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The origin and evolution of sewing technologies in Eurasia and North America

Francesco d'Errico [a, b, *], Luc Doyon [a, c], Shuangquan Zhang [d, e], Malvina Baumann [a], Martina Lázničková-Galetová [f, g], Xing Gao [d, e], Fuyou Chen [d, e], Yue Zhang [d, e, **]

[a] Centre National de la Recherche Scientifique, UMR 5199 - PACEA, Université de Bordeaux, Bât. B18, Allée Geoffroy Saint Hilaire, CS 50023, 33615 Pessac Cedex, France

[b] SSF Centre for Early Sapiens Behavior (SapienCe), University of Bergen, Øysteinsgate 3, Postboks 7805, 5020, Bergen, Norway

[c] Institute of Cultural Heritage, Shandong University, 27 Shanda Nanlu, Jinan 250100, China

[d] Key Laboratory of Vertebrate Evolution and Human Origins, Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences, 142 Xizhimenwai Street, Beijing 100044, China

[e] CAS Center for Excellence in Life and Paleoenvironment, 142 Xizhimenwai Street, Beijing 100044, China

[f] Institut Anthropos, Moravian Museum, Zelný Trh 6, 65937 Brno, Czech Republic

[g] Hrdlicka Museum of Man, Faculty of Science Charles University, Prague, Viničná 1594/7, 12800 Praha, Czech Republic

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ABSTRACT

When, how, and following which paths hominins created the innovations that allowed them to colonize regions of the planet that were not suited to their thermal physiology is still a matter of inquiry. In this paper, we elaborate a theoretical framework to investigate the origin and diversification of bone needles, summarize the evidence for their emergence, create a large database of their morphometric and stylistic characters, and present results of the study of an exceptionally well-preserved collection of needles from Shuidonggou Locality 12 (SDG12), a site located in the Ningxia Hui Autonomous Region, Northern China, dated to ca. 11.2 ka BP. Bone needles are reported from 271 sites and 355 archaeological layers. Revision of the evidence shows they represent an original cultural innovation that emerged in Eurasia between 45–40 ka BP. Size differences between the earliest known specimens, found in Siberia and China, indicate needles may have been invented independently in these two regions. Needles from Eastern Europe may represent either an independent invention or a geographic extension of earlier Siberian and Caucasian sewing traditions. In Western Europe, needles appear during the Solutrean. The wider size range characteristic of Magdalenian specimens supports the idea that needles of different sizes were used in a variety of tasks. In China, the robust sub-circular needles found at sites dated between 35–25 ka BP are followed, between 26–23 ka BP, by small flat needles, which may represent an innovation associated with the microblades/microcores toolkit. At SDG12, technological, functional, and morphometric analyses of finished needles and manufacturing by-products identify two previously undetected reduction sequences for the production of needles of different size and, probably, function. The bone needles found at Paleoindian sites are the smallest and reflect a never previously achieved mastery in the production of such tools.

1. Introduction

Clothing has allowed members of our genus to colonize regions of the planet not suited to their thermal physiology, cope with climate change, and elaborate means for communicating social and individual identity. However, when, how, and following which paths hominins created the suite of innovations that led to the variety of dresses known historically and to modern fashion remains a matter of inquiry. The phylogeny of human lice suggests the split between head lice, *Pediculus humanus capitis*, and body lice, *P. humanus humanus*, which live on clothing, occurred between 80,000 and 170,000 years ago, most probably between 80,000 and 100,000 years ago (Light and Reed, 2009; Toups et al., 2011; Allen

* Corresponding author.
** Corresponding author.
E-mail addresses: francesco.derrico@u-bordeaux.fr (F. d'Errico), zhangyue@ivpp.ac.cn (Y. Zhang).

