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Chalcolithic Tattooing: Historical and Experimental Evaluation of the Tyrolean Iceman's Body Markings

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The Tyrolean ice mummy known as Ötzi presents some of the earliest direct evidence of tattooing in the human past. Despite decades of study, it remains unclear how the Iceman's tattoos were created and what tools and methods were used. Popular discussions of the Iceman describe his tattoos as having been made by incision, first cutting the skin and then rubbing in pigment from the surface. The authors review the scholarly literature on the Iceman's tattoos and summarize ethnographic, historic, and anthropological research on global patterns of tattooing to contextualize the Iceman's marks within pre-electric tattooing traditions. The results of recent experimental tattooing studies are then compared to the physical signature of the Iceman's marks to evaluate existing claims and provide informed hypotheses as to how those tattoos were created.

Keywords: tattoo, Iceman, Chalcolithic, experimental archaeology, Tyrol, Ötzi

The partially preserved remains and possessions of the Tyrolean Iceman, popularly known as Ötzi, were discovered melting from the ice of the Hauslabjoch Pass in the Ötzal Alps in September 1991. This individual died in *c.* 3200 BC during the European Copper Age and is perhaps the most extensively studied ancient human. Over the past three decades, detailed scientific examinations have produced an extraordinary body of scholarship regarding his health, diet, environment, clothing, toolkit, genetic profile, and the circumstances surrounding his death (e.g. Höpfel et al., 1992; Spindler, 1994; Acs, 2005; Oeggl et al., 2007; Gostner et al., 2011; Maixner et al., 2013; Wierer et al., 2018; Junkmanns et al., 2019; Wang et al., 2023).

Among his various attributes, the Iceman exhibits some of the world's oldest preserved tattoos, consisting of sixty-one carbon pigment marks on his abdomen, lower back, lower legs, and left wrist (Samadelli et al., 2015; Deter-Wolf et al., 2016) (Figure 1). Since their discovery, the Iceman's tattoos have generated both public and scholarly interest and discussion. They have featured in exhibitions, documentaries, and been the subject of performance art and blockchain digital files, while academic

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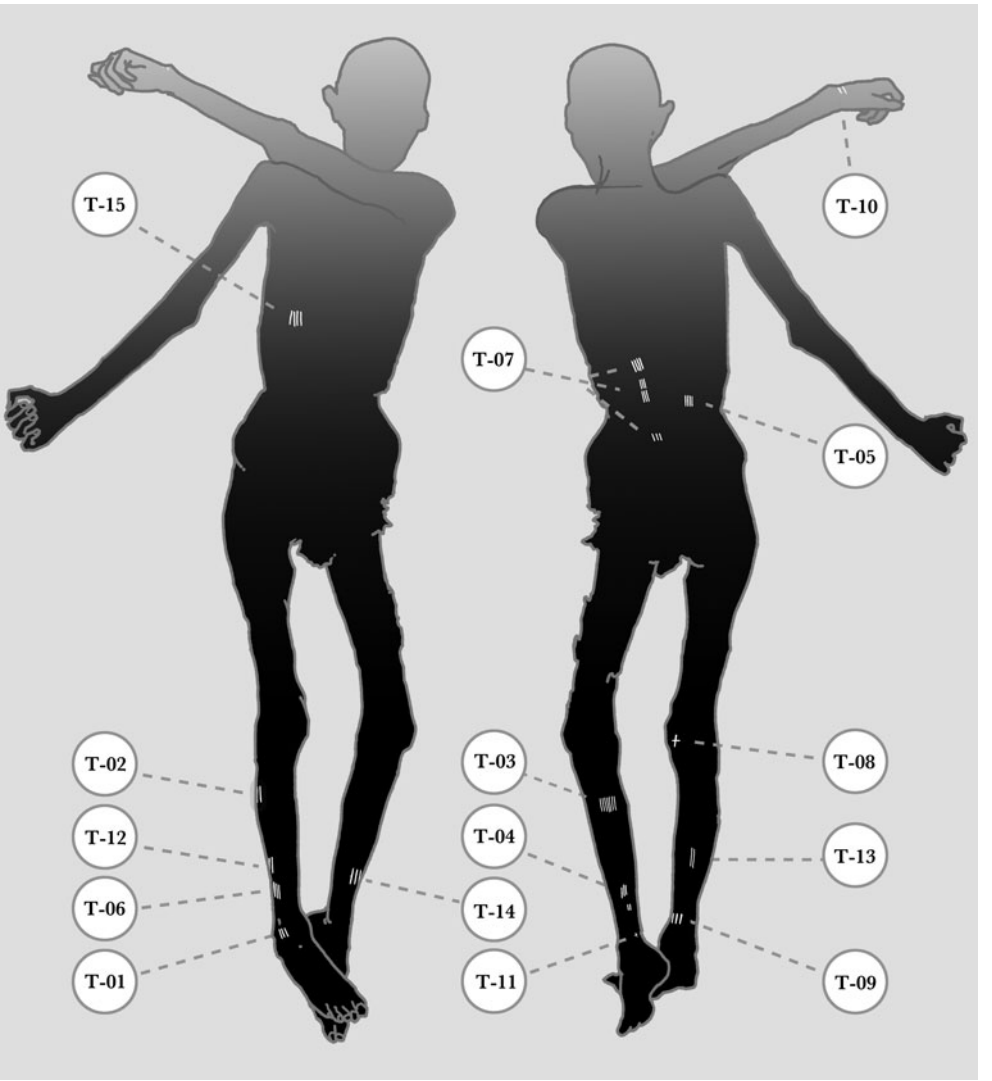

Figure 1. *Locations of tattoos on the Iceman's body (after Samadelli et al., 2015: fig. 1).* Adapted with permission of the South Tyrol Museum of Archaeology.

studies have employed advanced imaging and analytical techniques to catalogue the marks and investigate their microscopic structure (e.g. Gaber et al., 1995; Sjøvold et al., 1995; van der Velden et al., 1995; Pabst et al., 2009; Samadelli et al., 2015). Despite this scrutiny, details regarding the tools and techniques used to tattoo the Iceman remain unclear. Although scholarly sources remain ambiguous as to the specifics of their creation, nearly all popular discussions over the last decade describe the marks as being incised, made by cutting lines into the skin followed by rubbing pigment into the wounds.

This article reviews the literature on the Iceman's tattoos, including how and why they were created. The hypotheses advanced in such research are examined in the context of ethnographic, historical, and anthropological data on the distribution of early modern tattooing tools and

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techniques. The Iceman's marks are then compared with the results of a recent experimental study examining the physical characteristics of tattoos created with different pre-electric tools and methods (Deter-Wolf et al., 2022). The data allow us to conclude that the Iceman's tattoos were not incised but are likely to have been created with a single-point puncture tool.

