., of an individual. Forensic professionals compare ante-mortem descriptions of tattoos with post-mortem images, facilitating possible identification, subsequently confirmed through primary techniques like DNA analysis or odontology. Law enforcement agencies have devised cataloging systems for tattoo patterns, aiding the identification of victims and convicts. The widespread availability of digital data and social media has made it easier to identify a person from tattoo marks [39], thus multiple governmental organizations and emergency response teams has acknowledged tattoos as a component of the identification procedure. This comprehensive approach highlights the forensic significance of tattoos, showcasing their potential as a reliable tool in human identification during various forensic scenarios, including disaster victim identifications [39, 40]. Tattoos can prove valuable adjunct even in challenging situations where facial identification of an individual isn't possible due to the destruction of the victim's face by the criminal [36]. Thus, tattoos emerged as versatile forensic markers encompassing aspects of identity, medical treatment, behavioral history, cultural heritage, dermatological concerns etc. [11]. Specific tattoos linked to the personalized record of a person may be available to the law enforcement agencies that may help in recognition or identification of an individual. In absence of any medical history, tattoo marks may help the traditional healers or pathologists in uncovering the underlying illnesses associated with the individual.

The proper documentation of the location, style, type, pattern and other key features like names, dates or symbols of tattoos can help delve into the identity, lifestyle and cultural background of the deceased or the missing person. For instance, tattoos representing military insignias or motorcycle club symbols may showcase an individual's affiliation with such organizations. An occupational hazard tattoo may not have the same personal or cultural value as a consciously chosen or professional tattoo. Thus, understanding the mode of having tattoo marks is vital for assessing their forensic relevance and its impact on identity and the lifestyle of an individual [41]. Tattoos encapsulate a wealth of information crucial for identification, serving as a vital forensic tool that transcends the challenges posed by documentation gaps, geographical remoteness, and cultural intricacies in the identification of deceased individuals within the tribal population [42]. The forensic significance of tattoos and the associated features that provide identity clues can be summarized under following headings:

A) Suspect or victim identification

The law enforcement agencies routinely photograph and catalogue tattoo patterns to aid identification of the victims and convicts. Tattoos often can discern gang affiliations, religious beliefs, criminal records, and periods of incarceration. They can help in putative identification of the burnt, charred or decomposed bodies due to the fact that tattoo pigments are deeply ingrained in the dermal layers and are rarely obliterated even in these situations [43]. Tattoos have helped identify the tattooed people from crime scenes or natural catastrophes more accurately and efficiently [44, 45]. Tattoo recognition has emerged as adjunct tool in crime scene analysis, having multifaceted advantages for suspect identification, mapping subcultures, and facilitate identification of the deceased.

- **Suspect identification:** The identification of suspect based on description of tattoos given by eyewitness or the victim is possible. The witnesses' descriptions of tattoos during a crime can be matched against the tattoo marks database to enhance the suspect identification accuracy. The unique nature of tattoos allows for a clear distinction between individuals with similar names, especially in cases where false names or aliases have been provided by the suspect. [46] reported that identification can be done even without a crime scene photograph, using a local feature-based sparse representation technique that employs edge detection and Scale Invariant Feature Transform (SIFT) operators to compare the drawn sketches with a tattoo picture database available with investigating agencies.
- ***Gang and subculture mapping:*** The cultures, tribes, gangs, or even hate-groups affiliations of the suspect/s can be easily mapped-out using their tattoo marks which, in turn, can provide valuable insights into motives behind the crime or activities as specific crimes are limited to certain gangs or hate groups only [15].
- ***Alternate to traditional tattoos:*** For instance, the service personnel with military tattoos, ex-prisoners with rudimentary line tattoos, antisocial and anti-police sentiments, and illicit substance abusers with syringes, marijuana leaves, or mushrooms etc., usually reveal their identities. Moreover, Tribal people in India and around the world have unique tattoo designs, confirming their identity with a particular tribe [11].

B) Tattoos as soft biometric traits

Extracting unique tattoo properties can be used as soft biometric traits for identification and verification. Scars, marks, and tattoos (SMT) are also the soft biometric traits are characteristics that provide relevant identification information about an individual, though they lack the distinctiveness and permanence to sufficiently differentiate any two individuals.