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et al., 2013; Boyd et al., 2017). This speciation event indicates some human populations manufactured and used clothes on a regular basis well before 80,000 years ago. Direct archaeological evidence for early clothing is, however, elusive. The discovery in the middle latitudes of Eurasia of hominin sites dated to the Early and Middle Pleistocene, and in some instances attributed to cold phases and associated with cold-adapted taxa, suggests these populations must have used devices to cover their body in order to secure thermal insulation (Gilligan, 2010, 2017). Use wear studies have identified consistent evidence for hide scraping at the 400 ka BP site of Hoxne, England (Keeley, 1980), at the 380 ka BP site of Qesem Cave, Israel (Lemorini et al., 2015), at the 300 ka BP site of Schöningen, Germany (Rots et al., 2015), at the MIS6 site of Biâche-Saint-Vaast, France (Beyries, 1988), and at a number of Mousterian sites such as La Guba, Nosovo I (Plisson, 1998), and Weasel Cave, Russia (Kimball et al., 2017), Lichtenberg (Viel et al., 1994), and Sesselfelsgrotte, Germany (Rots, 2009), Axlor, Spain (Lazuén and González-Urquijo, 2015), Corbiac, Pech de l'Azé I and IV, Combe Grenal (Anderson-Gerfaud, 1990), and La Folie, France (Bourguignon et al., 2006). These case studies suggest the technology necessary to process hide, probably for clothing, was apparently available to Eurasian and Near Eastern hominins well before the phylogenetic split between head and body lice. Bone "smoothers", consisting of ribs and long bone fragments bearing a polished and rounded edge possibly resulting from use to process soft organic material, are signalled at Schöningen (Julien et al., 2015) and Pech-de-l'Azé I (Soressi et al., 2013). Lithic and bone tools which may have been used for tailoring, such as lithic borers and bone awls, are however very rare in Middle Paleolithic and Middle Stone Age assemblages. Retouched lithic borers rarely account for more than 2% in Mousterian toolkits (Bordes, 1953; Dibble, 1988; Kuhn, 1995; Mellars, 1996). Only two Middle Stone Age sites, Blombos Cave and Sibudu, South Africa, have yielded delicate bone awls suitable for piercing skins, in layers dated, respectively, to ca. 76–71 and 65–61 ka BP (Henshilwood et al., 2001; d'Errico et al., 2012a). Use wear on these bone tools is consistent with this interpretation. The earliest known bone awls from Eurasia, including thin pins, come from the Châtelperronian levels of Grotte du Renne, Arcy-sur-Cure, France dated to 45–42 ka BP, and are associated with Neanderthal remains, and from the Initial Upper Paleolithic level of Denisova Cave, Russia, dated between 48–37 ka BP (Derevianko, 2010). Use wear analysis of the Châtelperronian tools has shown they were intensively used to pierce soft materials, likely hides (d'Errico et al., 2003). Bone awls become a common feature of the Eurasian Upper Paleolithic toolkit after 42 ka BP (Camps-Fabrer et al., 1990; Güleç et al., 2002; Hoffecker, 2005; Bietti and Negrino, 2008; Bodu and Mevel, 2008; Langlais et al., 2010; Gurioli et al., 2011; Yanevich, 2014).

Eyed needles made of bone, ivory, and antler, appear at only a handful of Eurasian sites dated to the end of MIS3 and became widespread with the Last Glacial Maximum, hereafter LGM (see below). This specialized tool is generally considered to be the most obvious archaeological proxy for the manufacture of clothing since it allows both the creation of perforations and the passing of a thread through them. However, ethnographic data indicate eyed needles of different shape and size are involved in different tasks (Wilder, 1976; Bird and Beeck, 1980; Lyman, 2015). Populations living in challenging environments used different needles to manufacture complex clothing, i.e., garments shaped to fit closely to the body and involving the sewing of multiple layers to grant protection from wind chill. Needles also play a role in fixing adornments, embroidery, appliqué, and the production of bags and tents (Gilligan, 2010; Lyman, 2015). Morphometric analysis of Magdalenian eyed needles from the eponymous site of La Madeleine, Dordogne, France, has shown that their diameter was determined by the action of embroidering *Dentalium* sp. shells on clothes (Vanhaeren and d'Errico, 2001).

Little effort has been spent to document the first stages of this fundamental cultural innovation and develop a theoretical framework to assess its origin and guide the interpretation of the morphological and technological variability in needles. The aim of this paper is to create such a framework, and use it to critically evaluate what is known about when and where bone needles were invented for the first time, establish whether this technology spread by cultural diffusion or was reinvented at multiple times and places, document their morphological and size variability through the Pleistocene of Eurasia and North America, and identify evolutionary trends and the causes behind them. The inclusion of sites from North America is justified by the fact that they are contemporaneous with many occurrences of Late Pleistocene needles from Eurasia, including the Chinese collection analysed in detail here, and in all likelihood, represent a technology brought to the New World by Asian immigrants.