The Iceman's Tattoos

The Iceman's sixty-one tattoos consist of nineteen groups of parallel or intersecting linear marks. Each group includes between two and seven lines, 7–40 mm long, and predominantly aligned to the long axis of the body (see Samadelli et al., 2015: tab. 1). Exceptions to that orientation include two parallel lines placed across the left wrist and sets of crossed lines on the right knee and left ankle (Figure 1). Individual marks measure between 1 and 3 mm wide, with parallel lines situated 20 to 80 mm apart (Samadelli et al., 2015: tab. 1). This discussion employs the designations T-01 to T-15 established by Marco Samadelli and colleagues (2015) to reference the position of tattooed lines on the Iceman's body. Location T-04 includes five lines arranged in two separate groups, while T-07 consists of fourteen lines in four separate groups.

These permanent marks are significant for understanding the history of human body decoration, being among the oldest preserved tattoos so far identified in the archaeological record (Deter-Wolf et al., 2016). Radiocarbon dating of the Iceman's physical remains, possessions, and associated environmental materials confirm that he died around 3370–3100 cal BC (see Bonani et al., 1994; Prinoth-Fornwagner & Niklaus, 1994; Rom et al., 1999). Such a date is roughly contemporaneous with examples of directly dated tattooed individuals from Predynastic Egypt, albeit with a maximum age that slightly predates the early calibrated Egyptian ranges (3351 and 3341 cal BC; Friedman et al., 2018).

In September 1991, as the corpse was freed from the ice, observers noted clusters of dark marks along his lower spine that were initially thought to be lashes or brands (Spindler, 1994; Gaber, 1995). Torstein Sjøvold (1992) subsequently published the first description of marks on the lumbar region, left calf, right knee, and right ankle, tentatively identifying them as tattoos, albeit with a cautionary note encouraging further study. Parallel lines on the Iceman's left wrist (T-10) were thought to be rope marks associated with garment fastening. The following year, Luigi Capasso (1993: 179) described the marks on the lumbar region and legs as being 'almost certainly' tattoos.

Initial infrared imaging (Gaber et al., 1995; Sjøvold et al., 1995; Sjøvold, 2003) identified additional tattoos in the lower lumbar region and both legs, thereby increasing the recorded total to fifty-seven individual marks in fourteen groups. Investigators concluded that, based on their position, at least some of the tattoos must have been applied by another individual (Gaber et al., 1995). Although the parallel lines on the left wrist (T-10) were also determined to be tattoos, those continued to be identified as pressure marks in some sources (e.g. Sjøvold, 2003; Kean et al., 2013).

Three of the Iceman's tattoos were biopsied in 1992 for direct examination with a scanning electron microscope (van der Velden et al., 1995). That study noted a complete absence of the epidermis in all three samples. Homogeneous soot particles observed between collagen and dermal fibres were identified as remnants of tattoo pigment (van der Velden et al., 1995: 276).

Further direct studies by Pabst and colleagues (2009) examined thin section samples of three tattoos using multiple techniques including optical microscopes, bright

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field transmission electron microscopy, energy dispersive X-ray spectroscopy, electron energy loss spectrometry, energy filtering transmission electron microscopy, and electron diffraction. These investigations confirmed that the Iceman's epidermis was mostly absent and reported that pigments deposited within connective tissue included particles of soot and fine ash. In some samples, these particles were interspersed with small quartz and possible almandine crystals that are likely to have come from the hearthstones where the carbon was collected (Pabst et al., 2009: 2338).

In 2015, Samadelli and colleagues employed digital imaging technology augmented with multispectral filters and image processing software to produce a complete catalogue of the Iceman's marks (Samadelli et al., 2015) (Figure 2). This resulted in the identification of a final group of four parallel lines tattooed on the Iceman's lower rib cage (T-15). The report provided final measurements for all tattoos, further confirmed the identification of carbon pigment, and established a standard reference system.

Suggestions for Tattoo Function

Due to their schematic nature and placement on the body, the Iceman's tattoos have led to speculation regarding their intended purpose and to the idea that they

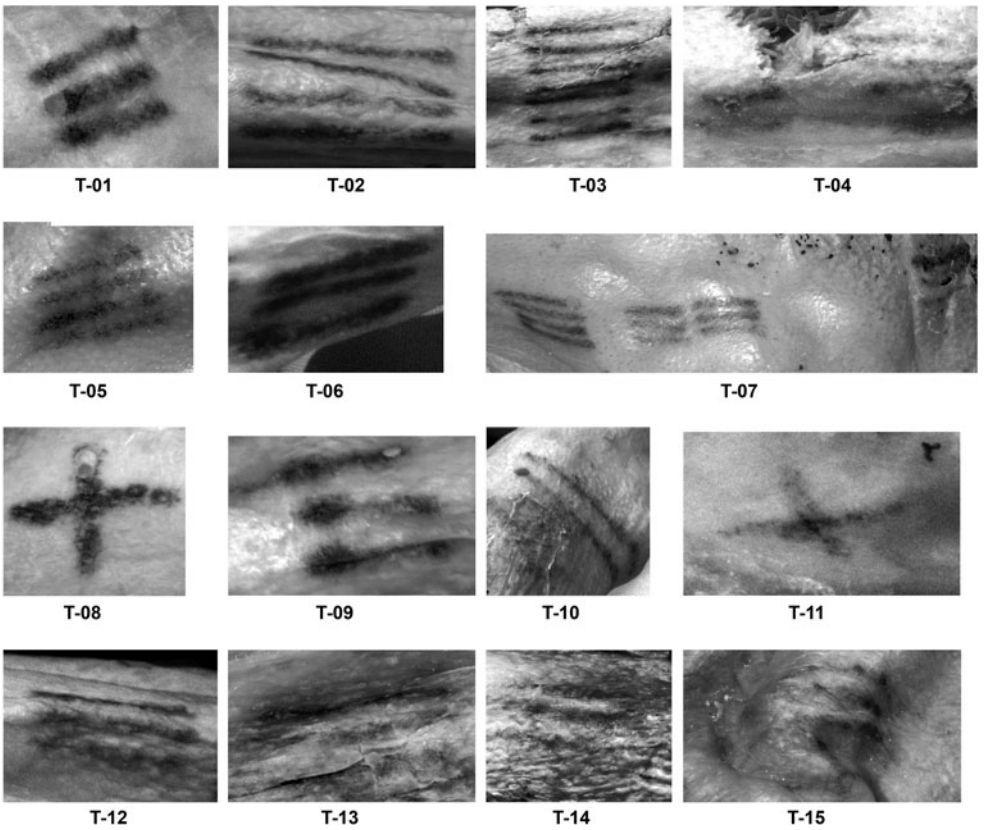

Figure 2. *Details of the Iceman's sixty-one carbon pigment tattoos (after Samadelli et al., 2015: fig. 2).* © South Tyrol Museum of Archaeology/Eurac/Samadelli/Staschitz. Reproduced by permission of the South Tyrol Museum of Archaeology.