C) Post-mortem identification

A doctor can better identify the deceased having tattoos in the mortuary [10]. Tattoos can serve as a distinguishing attribute to establish one's identity, and their distinct qualities can play a crucial role in identifying unidentified corpses. During autopsy, tattoos either provide clues about the identity of the deceased or work as a means of verifying an individual's identity. Accurate documentation of tattoos during autopsy is advisable, as they might offer valuable insights into the deceased person's identity. Tattoos are observable features that can be readily recorded during a post-mortem examination

and can be used for comparative identification only when accurate ante-mortem information about the deceased is available. The superimposition of ante-mortem and post-mortem photographs of tattoos can also serve as a method of identification.

Tattoos may also help identify an individual even in the later stages of decomposition as the ink pigments stay intact in the deep dermal layer. Due to deeper tissue inking, many professional tattoos retain their design and colors even after the outer dermis sloughs off. The degree of decomposition can have a substantial impact on the forensic examination of tattoos for identification. During the later phases of decomposition, the pigments of the tattoo may lose their intensity, and the contours can progressively lose their sharpness, resulting in challenges in identification from the tattoo marks [47]. However, in the immediate aftermath of death, the tattoo may undergo a process of becoming more distinct and vibrant. Comprehending the alterations that might take place in the pigments and patterns of tattoo ink in later decomposition stages is crucial for the identification of unidentified human remains.

D) Tattoos in missing persons cases

Tattoos may help in discovering and identifying the missing individuals in mass disasters, especially in identifying the unidentified corpses individuals by utilizing databases and doing visual comparisons. They may serve as an independent mean of identification, a supplementary material, or help strategize and provide priority to investigations. A tattoo database enables cross-referencing and probable identifications of missing individuals, unresolved murders, or unclaimed bodies. For instance, in Mexico, a proposal recommends to create a guide for categorizing tattoo motifs as a tool of identifying unidentified bodies, thus promoting the use of tattoos for identification. Researched have demonstrated that the distinctly tattooed body areas and the reasons behind them serve as a strong indicator of the significant role tattoos can play in identifying, particularly when letters and numerals are involved. Thus, tattoos function as significant indicators for identifying individuals who are missing or the unidentified bodies, assisting law enforcement and forensic authorities in their inquiries, and facilitating the process of providing closure to the relatives of the lost [35, 48].

E) Tattoo matching and database integration

An automated image-based tattoo recognition system (like the Tatt-E project) involves organizing and comparing tattoo databases to assist in identifying the missing individuals or unidentified corpses. Tattoo recognition systems undertake the task of segmentation, extraction and classification of tattoo images into clusters and use machine language algorithms to distinguish between tattoo patterns [49, 50]. Recent advances have also used CNN for developing a tattoo detection model. Such systems undertake to utilize specialized software technology to match the unknown tattoo found on the body of the unidentified individual against a database of tattoos to identify the unknown. The software may be presented with partial shots to match the entire collection of the database and allows VPN tattoo searches with suitable limits. It compares the "probe" image to potential matches for visual inspection, including magnification. The resultant tattoo thumbnails are displayed along with respective match percentages. The expert can then visually analyze the photographs to identify identical tattoos. The software works with controlled images that meet recognition standards. Identifying the correct match requires human intervention, even though it should be near the top. However, the development of such databases has

raised concerns about privacy and the potential for stereotyping individuals based on their tattoos [43, 45, 51]. Currently, the automatic methods for identifying tattoos can be classified into following categories:

Fully automatic tattoo image processing and retrieval system: This technique entails the identification of a specific region of skin within an image and the detection of many key points within that region. These key points are characterized by being discontinuous. The method additionally involves retrieving and preserving both the location information and at least one characteristic of the tattoo on the skin surface [43, 52].

Tattoo-ID: This system employs preprocessing methodologies, including edge-based operations and computations of gradient magnitude and direction, to segment the specific region of interest containing the tattoo. Subsequently, it employs picture characteristics and similarity metrics to compare the query tattoo with the tattoos in the database [43].

Tatt-E: The National Institute of Standards and Technology (NIST) is carrying out this study to evaluate and quantify the capabilities of systems to do automated tattoo recognition using images. The system assesses methods for the recognition of tattoos or regions of interest, the comparison of multiple occurrences of the same tattoo picture, and the search of a tattoo or sketch image against a central tattoo database, even when the image is not in the database [51].