Assessing the origin of a cultural innovation is a notoriously tricky endeavour in Paleolithic archaeology. This is more so for needles as the earliest instances seem to appear in the archaeological record in a time frame at the very limit of ^{14}C dating applicability. This dating method is clearly not suitable to precisely establish the age of a cultural event nor to follow the spread of an innovation occurring at the very beginning of the Upper Paleolithic. Since needles are, like personal ornaments, small artefacts prone to post-depositional displacement, isolated occurrences do not necessarily imply, without robust contextual supporting evidence, that their use at the site corresponds to the age of the archaeological layer in which they were found. In known hunter-gatherer societies using bone needles, each user owns a case containing a number of them (Hatt and Taylor, 1969; VanStone, 1989). Each lot is periodically rejuvenated following fracture of the eye, non-repairable breakage of the tip, or accidental loss. One may expect that if needles were used by a Paleolithic group, residential sites containing evidence of prolonged occupation should yield at least a few specimens. In light of the above, reliable evidence for the emergence of this innovation should be represented by the discovery of several specimens, preferably at several sites from the same region, in well-preserved layers containing similar material culture and yielding comparable ^{14}C ages. Ideally, the recovered needles should share a degree of similarity in their technology, shape, dimensions, and traces of utilisation.

Adoption of this innovation by diffusion could in some circumstances be distinguished from independent invention. The former should entail a detectable continuity in technology, morphology, and dimensions ideally associated with a consistent geographic expansion and a coherent time lag. The latter would be possibly signalled by differences in technology, shape, size, and traces of utilisation between needles found at sites from distinct regions, attributed to different cultural traditions, and for which the limitation of radiocarbon dating cannot, in and of itself, explain the time lag between the occupations.

In regions in which needle use is attested over a long period, variability in technology, shape, size, and use wear can be caused by raw material and species availability, cultural drift, population replacement, cultural influence, and diversification of, or shift in, function. Change in raw material and species availability is difficult to assess from the needles alone because these artefacts are highly modified and can be produced with bone from mammals and birds of very different sizes. Identifying this cause of change requires the discovery of manufacturing by-products bearing diagnostic anatomical features. If cultural drift is responsible for the observed changes, one would expect to identify gradual trends, in both time and space, in morphology and technology rather than in size and use wear (Binford, 1963; Koerper and Stickel, 1980). In contrast, we assume population replacement would likely result in drastic changes in needle manufacture, morphology, or use, associated with marked novelties in the remainder of the material culture. Cultural influence would be likely reflected by changes in morphology and size, i.e., style, and would not, or only marginally, affect technology and use wear. Shift in function entails identifiable changes in use wear associated with possible changes in size and morphology. Functional diversification may lead either to the creation of needle types significantly distinct in use wear, size, morphology, and possibly technology, or to an increased range of variation in all these aspects corresponding to a variety of tasks, e.g., adornment, embroidery, appliqué, and sewing different types of clothes, bags or tents.

In this paper, we apply these interpretive guidelines to a large dataset of needles to trace back the origin of this artefact and explore the reasons behind its variability between 45 and 10 ka BP. Morphometric comparison of Paleolithic specimens from Eurasian and North American sites identifies evolutionary trends with large needles followed by a diversification in size suggesting the development of more specialized activities starting with the LGM. We accompany this analysis with the study of a collection from the key Chinese Tardiglacial site of Shuidonggou Locality 12 (SDG12). This is the only collection from East Asia that comprises well-preserved bone needles and manufacturing by-products. Technological, morphometric, and functional analysis of this material identifies two previously undetected reduction sequences for the production of needles of different size and morphology, which is interpreted in the light of our theoretical framework as an instance of functional diversification.

2. Materials and methods

2.1. The Pleistocene needle database

Building on the seminal work of Stordeur-Yedid (1979), a database of Eurasian and North American Pleistocene sites that have yielded osseous needles was created. It consists of two datasets, one gathering contextual (Supplementary Online Information [SOM] -Table S1) and the other morphometric information (see Morphometric analysis). The first dataset records the name of the site, the region and the country, and, when available, the layer in which the needle was found, the broad and specific cultural attribution of the archaeological context, the number of specimens, the presence of manufacturing by-products, and the references.