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primarily had a medicinal or therapeutic function. Several decades before the Iceman's discovery, Sergei Rudenko (1970: 112) proposed that dots tattooed on the spine and ankle of the man from the Iron Age Kurgan 2 at Pazyryk in the Siberian Altai mountains were not decorative, but had 'a therapeutic aim, to counteract pains in this area'. The comparable position of several of the Iceman's tattoos prompted initial suggestions of a similar therapeutic nature (Capasso, 1993: 180–81; Gaber et al., 1995: 349–53). This hypothesis fully entered the Iceman's narrative following the identification of arthritis and other ailments close to some tattoos, as well as studies asserting that the tattoo locations corresponded with traditional acupuncture meridians (e.g. zur Nedden & Wicke, 1992; Sjøvold et al., 1995; Dorfer et al., 1998, 1999; Bahr et al., 2015; Zink et al., 2019; see also Renaut, 2004a). Further suggestions of a therapeutic function are based on comparative cross-cultural evidence (Krutak, 2013, 2019; Piombino-Mascali & Krutak, 2020), and anecdotal results of experimental efforts (Krutak, 2014a).

Other lines of evidence used to identify the Iceman's tattoos as primarily medicinal or therapeutic are rooted in an assumption that they are 'non-decorative' (Kean et al., 2013: 14) and do not hold symbolic value (Capasso, 1993; Dorfer et al., 1999). According to Capasso (1993: 179), the position of the Iceman's marks on areas of the body that could be covered by clothing, and therefore their lack of permanent visibility, 'would exclude a "communicative" function'. It is an interpretive fallacy to assume that tattoos in either the past or present must be publicly displayed to be culturally or symbolically significant; for example, the intricate iconography tattooed on the shoulders, legs, and arms of Iron Age mummies from the Siberian Altai (e.g. Pankova, 2017) unquestionably held symbolic value, and yet, like the Iceman's marks, they were covered by clothing depending on the time of year and social setting.

Another argument for the Iceman's tattoos lacking symbolic value hinges on their perceived simplicity (e.g. Capasso, 1993; Dorfer et al., 1999). Capasso (1993: 179–80) writes: 'The pigmented marks on the skin are geometric, without curved segments, are simple, and contain neither anthropomorphic nor zoomorphic motifs. This allows us to rule out an ornamental function for the tattoos.' The importance of visual symbols in ancient and non-western societies is not contingent on their legibility to outside observers. Further, the cultural value of traditional tattooing extends beyond iconography and is also rooted in aspects of immaterial culture such as status, gender, lineage, community identity, and belief system(s). All these aspects combine to transmit culturally coded information that may relate to the marked individual's age, achievements, social and/or spiritual status, group affiliation, and connection to spiritual forces (e.g. Krutak, 2007). For example, simple straight lines traditionally tattooed horizontally across an Inuit woman's fingers were not considered representational to early European ethnographers (Figure 3). Interviews with living Inuit culture members in Canada and Greenland nevertheless reveal that, prior to forced acculturation, these tattoos centred women's bodies within a complex immaterial framework invoking the origin story of the ocean spirit Sassuma Arnaa, and acted as persistent reminders as to the importance of maintaining cultural taboos (Jacobsen, 2024).

Despite a correlation between the location of some of the Iceman's tattoos and diagnosed health conditions, it seems unreasonable to assume that the tattooing practice was entirely of therapeutic or medicinal intent. Of the nineteen recorded

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Figure 3. *Inussakkut Kakiornerit, horizontal lines tattooed on Inuit women's fingers. The lines vary in number and placement according to territory and invoke the origin of the sea spirit Sassuma Arnaa, the Woman of the Deep. Photograph by Maya Sialuk Jacobsen*

groupings of tattoos on the Iceman's body, just nine are located on or close to traditional acupuncture points (Dorfer et al., 1999; see Renaut, 2004a), while only seven groups (T-05, T-07, T-08, T-15) are positioned at the locations of diagnosed injuries or ailments (Figure 4). Most of the Iceman's tattoos are not situated at the sites of clearly identified pathologies, and some locations of diagnosed health problems are not tattooed (Nystrom & Piombino-Mascali, 2017; Nystrom, 2019; Zink et al., 2019). We should therefore consider that the function of the Iceman's tattoos was not limited simply to curative practices.

Proposed Tattooing Techniques

Initial interpretations as to how the Iceman was tattooed drew primarily on Renate Rolle's (1992) theories of body marking traditions among the Iron Age Pazyryk culture. Specifically, Rolle suggested that the dots on the spine of the man from Pazyryk Kurgan 2 were the result of cauterization or branding practices analogous to Tibetan folk medicine. Capasso (1993: 179) subsequently proposed a connection with that hypothesis, writing that the Iceman's marks were produced 'by scarifying or cauterizing the skin, and impregnating it, either simultaneously or immediately after, with powdered vegetable carbon'. He later claimed unequivocally that the tattoos 'were produced by making multiple parallel or intersecting linear incisions with a scalpel, filling the incisions with a mixture of herbs, and lighting the herbs' (Capasso 1998: 1864). Konrad Spindler (1994) proposed a similar technique, involving a heated branding iron that was loaded with herbs at the tip and applied to the skin. No physical data presented to date indicate that the Iceman's tattoos were created by branding or through the ignition of plant matter on or within the skin. Further, Luc Renaut (2004a) has demonstrated that Rolle's referenced Tibetan practice does not actually involve the combustion of materials on the skin and does not result in visible scars or tattoos.

Other claims as to the possible tools and methods used to create the Iceman's tattoos have been more circumspect. Spindler (1994: 169) noted that bone awls, such as the one the Iceman carried, might have been suitable for tattooing (Figure 5) but discounted the possibility that this specific tool was used, as 'self-tattooing is practised only in very exceptional situations'. Van der Velden and colleagues (1995) also reiterated that the specific method was unknown but suggested that pigment was rubbed on the skin before or after puncture tattooing. Sjøvold (2003: 119) similarly stated that there was 'no conclusive evidence' as to how the tattoos were created, while hypothesizing that thickening at the ends of some lines might result from incision:

> 'Several of the tattooed lines show enlarged pigmentation at both ends, which could point to cutting the skin