CNN-based tattoo detection model: This approach employs a convolutional neural network (CNN) to identify tattoo photos that are stored in the information technology (IT) devices of individuals who are under suspicion. The Convolutional Neural Network (CNN) is trained using a dataset consisting of both tattoo and non-tattoo photographs. It demonstrates exceptional accuracy in identifying tattoo images [45].

F) Advancements in tattoo documentation and techniques

Technological improvements have improved the accuracy and precision of documenting tattoos in forensic and archaeological contexts, therefore adding to the evolving field of tattoo analysis and identification [53]. Latent evidence detection, high-resolution imagery, and three-dimensional mapping enhance forensic tattoo analysis by improving visualization, accuracy, and digital search. Forensic tattoo analysis has seen an increased utilization of high-resolution imagery and three-dimensional (3D) mapping techniques. The use of infrared photography and radiography has demonstrated enhanced tattoo visualization, thus assisting in the identification of tattoos for a range of forensic applications. In forensic pathology, 3D multispectral full-body imaging involves capturing realistic and detailed features (including tattoos) for forensic investigations wherein the tattoo details are captured in photorealistic photogrammetry data. This field is advancing by providing more accurate, thorough, and digitally available material for human identification and forensic investigations [53, 54].

2. Discussion

Tattoos represent a non-verbal way of expression of thoughts which may reflect the idea behind their inscription. Tattoo designs and motifs may be etched temporarily or permanently on the skin; the later ones are deep to the dermis and are difficult to remove. They contain huge information inscribed under the skin as messages, images or designs or patterns in different cultures and populations. Anthropologically, tattoo have been

explored to understand the cultural practices and social behaviours of the indigenous populations over time [55, 56]. Tattoos have served as a means of identification in both historical and contemporary settings. Historically, tattoos have been used for assessing the tribe or religious sect affiliations, rank or hierarchical status within a group framework, as identifiers of criminal history, political and religious beliefs, preferences, orientations and affiliations of the individuals [57]. Historically, they were used for slave branding or the criminal profiling as evidenced from ancient mummified corpses. Ancient Egyptian 11th dynasty court dance girls or concubines had tattoos, and archeological literary records suggest that the Scythians, Celts, Picts, and Germanic tribes were tattooed throughout early Europe. Forensically, these inked-markers can provide potentially useful information about the identity, region of origin, hobbies or sporting interests, medical or drug-abuse history, psychiatric illness, societal outburst, familial or gang affiliations, military service/occupation, important life-events etc., of an individual [11, 58, 59]. It is the unique nature of tattoos which make them distinctive forensic identifiers, alike to dermal ridge patterns. The permanent and region-specific nature of these markings help to trace origin, migration history and community affiliations. The advancements in imaging technologies have helped in generating individualized profiles for forensic identifications. The detailing, documenting, cataloguing and interpreting tattoo designs and patterns play a crucial role in forensic identifications, particularly in symbolizing the societal, behavioural, psychological, religious or criminal identity of both the living as well as deceased individuals [57, 58]. They also provide significant insights about the identity of decomposed, mummified, incinerated/charred, dismembered or otherwise unidentifiable human remains, particularly when the gold-standards of physiognomic features, fingerprints and the laboratory-based DNA technology fail to do so [58, 60]. The increased use of tattoos by the adolescent and young adults have necessitated their applications by the experts in medico-legal and forensic investigations for uncovering the truth in certain complex cases [59]. Utilization of tattoos for identification of illegal immigrants and the victims of human trafficking is a recent addition to the field, and a systematic and comprehensive global approach is needed to record and document tattoos, interpret and understand the message encoded within their designs and patterns and impact of such information on the course of forensic investigations [59].

Tattoos and criminally deviant behaviour have been found correlated among Italian soldiers and criminals. While establishing the role of anthropometry and fingerprints in identification of unknown individuals, Francis Galton and Alphonse Bertillon also recognized the importance of tattoo marks in identification [59]. Tattoos and the chemistry of tattoo inks have been acknowledged as secondary identifiers in forensic casework, scholarly research and the courtroom discussions as relevant, reliable evidence, at least to provide investigatory leads in identification strategies of missing persons. [59] emphasized that systematic interpretation and analysis of tattoos can make reveal the silent stories and/or life history of an individual.