2.2. Shuidonggou Locality 12 (SDG12) needles

Archaeological context SDG12 is an open-air site located 3 km south-east from the famous Shuidonggou Locality 1, a site found and investigated in the 1920s by Licent and Teilhard de Chardin (1925). Located on the second terrace of the Biangou River bank (Ningxia Hui Autonomous Region, Northern China) (Liu et al., 2008; Pei et al., 2012; Yi et al., 2013; Peng et al., 2018), it was discovered in 2005. Salvage excavation was carried out in 2007 over a 12 m^2 area and a depth of c. 9 m. Twelve geological layers were identified based on sediment granulometry and color (Fig. 1). Layer 11 is the only sedimentary unit that yielded archaeological material. Sediments from this layer were sieved with a 2-mm mesh. The dating of charcoal from the middle part of layer 11 provided a ^{14}C age of 9797 ± 91 BP (11,164–11,378 cal BP). OSL ages from layer 10 and 12 are consistent with ^{14}C determinations from layer 11 (Liu et al., 2008). This indicates the site was occupied just after the Younger Dryas Cold Event (ca. 12,900–11,700 cal BP; Rasmussen et al., 2014). Information on lithics and faunal remains are provided in the SOM (SOM Text S1.1 Lithics and faunal remains from SDG12). A first description of some needles from SDG12 was published by Zhang et al. (2016). Here we enlarge the sample size to include all the needles found at the site and the other artefacts linked to the reduction sequence leading to their production and use.

Technological and morphological analysis The osseous industry from SDG12 is curated at the Institute of Vertebrate Palaeontology and Palaeoanthropology (IVPP) of China, Beijing. The SDG12 artefacts analysed in this study were examined with a Nikon SMZ1500 stereomicroscope at magnifications ranging from 7.5× to 112.5×. Anthropogenic modifications were identified on the basis of criteria known in the literature (Behrensmeyer, 1978; Shipman and Rose, 1983; Behrensmeyer et al., 1986; Noe-Nygaard, 1987, 1989; Lyman, 1994; Fisher, 1995; Fernández-Jalvo and Andrews, 2016). Identification of manufacturing techniques and use-wear traces was based on observation of ethnographic, experimental, and archaeological bone tools with a particular focus on needle manufacture and use-wear (Wilder, 1976; Stordeur-Yedid, 1979; Bird and Beeck, 1980; Utrilla and Mazo, 1991; LeMoine, 1994; Castel et al., 1998; Green et al., 1998; Bonnissent and Chauvière, 1999; Hoffman, 2002; Derevianko and Shunkov, 2004, 2009; Tejero Cáceres, 2004; Tejero Cáceres and Fullola i Pericot, 2006, 2008; Corchón Rodríguez and Garrido Pimentel, 2007; Legrand, 2008; Golovanova et al., 2010; Lázničková-Galetová, 2010; Goebel et al., 2011; Stone, 2011; Borao Álvarez, 2012; Pitulko et al., 2012; Rios-Garaizar et al., 2013; Derevianko et al., 2014, 2016; Bignon-Lau and Lázničková-Galetová, 2016; Lyman, 2015; Kandel et al., 2017; Pétillon, in press). When identifiable, the species and anatomical elements selected as blanks were recorded. Otherwise, an animal size class was estimated from the cortical thickness. Techniques of manufacture, the area where they were applied, and the location and type of use-wear were documented. These data allowed the identification of preforms (partially shaped needles), blanks (bone fragments to be shaped into needles), and blocks (modified bone fragments from which blanks are extracted). Recognition of these artefact categories requires the analysis of the whole bone assemblage and the application of the chaîne opératoire approach, which provides a comprehensive reconstruction of the reduction sequence (Leroi-Gourhan, 1964; Lemonnier, 1976, 1986). Finally, we used width/thickness ratios to distinguish flat from sub-circular needles. Correlations were sought between technological, morphological and use-wear data.

2.3. Morphometric analysis

Morphometric information comprises width and thickness data for 20 Chinese needles, blanks, and preforms from four sites, 89 French needles from 10 sites, 73 Moravian needles from two sites, 14 Caucasian needles from two archaeological horizons of Mezmaiskaya, four Siberian needles from two sites, and 37 North American needles from four sites (Table 1). Width and thickness were measured with a digital calliper on the original specimens from SDG12, on casts from Xiaogushan and Zhoukoudian Upper Cave, also curated at the IVPP, and on the French and Moravian original needles. The French specimens are curated at the Musée National de Préhistoire (MNP), Les-Eyzies-de-Tayac and the Musée d'Archéologie Nationale, Saint-Germain-en-Laye, France. Most of the needles from Moravia are curated at the Anthropos Institut of the Moravské zemské muzeum, Brno, Czech Republic. Three Moravian specimens from the Wankel Collection curated at the Naturhistorisches Museum Wien, Vienna, Austria, were also included in this study. The remaining data were gathered from the literature (Golovanova et al., 2010; Lyman, 2015; Derevianko et al.,