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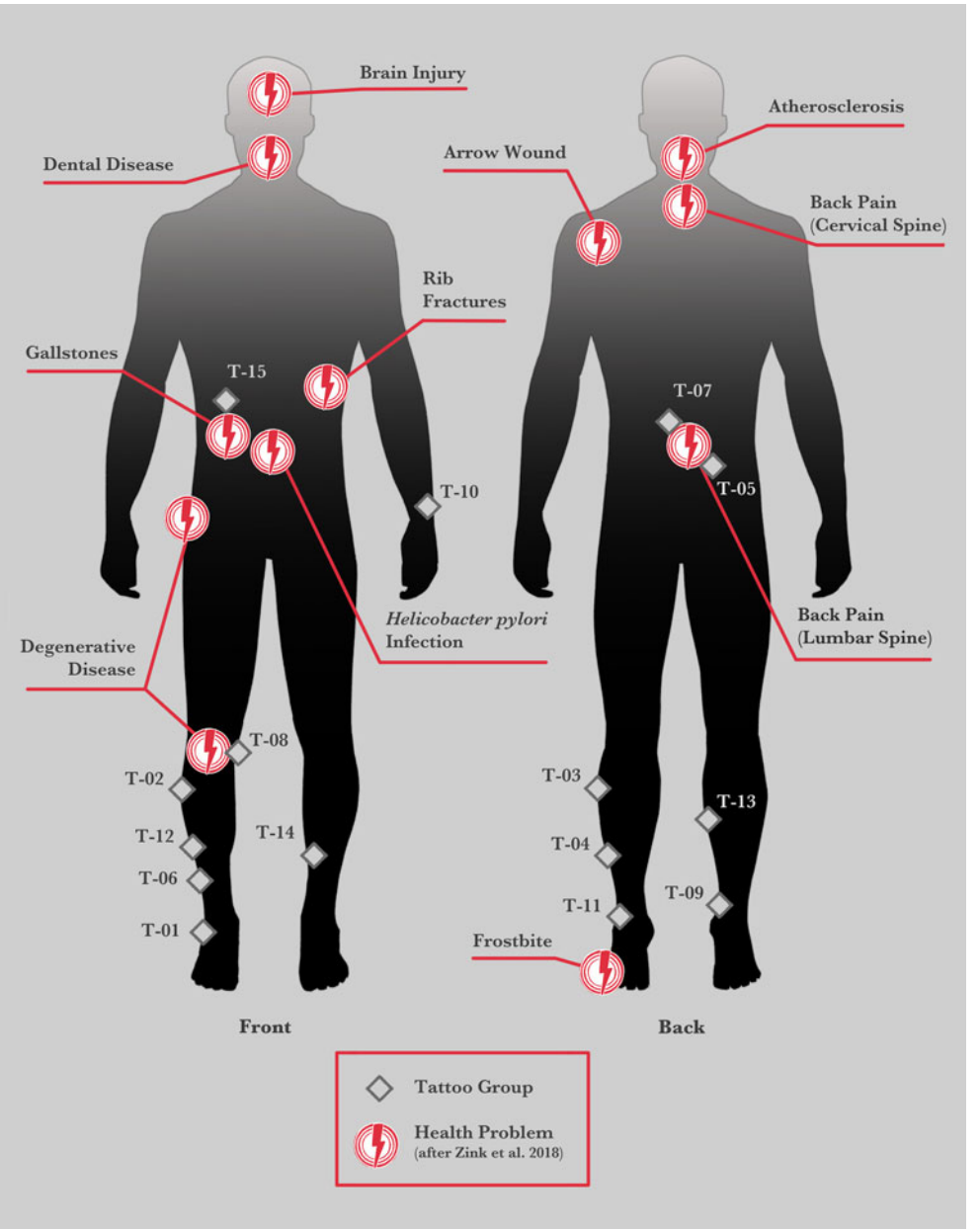

Figure 4. *A comparison of the Iceman's tattoo locations to sites of diagnosed health issues.*

and rubbing the pigmentation into the cut. On the other hand, inspection of some of the Iceman's tattoos with a microscope … revealed that the pigmentation is distributed in patches, pointing to the possible use of a tattooing needle.' (Sjøvold, 2003: 120)

Recent discussions remain cautious as to the method by which the Iceman was tattooed (e.g. Piombino-Mascali & Krutak, 2020). Nevertheless, most popular media sources state unequivocally that his marks were created by incising the skin (e.g. Lobell & Powell, 2013; Angler,

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Figure 5. *Sharpened bone awl from the Iceman's toolkit.* © Harald Wisthaler (www.wisthaler.com) adapted and reproduced by permission of the South Tyrol Museum of Archaeology.

2016; Holloway, 2017; Collins, 2018; McQuaid, 2021; Diamond, 2023). These claims appear to draw directly from the web page of the South Tyrol Museum of Archaeology (https://www.iceman.it/en/the-mummy/), which states: 'Unlike modern tattoos, they were not made with a needle; they were fine incisions into which pulverised charcoal was rubbed.' Information returned for a search of the Iceman Database hosted at that same site (https://www.iceman.it/en/database/) is more ambiguous: 'In contrast to today, where tattoos are performed with a machine, Ötzi's skin was stuck or scratched with a bone needle or a flint blade and soot was rubbed in.'

Ethnographic and Historical Evidence

Human cultures across the globe have used various techniques and tools to permanently insert pigments beneath the skin. Since the mid-nineteenth century, historical, ethnographic, anthropological, and archaeological data have been mustered in efforts to classify and map these variations at a global scale (e.g. Magitot, 1881; Roth, 1900; Brilot, 2003; Robitaille, 2015; Robitaille et al., 2024) (Figure 6). Following those studies, the methods of deliberate tattooing shared across human cultures may be broadly grouped into two main categories: puncture tattooing and tattooing by incision.

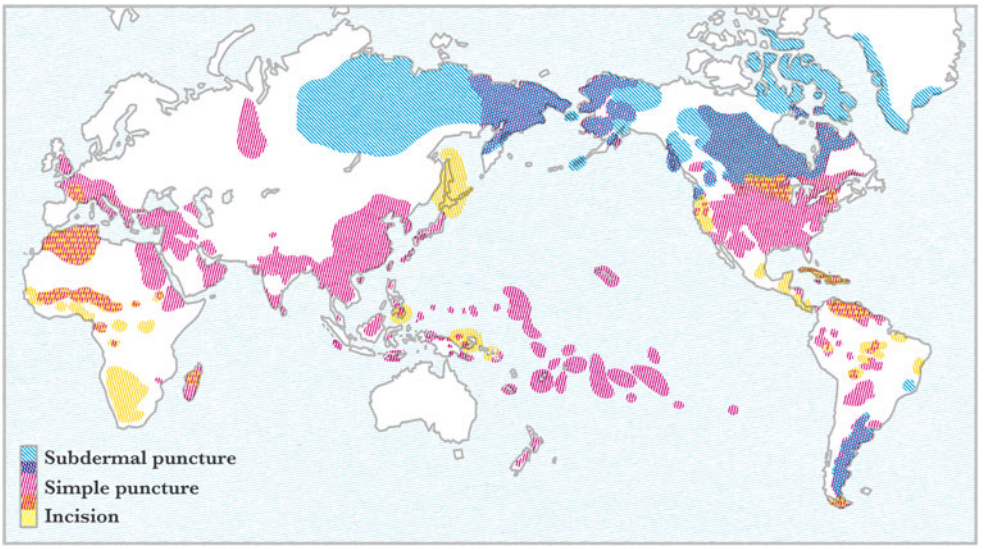

Figure 6. *Map showing generalized global distribution patterns of tattooing techniques, based on ethnographic and historical data (after Robitaille et al., 2024: fig. 1).* Image by Benoît Robitaille.

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In puncture tattooing, the skin is pierced using a hafted or unhafted single-point tool or group of points. Pigment is carried into the skin on the apical end of the point(s), and/or rubbed in from the surface following puncture. The tools used in puncture tattooing may be divided into four general, morphological categories: 1) pointed implements held directly in the hand; 2) straight-hafted points secured to the end of a handle; 3) tools with one or more points hafted at an angle to the handle and applied using percussive force; and 4) subdermal tattooing tools. Categories 1 and 2 are colloquially known by modern English speakers as 'hand-poke' or 'stick-and-poke' tattooing. Category 3 is today known as 'hand tapping', while Category 4 includes the method popularly called 'skin stitching'.