3. Limitations and challenges

The challenges of using tattoos as a tool of identification faces several challenges due to modifications in the appearance of tattoos due to skin changes, subjectivity and personal perception, issues associated with the removal and alteration of tattoos over time, and the changing dynamics of cultures make it difficult to create a universal

identification system. The probable use of tattoos as a tool in forensic anthropology faces significant limitations owing to a lack of peer-reviewed literature, preventing the establishment of a robust knowledge base. Additionally, there is a lack of substantial forensic data regarding tribal tattoos as a mean of identification, hindering their potential application in forensic investigations. There is a lack of comprehensive research explicitly examining the use of tattoos for identification in forensic anthropology, which hinders the development of standardized methods and best practices. To address these gaps, further literature development is recommended, focusing on in-depth studies to understand the tattoo patterns and their cultural significance. Data collection through interviews is proposed to gather insights into the prevalence and characteristics of tattoos. Moreover, the creation of a centralized tattoo database is advocated, providing a valuable tool for healthcare professionals and law enforcement agencies in visual identification scenarios [47]. Overall, addressing these limitations is crucial for advancing our understanding of tattoos and enhancing their utility in forensic practices and cultural preservation.

Modifying tattoos and disguises might complicate the process of forensic identification. Skilled tattoo artists can conceal ancient tattoos by including layers, depth, intricate designs, and using darker ink. Nevertheless, these modifications have the potential to obscure or modify the initial tattoo, so complicating the process of identification. This hampers the task of law enforcement in documenting and identifying tattoo designs for forensic purposes.

In India, the utilization of tattoos for forensic purposes have serious legal and ethical concerns owing to the cultural significance attached to these inked patterns. Tribal tattoos have a strong connection to the cultural identity and societal customs of people in India and may represent various phases of life, marital status, social hierarchy, and tribal associations. Nonetheless, the utilization of tribal tattoos for the purpose of identification necessitates a cautious and respectful approach that acknowledges and appreciates their cultural value. Utilizing traditional tattoo symbols or designs for forensic purposes, without proper understanding or respect might constitute cultural appropriation, a notable ethical issue. It is crucial to carefully evaluate the legal and ethical issues to guarantee cultural sensitivity and appropriateness [9, 36, 61].

Therefore, it is a well-established fact that tattoo-based identifications face several challenges especially due to eyewitness error, visual and postmortem variability, and the dependence on image quality. Thus, suggesting that tattoo-based evidence should be treated as corroborative evidence rather than definitive one in the identification process. Eyewitness accounts of tattoos are highly prone to error due to cognitive biases and memory distortions. Any form of exposure to misinformation or co-witness discussion may potentially lead to memory conformity, where inaccurate details if incorporated in the recall may increase the chances of wrongful identification. This problem may amplify with the passage of time when the memory associated with the particular event starts fading. Verbal overshadowing can further impair the accuracy, as incorrect verbal descriptions may interfere with reliable visual identification. This issue is further enhanced by postmortem changes, which may potentially reduce the reliability of tattoos as identifiers. Postmortem changes such as decomposition, bloating, and skin slippage may distort or obscure the tattoo features, while antemortem factors like aging, scarring, fading and any modification in tattoos



may further lead to modification in its appearance. Besides, the accurate tattoo comparison is also dependent upon the image quality. In case of poor or distorted images retrieved from the crime scene or postmortem documentation, there is a higher possibility of limited means of human and automated analysis. Automated recognition systems face challenges due to variations in scale, lighting, and design diversity, while even trained examiners may struggle to interpret insufficient or low-quality visual data. Given these set of limitations discussed above in relation to tattoo-based evidence, it should be regarded as corroborative rather than acting as definitive evidence [35, 51, 62, 63, 64, 65].