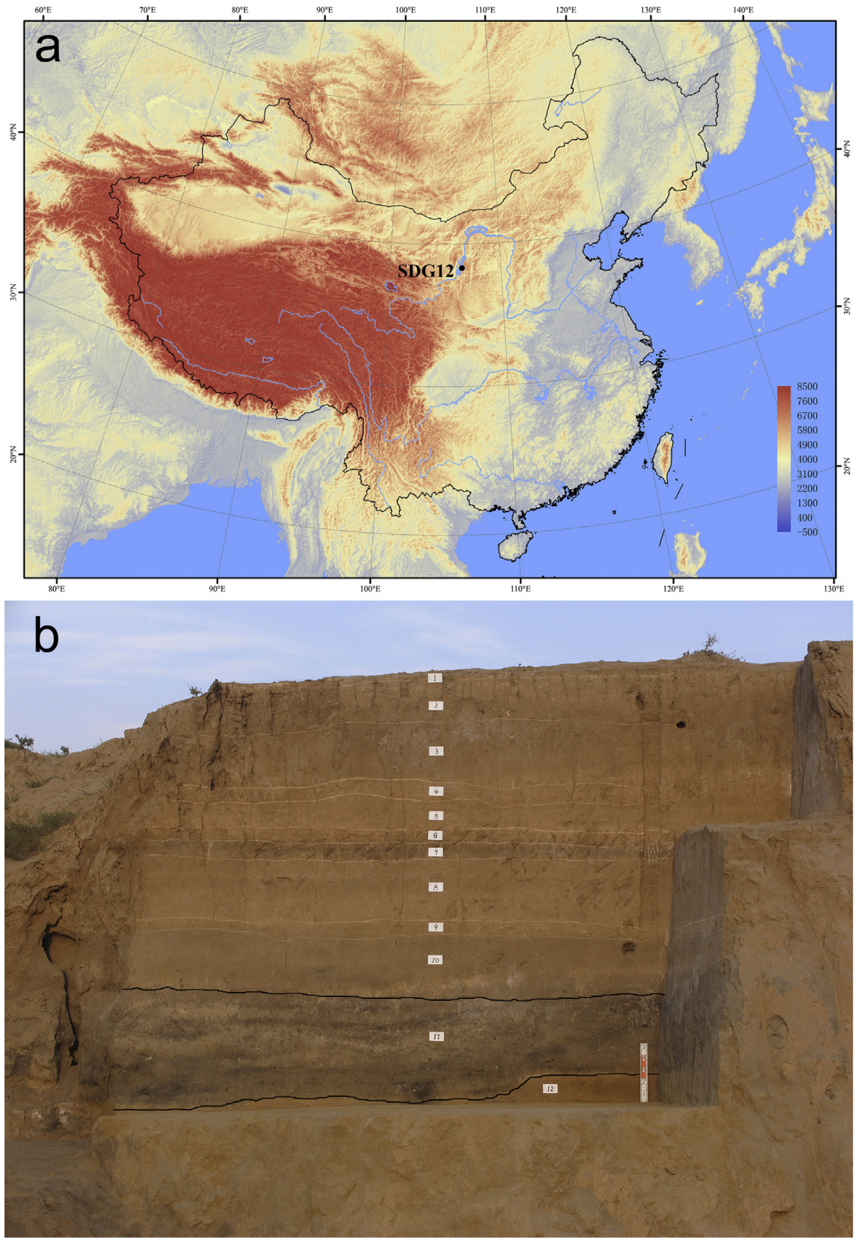

Figure 1. (a) Location of Shuidonggou Locality 12; (b) Photo of the stratigraphy indicating the layers and their limits (modified after Pei et al., 2012).

2016; Song et al., 2016; Shalagina et al., 2018). Only primary sources, i.e., data collected by the authors on original specimens, were used. In the case of Lyman (2015), which reports both primary and secondary data, only the former were used. As is often the case in archaeology, sample size varied from one region/cultural attribution to the next, and the values for width and thickness were not normally distributed. To overcome these issues, PERMANOVA (Anderson, 2001) was employed to identify significant pairwise differences between subsets of specimens attributed to distinct archaeological cultures and coming from different regions (see SOM-Text S1.2 for details). PERMANOVA is a non-parametric test similar to MANOVA, the multivariate equivalent of an ANOVA. This test was preferred to t-tests (univariate or multivariate) and Wilcoxon-Mann-Whitney U test for three reasons: (1) it does not require the values to be normally distributed; (2) it can be performed on two quantitative variables simultaneously, in this study width and thickness; (3) it does not require the *post hoc* correction of the *p*-value for multiple testing. In addition to the maximum width and thickness, two morphological, 24 morphometric variables (SOM-Fig. S1), and the occurrence of thinning on the perforated area were recorded on the Chinese and French specimens curated at the IVPP and the MNP. Metrics were preferred to more subjective morphological or technological variables to explore needle variability. This approach offers the advantage of making our study replicable and expandable in the future. Univariate and multivariate analyses (see SOM Text S1.2 for details) were performed with the software PAST 3.1 (Hammer et al., 2001).