Traditional unhafted and straight-hafted puncture (hand-poke) tattooing tools include, but are not limited to, metal needles, plant thorns, fish teeth, sharpened bone tools, and lithic implements (Video S1). This method is the most frequently encountered form of traditional tattooing and has been used by cultures on all continents except Australia and Antarctica (Robitaille, 2015; Robitaille et al., 2024) (see Figure 6). Conversely, perpendicularly hafted (hand tapping) tattooing tools are closely tied to people speaking Austronesian languages and appear within a limited geographic area circumscribing Oceania, insular Southeast Asia, pockets of mainland Southeast Asia, and the adjacent Himalayan slope (Robitaille, 2007) (Figure 7, Video S2).

Subdermal tattooing involves the passage of an awl or eyed needle horizontally through the skin to create paired, adjacent wounds (Deter-Wolf et al., 2022) (Video S3). Pigment is introduced along the same channel via ink-soaked thread or sinew pulled behind the needle, or is pushed through on the tip of a secondary implement such as a wooden awl. Inuit

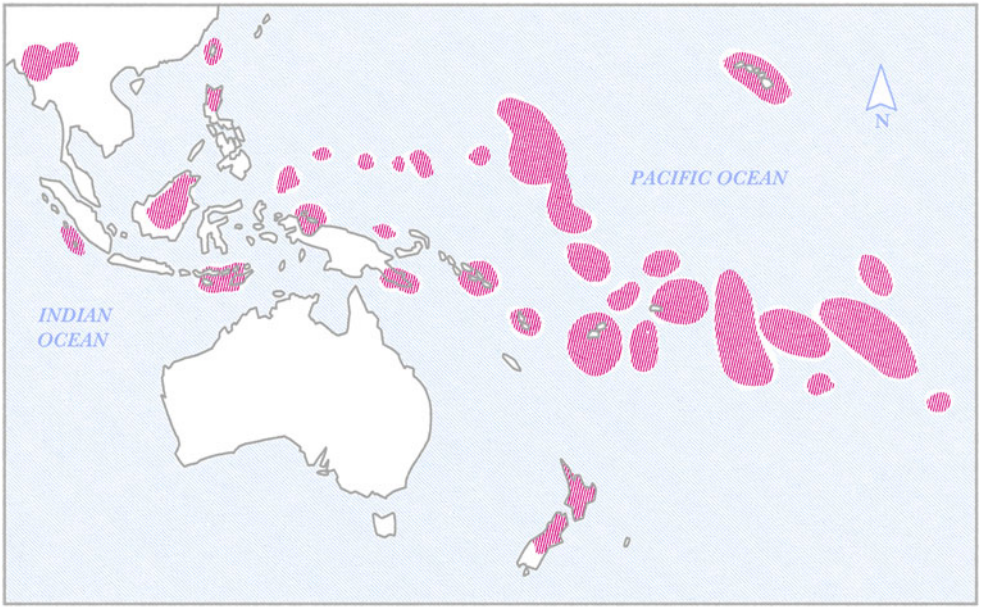

Figure 7. *Map showing the global distribution of perpendicularly hafted (hand tapping) puncture tattooing (after Robitaille, 2007: fig. 2).* Image by Benoît Robitaille.

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knowledge systems attest to a deep history of subdermal tattooing in the circumpolar region, while the practice also appears among several subarctic groups in North America's Pacific Northwest, in Brazil, and the southern reaches of South America (Robitaille et al., 2024) (see Figure 6).

Incised tattoos are produced by slicing the skin with a sharp cutting instrument that frequently consists of a metal blade or lithic tool (Video S4). Because tools used for incision tattooing are typically non-porous and therefore poor pigment carriers, this technique relies on pigments being rubbed into a wound from the surface. Some historical examples of incised tattooing involve continuous, linear incisions (e.g. in Central America: Ximénez, 1999), while others employ short, sequential cuts (e.g. in Japan: Kodama, 1970). Incision tattooing occurs on all continents except Antarctica and Australia, but is markedly rarer than puncture tattooing (Robitaille, 2015; Robitaille et al., 2024).

Today, tattooing is part of the popular vision of European antiquity and is associated with groups such as the protohistoric Picts, Celts, and medieval Norse. There is, however, no unequivocal historical or archaeological evidence apart from the Iceman demonstrating that the practice existed north of the Alps before the late Middle Ages (Dibon-Smith, 1989; Renaut, 2004a, 2004b; Lodder, 2022). Early historical sources, although of questionable reliability, uniformly describe puncture tattooing (e.g. Herodian, *Historiarum* Book 3: 14.7; Isidore of Seville, *Etymologiæ* 19.23.7; William of Malmesbury, *Gesta Regum Anglorum*, Rolls Series edition: 305).

Some of the earliest reliable records of tattooed European bodies describe devotional marks received in the Holy Land during the fifteenth to seventeenth centuries, where they were applied by puncture with unhafted metal needles (e.g. Terry, 1665; Maundrell, 1707). From the sixteenth century onwards almost all tattooing in Europe, as well as in western Asia and the Near East, was undertaken with handheld or straight-hafted puncture tools (e.g. Smeaton, 1937; Chenciner et al., 2006; Taşğın & Mollica, 2016; Guerzoni, 2018; Dauge-Roth, 2020).

The exception to historical European puncture tattooing is the occurrence of incised tattoos in nineteenth-century France, where the practice was apparently tied to the criminal class (e.g. Charrière, 1969; Pierrat & Guillon, 2004) and does not seem to have had deep historical roots. Rather, the period and cultural setting may indicate connections between the florescence of tattooing in Biribi penal colonies of French colonial Africa (Cooper, 2018) and the adoption of incised tattooing from indigenous traditions in Morocco, Algeria, and Tunisia (e.g. Roth, 1905; Giacobetti, 1916).

The only historical description of tattooing we have identified from the region surrounding the Iceman dates to AD 1751. In that account, the German historian Johann Keyßler (1751: 40) wrote that parents in the Tyrol used either a needle or the point of a knife to give identifying marks to children who were sent to work in the mines or salt works. After the skin was marked, black pigment was rubbed into the surface. Although Keyßler's brief account includes mention of a knife, the description ('*stechen ihnen mit einer Nadel oder mit einem spißigen Messer viele Puncte*'; 'they pierce them with many points with a needle or with a pointed knife') indicates puncture tattooing rather than incision.

Experimental Data

In 2021–2022, Deter-Wolf, Riday, and Jacobsen conducted an experimental study designed to investigate physical differences between tattoos created with different

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methods and tools (Deter-Wolf et al., 2022). Danny Riday, a professional tattooist specializing in both hand-poke and incision tattooing, tattooed himself with identical patterns using a variety of tools and techniques. Among these tests, an eyed bone needle was used for subdermal tattooing, the tip of an obsidian flake was used for puncture tattooing, and a separate obsidian flake was used for incising tattoos. Single-point copper and bone awls were used for hand-poke puncture tattooing. The tattoos were then documented with a digital microscope over six months to examine the healing process and compare specific physical characteristics of the healed tattoos.