A) Admissibility and legal weight of tattoo evidence

The legal admissibility and the probative value attached with tattoo-based identification is primarily dependent on the reliability of the method employed for observation, documentation, comparison and interpretation of tattoos, rather than being dependent solely on tattoos itself. This is in fact consistent with the principles governing expert testimony standards like Daubert, which emphasizes on the scientific reliability and validity of the methodologies employed by the experts for assessment of evidence in forensic contexts. Therefore, for determining the expert testimony in forensic evidence involving tattoos, the court must assess whether the testimony is the product of reliable principles and methods and the method employed for the assessment are reliably applied to the facts associated with the particular case or not. Therefore, this admissibility depends upon whether the method employed is testable, has undergone peer review and has known error rates or not. Moreover, it should always adhere to the established norms and standards and should be acceptable within the scientific community. Therefore, the experts, must clearly explain the methodology used and justify it through the means of conclusions drawn by them. Since, tattoos are often regarded as secondary identifiers in forensic investigations due to the persistence and informational values attached to it. Therefore, permanent tattoos can remain visible even during advanced stages of body decomposition, thereby, aiding the identification process in forensics. They are capable of relaying valuable individualistic information like ethnicity, occupation, affiliations or personal history, thereby furthering the forensic investigations. Furthermore, the inherent uniqueness of tattoo designs enhances their evidentiary values. Moreover, classification of tattoos into different types may offer contextual information regarding their origin and reliability. Furthermore, even in cases involving removal of tattoos, a residual trace amount of tattoo pigment may still be detectable using analytical techniques for assessment [36, 66]. To better understand the legal admissibility of tattoo based expert evidence, it is essential to examine how such evidence is evaluated under established legal frameworks, including the Frye standard, the Daubert standard, and the Federal Rule of Evidence 702, and to compare these with the provisions of the Bharatiya Sakshya Adhiniyam, 2023 [66, 67, 68, 69, 70 (sections 39–40)].

The Frye Standard bases the admissibility of expert evidence on whether the underlying methodology employed is generally accepted within the relevant framework of scientific community. In the case of tattoo-based evidence, courts evaluate whether techniques such as visual comparison, cultural interpretation of tattoos, or analysis of the altered tattoos are widely recognized by experts in fields like forensic anthropology or not. If the method undertaken is among the acceptable practices, it is likely that the evidence will be considered as admissible. However, Frye Standard may face

limitations due to exclusion of emerging and reliable techniques that may have not yet achieved widespread acceptance [67]. Daubert standard is another well-established legal framework existing for determining the admissibility of expert testimony. It requires the judges to act as gatekeepers, ensuring that expert testimony is both relevant and reliable by going beyond the general acceptance attached to it. Therefore, in context of tattoo-based evidence, courts evaluate the scientific methods employed such as the pigment analysis or image comparison based on factors such as testability, peer review, potential error rates, presence of standards and controls and general acceptance of the same in the scientific community. Following the Kumho Tire Co. v. Carmichael, these principles can also be applied to non-scientific or specialised expertise such as special tattoo expertise, associated with cultural or artistic interpretation of the same. But it must be well-reasoned and grounded in the established knowledge or existing experience. Furthermore, as affirmed in the General Electric Co. v. Joiner, decision associated with the admissibility of such expert evidence are subject to appellate review for abuse of discretion [68]. Federal Rule of Evidence 702, is another standard shaped by the Daubert framework based on the admissibility of expert testimony by necessitating it to be relevant, reliable, and helpful to the trier of fact. In context of tattoo evidence, courts are tasked with determining whether the expert's knowledge aids in the understanding of issue such as identification or affiliation in this case. Also, whether the opinion is based on sufficient facts or data and relies on reliable principle and methods for its assessment. The expert must also demonstrate that these methods have been applied reliably to the specific case. Emphasis is placed on clear reasoning, methodological soundness, and avoiding overstatements of certainty, particularly where subjective interpretation is involved [66]. Therefore, Daubert/Rule 702 suggests that the fate of tattoo-based evidence in federal or many state courts is dependent on the reliability of the methodology employed by the experts in terms of its scientific, technical and specialized appeal, especially when backed by sound reasoning and proper application to the facts related to the case. While states still adhering to the Frye standard focus on the general acceptability of the methodology employed within the relevant field. [36, 66, 67, 68].