The experiment demonstrated that tattoos created with different tools and techniques exhibit distinctive physical traits (Deter-Wolf et al., 2022). For example, lines tattooed by puncture using a bone awl have irregular edges and some internal separation due to the varying proximity of individual wounds. Those created with a copper awl had sharper edges as compared to those made by hand poking with either bone or obsidian tools, while also exhibiting some internal separation. The ends of lines tattooed by hand poking with both copper and bone tools were generally rounded and of uniform thickness, while puncture tattooing with an obsidian flake resulted in irregular line edges due to the shape of the tool tip. Incised tattoos exhibit firm, clear margins, and distinctive tailing at one or both ends of individual lines.

Digital images and data from the experimental tattooing were compared to published imagery of the Iceman's tattoos (e.g. Samadelli et al., 2015), to natural light and ultraviolet images from the Iceman Photoscan webpage of the EURAC Institute for Mummy Studies (http://www.icemanphotoscan.eu/), and to high-resolution digital images provided by the South Tyrol Museum of Archaeology (Figure 8). We further compared the Iceman's marks with incised tattoos created professionally by Riday in 2022 that duplicate the size and position of tattoo group T-09 on the Iceman (Figure 8D). When comparing the preserved marks with experimental results, particular attention was given to line ends and edges, internal stippling, and indications of line interruptions.

Discussion

The Iceman's skin, and potentially his tattoos, had undergone various taphonomic processes and so may not be directly comparable with the results of experimental tattooing on fresh human skin. Nevertheless, when combined with historical and ethnographic data, the results of the experimental study provide important information for assessing how the Iceman's tattoos may have been applied.

Based on ethnographic and historical evidence that informs the current understanding of global distribution patterns of tattooing methods (Robitaille, 2015; Robitaille et al., 2024), we may discount any suggestion that the Iceman's tattoos were applied using perpendicularly hafted tools. The hand tapping method is sometimes viewed by the public as synonymous with ancient tattooing. However, no historical or archaeological data demonstrate that this technique existed outside Oceania and Southeast Asia prior to the spread of traditional tattooing techniques during late twentieth-century globalization (see Figure 7).

Although eyed bone needles were present in western and southern European assemblages by the Solutrean period (*c.* 23–26 ka BP; d'Errico et al., 2018), no historical or archaeological evidence demonstrates the presence of subdermal tattooing in central Europe. The nearest historically documented examples of this practice to

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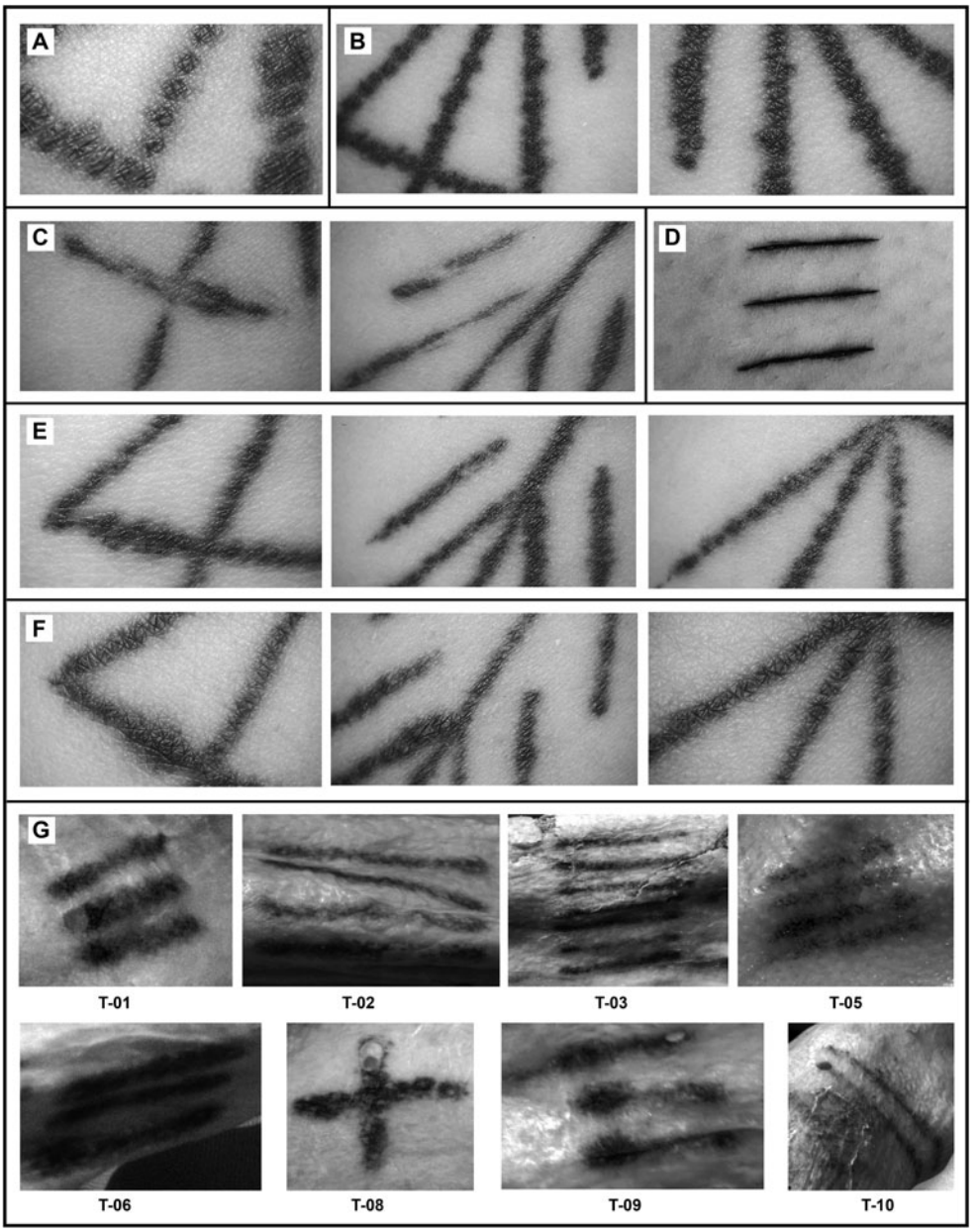

Figure 8. *Comparison of experimental and preserved tattoos. A) subdermal tattoos created using an eyed bone needle and thread (after Deter-Wolf et al., 2022); B) puncture with an obsidian flake tip; C) short lines incised with an obsidian flake; D) continuous lines incised with an obsidian flake; E) puncture with a bone awl; F) puncture with a copper awl; G) details of selected tattoos on the Iceman (after Samadelli et al., 2015: fig. 2).* G: Reproduced by permission of the South Tyrol Museum of Archaeology.

the Iceman are over 5000 km distant and 5000 years more recent, among the Evenk in northern Asia (Gmelin, 1767) and the Inuit in eastern Greenland (Holm, 1972). In our 2022 experimental study, subdermal tattooing using an eyed

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bone needle and thread resulted in lines of variable width, with internal separations between some entry and exit points (Figure 8A). These characteristics are not replicated in the Iceman's tattoos (see Figures 2 and 8G).