In the Indian context, under the Bharatiya Sakshya Adhiniyam (2023), tattoo-based expert opinion is admissible as relevant evidence under section 39 and 40. While section 39 recognizes the relevance of expert opinions in specialized fields, such as forensic tattoo analysis, Section 40 ensures that the facts and methodologies responsible for forming such opinions should also be relevant. However, such evidence remains corroborative in nature and must be evaluated alongside other supporting evidence [69, 70].

Therefore, within the hierarchy of forensic identifiers, tattoo evidence occupies a valuable but secondary position relative to primary identifiers such as DNA, fingerprints, and dental records. Unlike the biologically inherent or high individualized markers part of an individual's identity, tattoos as acquired features serves as a useful tool due to its evidential strength in distinctive design, placement, combination, and persistence overtime. Hence, tattoos may be considered as corroborative or supportive identifier that can significantly aid the identification process especially when primary methods are unavailable or compromised [18].

4. Recommendations and a Way Forward

This section offers scope and suggestions to ensure the development tattoo database for forensic identification purposes. The tattoo patterns and designs associated with certain age, sex,

ethnicity, social groups, criminal gangs should be identified to aid in putative identifications. The first and the foremost fundamental task is photographic documentation of the tattoo details such as size, color, and location by the forensic experts. The creation of a centralized tattoo database including comprehensive information and metadata from the biometric analysis, 3D scanning technology, and microscopic examination will enhance the precision of the identification process by quantifying the tattoo features and providing a 3D understanding of the same. Furthermore, ink composition analysis and UV and infrared imaging may unveil the hidden details about the age and origin of tattoos. Tattoo recognition software powered by machine learning algorithms can accelerate the comparison and matching process if all the methodologies mentioned above are incorporated into a single software. Pattern recognition algorithms contribute to effective categorization based on recurring themes or motifs. Collaboration with various stakeholders such as forensic anthropologists, cultural experts, and law enforcement may lay the foundation for a much more robust and accurate forensic identification. Specialized training programs may be developed for forensic experts especially focusing on the interpretation of tattoos in post-mortem analysis.

The national legal systems should recognize the relevance of tattoos as allied evidence in criminal investigations. The inclusion of tattoo marks as a soft biometric tool in national identifier database like UDAI Aadhar may enhance the accuracy and uniqueness of the personal identification process, though careful measures should be adopted before the inclusion of tattoos as a secondary source of biometric identification as it may raise some privacy concerns. Furthermore, implementing and maintaining such a system can be a tedious task and requires accurate capturing and verification of tattoo marks that may pose a technical challenge for integration into the official identification system The study of tattooed remains by forensic anthropologists should be conducted in an ethical and culturally sensitive manner. Efforts must be made to develop an integrative and comprehensive forensic anthropological module that emphasizes the study of tattooing and other secondary identifiers. Hands-on workshops and seminars may provide a practical training platform allowing professionals to enhance their skills in dealing with tattooed remains. The legal professionals, law enforcement, and policymakers should be sensitized about the importance of tattoo analysis in victim identification. Training programs and workshops can be organized to familiarize legal personnel with the use of tattoo evidence in forensic investigations. Additionally, the development of guidelines and protocols for the documentation and analysis of tattoos in medico-legal contexts is essential to ensure standard practices across legal institutions.

5. Conclusions

Tattoos encapsulate a wealth of information that can help in the identification of unknown deceased individuals. The increased use of tattoos by the younger generation has necessitated their use in medico-legal death investigations, particularly in complex cases where the primary methods like dentition and fingerprints fail to provide any clue about the identity of an unknown individual. Tattoos have been acknowledged as secondary identifiers in forensic casework, scholarly research and the courtroom proceedings as relevant and reliable evidences, at least for providing some investigatory leads in the identification strategies. It is the intricate and permanent nature of tattoos which make them withstand trauma and damage,

thus useful in forensically challenged situations like decomposed or partially burnt bodies. The proper documentation of the location, style, type, pattern and other key features of these inked-markers can be valuable adjunct in providing information about the identity, geolocality, lifestyle, cultural affinity, medical or drug-abuse history, psychiatric illness, societal status, familial or gang affiliations, military service/occupation, important life-events etc., of an individual. A comprehensive database of the unique patterns, designs, motifs, inks, symbols etc. of tattoo marks used by the individuals of different regions and cultures can help in developing an automated tattoo recognition system for reliable identification of the missing individuals or unidentified corpses.

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