Since the early twentieth century, various flint tools from European archaeological collections have been intuitively identified as possible puncture tattooing implements (e.g. Girod & Massenat, 1900; Cheynier, 1931) (Figure 9). Our study suggests that the Iceman was not tattooed in this manner. Unlike bone or copper awls, the tips of lithic tools are not rounded and may exhibit dramatic angle changes due to flake removal. The shapes of individual punctures made with these tools match the forensic definition of stab wounds, in that they mirror the cross-section of the working tip (Figure 10A, B). Variations in the placement of lithic punctures relative to one another and changes in the angle and orientation at which the tool is held therefore result in tattooed lines with highly irregular edges (see Figure 8B). These traits do not match the Iceman's tattoos, which, although they exhibit some variation, have generally even widths (see Figures 2 and 8).

Traditional societies throughout the world, including the Americas, Melanesia, and Africa, employed lithic tools and metal blades for incision tattooing (Robitaille, 2015). Wherever available, there appears to be a preference for obsidian over other lithic materials (e.g. Kodama, 1970; Krutak, 2014b). No obsidian has been identified from archaeological contexts in the Alps (Williams-Thorpe, 1995; Freund, 2018), although the copper used to manufacture the Iceman's axe demonstrates a measure of access to southern trade routes that overlap with obsidian distribution networks (Artioli et al., 2017). The Iceman's possessions included various flint tools, among them a small flake that, while suitable for incision tattooing, does not exhibit use-wear or residues consistent with the practice (Wierer et al., 2018).

The results of our experimental study, further supported by forensic sharp force injury data, indicate that the Iceman's tattoos were not created by incision. Incised tattoos created during experimental studies exhibit maximum widths of less than 1 mm, tailing at one or both ends, and clean margins (Figure 8C and D). These characteristics are not a result of the skill or technique of the individual tattooist, but conform to established forensic traits for incision wounds. As opposed to stabbing/puncture wounds, incision sharp force injuries are created when an edged object is drawn through tissue parallel, or at an acute angle, to the skin surface (Vij, 2014; Prahlow, 2022). This results in wounds with clean margins, an absence of tissue bridging, and (contrary to Sjøvold, 2003) thinning at one or both ends due to differential tissue contraction (see Figure 10C). None of the traits described above are present in the Iceman's marks, which are 1–3 mm wide, have irregular line edges, and exhibit rounded rather than tapered ends (see Figures 2 and 8G).

The physical structure of the Iceman's tattoos, including stippling, line widths, rounded ends, and diffusion of pigment along the edges are all strongly evocative of puncture tattooing using a single-point hand-poke tool. Of the implements tested during our experimental study, the Iceman's marks compare most favourably with tattoos created using a bone point (Figure 8E) or copper awl (Figure 8F). Sharpened bone tools including awls and needles were a standard part of Copper Age material culture, as attested by artefacts carried in the Iceman's belt pack (see Figure 5). Although the bone awl he carried appears to be sharp enough for use in tattooing, as potentially does the antler tine from his quiver, no study to date has examined microwear or residues on those tools.

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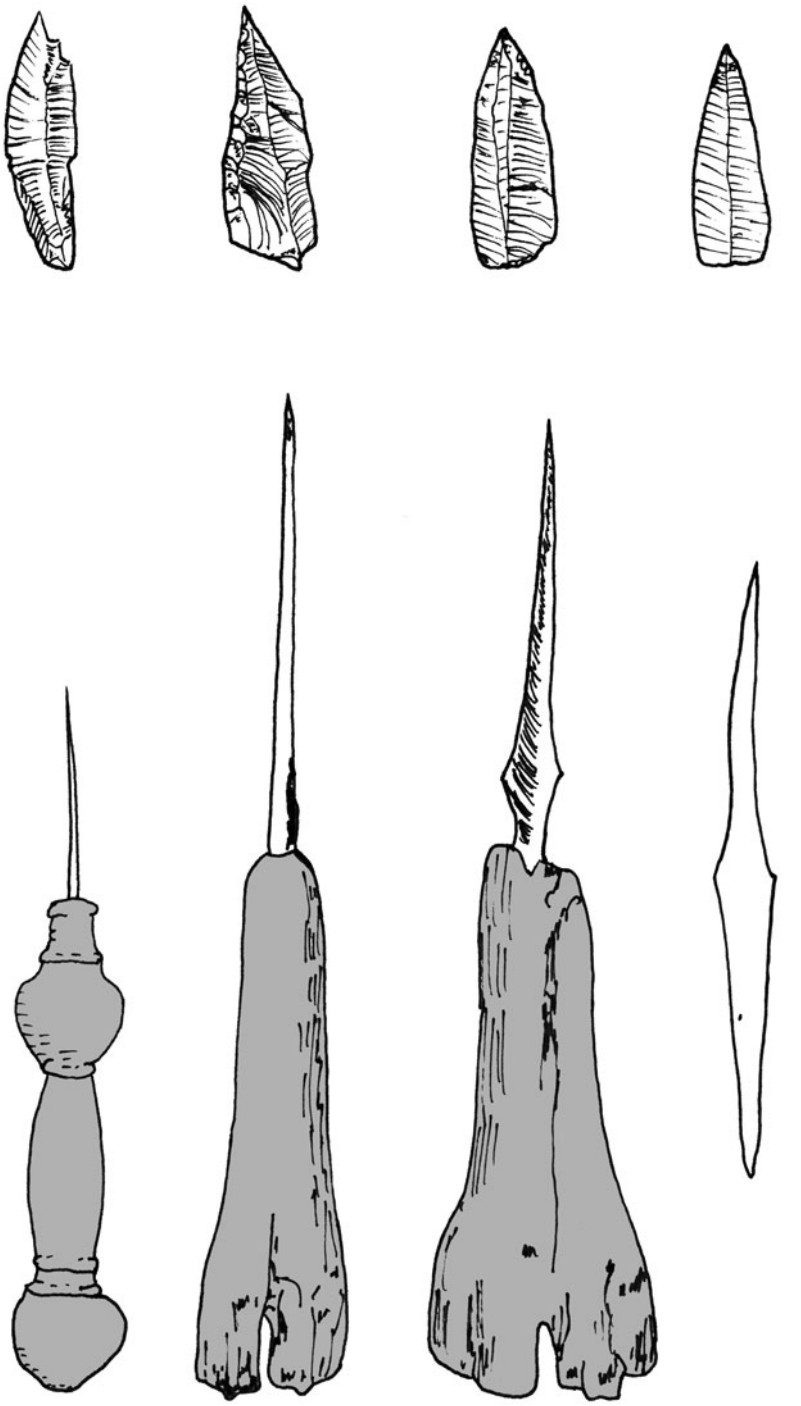

Figure 9. *Examples of identified but unconfirmed tattooing tools from the European archaeological record. Top row: lithic* 'pointes à piquer' *(after Cheynier 1931: 487). Bottom row:* 'alènes pour tatouage (âge du bronze)' *(after Déchelette 1907: fig. 4). Not to scale.* Re-drawn and adapted by A. Deter-Wolf.

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Figure 10. *Forensic diagram of sharp force injuries. A and B: stab or puncture wounds are created when a sharp object is pushed through tissue at an angle generally perpendicular to the skin. The shape of the wound mirrors the object's tip (A: bevelled; B: rounded). C: incised or cut wounds are created when an object with a sharp edge or tip is drawn through the skin at an acute angle to the surface. These wounds are thinner at the end(s) due to differential tissue contraction (adapted with additions from Prahlow, 2022). Not to scale.*

Copper or copper alloy awls represent some of the earliest forms of metalwork, and evidence of smelting copper ore and manufacturing cast copper objects in the northern Alps dates to the latter half of the fifth millennium BC (Roberts, 2009). While the timing and origin(s) of metallurgy south of the Alps remain contentious, the practice was well established in northern and central Italy several centuries before the Iceman's demise (Dolfini, 2013; van Willigen, 2017). Axeheads and awls are among the most common copper artefacts identified south and west of the Alps before the Italian Early Chalcolithic (*c.* 4700–3600 BC). Samuel van Willigen (2017: fig. 1) identifies some fifty-three copper objects dating to this period recovered from an area including parts of modern-day Slovenia, Austria, Italy, and France. That corpus includes sixteen awls (thirteen from Italy and three from France), all dated to *c.* 4300–3800 BC. Most were recovered from domestic sites, although by the Early/Middle Chalcolithic transition (*c.* 3600 BC) some Italian examples begin to appear in funerary contexts (van Willigen, 2017: 922, 925).

Copper awls are typically interpreted as having been used for tasks including leatherworking, basketmaking, working shell, decorating pottery, and pressure flaking (Pearce, 2000). Unhafted and hafted metal awls from the European archaeological record have also been identified as potential tattooing implements (e.g. Müller, 1897; Déchelette, 1907; Willroth, 1997) (see Figure 9). Copper and copper alloy points are certainly capable of piercing the skin for tattooing, although no direct evidence supporting that function has been mustered for any specific artefact. The identification of these tools as tattooing implements instead relies almost entirely on chains of citations combined with references to historical source materials that significantly postdate the period(s) in question (Deter-Wolf & Gillreath Brown, 2023; see Renaut, 2004b).

Conclusions

The Iceman's tattoos provide the only direct evidence to date of permanent body marking practices in the European Copper Age. Those marks nevertheless reveal the presence of an established tattooing tradition within alpine communities of the era (Deter-Wolf et al., 2016; Zink et al., 2019). In this study, we used comparative historical data and the results of experimental tattooing to evaluate the possible methods and tools of Chalcolithic tattooing in central Europe. This comparative approach carries important caveats, as direct evidence of early tattooing methods in the region is extremely limited, with the earliest reliable accounts postdating the Copper Age by millennia. Additionally, physical comparisons between the Iceman's marks and the results of experimental tattooing are based on healed tattoos observed on living, intact skin. The Iceman's epidermis is mostly, or entirely, absent, and the

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potential for taphonomic changes to his tattoos following millennia of exposure to ice is unknown. Nevertheless, this effort provides compelling evidence as to the tattooing method likely employed in the European Copper Age.

Although scholars remain generally ambivalent as to the method and tool(s) used to make the Iceman's sixty-one carbon pigment marks, public understanding appears to have settled on the tattoos being incised into his skin. Our study shows that the Iceman's tattoos were not created by incision, by subdermal methods, or with perpendicularly hafted puncture implements. Instead, the physical characteristics of the preserved marks suggest that they were tattooed with a single-point puncture tool. These findings are consistent with historical data, as well as current understandings of the geographic distribution of pre-electric tattooing methods. Bone and copper awls, as well as other artefacts suitable for puncture tattooing, appear throughout the regional archaeological record. While no tattooing implements have yet been conclusively identified in Copper Age assemblages, we hope that our findings will inspire informed investigations of potential tattooing artefacts, including use-wear and residue analyses, that may further inform our understanding of Chalcolithic tattooing traditions in central Europe.

Supplementary Material

To view supplementary material for this article, please visit https://doi.org/10.1017/eaa.2024.5.

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Le tatouage au Chalcolithique : évaluation historique et expérimentale des marques sur le corps de « l'homme des glaces » du Tyrol

Le corps de l'homme conservé par le glacier de l'Ötztal, surnommé Ötzi, présente parmi les plus anciennes preuves de tatouage dans l'histoire de l'humanité. Cependant, malgré des décennies de recherches, la méthode de tatouage et les instruments utilisés pour tatouer Ötzi restent incertains. On présume que ces tatouages avaient été incisés, donc produit par une entaille dans laquelle on frottait ensuite un pigment. Les auteurs de cet article passent en revue les publications sur le tatouage de l'homme des glaces et font le point sur les études ethnographiques, historiques et anthropologiques concernant le tatouage à l'échelle mondiale dans le but de contextualiser les marques découvertes sur Ötzi avant l'avènement du tatouage électrique. Ils comparent les résultats obtenus par expérimentation aux traces relevées sur les tatouages anciens afin d'évaluer les théories en vigueur et de formuler des hypothèses valables sur la réalisation du tatouage de l'homme des glaces. Translation by Madeleine Hummler

Mots clés: tatouage, homme des glaces, Chalcolithique, archéologie expérimentale, Tyrol, Ötzi

Kupferzeitliche Tätowierung: eine historische und experimentelle Auswertung der Markierungen auf dem Körper des tirolischen „Mannes im Eis"

Die im Tirol entdeckte Gletschermumie, auch „Mann im Eis" oder „Ötzi" genannt, gehört zu den ältesten Beweisen der Tätowierungskunst der Menschheit. Trotz jahrzehntelange Untersuchungen bleiben die Verfahren und die Geräte, die bei der Tätowierungen von Ötzi benutzt wurden, weitgehend unbekannt. Man hat angenommen, dass seine Tätowierungen eingeschnitten wurden, also dass die Haut zuerst geschnitten wurde und dann ein Pigment eingerieben wurde. Die Verfasser besprechen die wissenschaftlichenVeröffentlichungen, die Ötzis Tätowierungen betreffen, und fassen die Ergebnisse von ethnografischen, historischen und anthropologischen Studien über globale Tendenzen in der Tätowierungskunst zusammen, um die Markierungen auf dem Körper der Mumie im Rahmen der vor-elektrischen Tätowierungstraditionen zu kontextualisieren. Sie vergleichen die Ergebnisse von neuen experimentalen Studien mit den erhaltenen Tätowierungen, bewerten bestehende Aussagen und formulieren informierte Hypothesen über die Erzeugung der Tätowierungen der Gletschermumie. Translation by Madeleine Hummler

Stichworte: Tätowierung, Mann im Eis, Kupferzeit, experimentelle Archäologie, Tyrol, Ötzi