3. Results

3.1. The chronology and geography of Pleistocene needles

In the Northern Hemisphere, bone needles are reported fr om 271 sites and 355 archaeological layers (Table 2; SOM Table S1; see

Table 1
Geographic provenance and cultural attribution of the needles analyzed in this study.

Region	Cultural Attribution	Site	Morphometric data		References
			Width & Thickness	Multiple morphometric variables[a]	
France	Solutrean	Badegoule	4		this study
		Combe Saunière	6	1	this study
		Fourneau du Diable	1		this study
		Les Peyrugues	7	5	this study
	Badegoulian	Abri Casserole	1	1	this study
		Pech de la Boissière	7		this study
	Magdalenian	La Madeleine	52	30	this study
		Laugerie-Basse	2	1	this study
		Laugerie-Haute-Est	2	1	this study
		Les Marseilles	7	5	this study
Moravia	Magdalenian	Býčí skála	2		this study
		Pekárna	71		this study
Caucasus	Early Upper Paleolithic	Mezmaiskaya	10		Golovanova et al., 2010
	Epipaleolithic	Mezmaiskaya	4		Golovanova et al., 2010
Siberia	Early Upper Paleolithic	Denisova	2		Derevianko et al., 2016
		Strashnaya	1		Shalagina et al., 2018
	Epipaleolithic	Strashnaya	1		Shalagina et al., 2018
China	Cores and Flakes	Xiaogushan	3	2	this study
		Zhoukoudian Upper Cave	1		this study
	Microlithics	SDG12	12	1	this study
		Shizitan Loc. 29	1		Song et al., 2016
North America	Paleoindian	Agate Basin	14		Lyman, 2015
		Lind Coulee	13		Lyman, 2015
		Marmes	9		Lyman, 2015
		Winkler-1	1		Lyman, 2015
		Total	**234**	47	

[a] See SOM Figure S1.

Table 2
Summary of the bone needle database. See SOM Table S1 for details.

	Western Europe	Southern Europe	Central Europe	Eastern Europe	Siberia	Asia	North America
Total number of sites	**142**	**28**	**24**	**16**	**35**	**11**	**15**
Total number of layers	**188**	**49**	**24**	**20**	**49**	**11**	**15**
Number of layers that yielded bone needles by cultural attribution							
Early Upper Paleolithic				2	4		
Cores and flakes technology						3	
Upper Paleolithic			1	9	36	1	
Gravettian				3			
Gorodtsovian				1			
Epigravettian				2			
Gravettian/Solutrean	1						
Solutrean	19	6					
Badegoulian	15	1					
Magdalenian	146	42	23				
Epipaleolithic				2	9		
Creswellian	2						
Proto-Azilian	1						
Azilian	4						
Microblade technology						3	
Cores and flakes technology with ceramic						4	
Paleoindian							15
Boreal Mesolithic				1			

SOM for references). In most cases, sites have yielded less than 10 specimens from a single occupation level. Only 41 sites (15.1%) yielded needles from multiple archaeological horizons. Radiocarbon ages are known for almost a third (31.8%) of the layers. Manufacturing by-products are reported for 41 sites (15.1%).

Identifying the first reliable occurrence of bone needles is made difficult by issues of radiocarbon dating and stratigraphic provenance. A bone needle found at Denisova Cave, East Gallery, layer 11 is attributed an age of >50 ka BP (Derevianko et al., 2016) based on a ^{14}C age obtained for this layer (OxA-V-2359-16, Reich et al., 2010). However, the four other ^{14}C ages available for the same layer are either infinite or ranging from 32 to 17 ka BP. The other needles found at Denisova Cave complex come from layers dated between 25 and 15 ka BP. Another early instance of a bone needle is found at Strashnaya Cave, layer 3_3, in Siberia, where deposition occurred between 44 and 49 ka BP (Fig. 2c). Needles later appear in Caucasus at Mezmaiskaya layer 1C, dated between 35 and 40 ka BP. Six sites dated between 35 and 25 ka BP from Caucasus (Mezmaiskaya, layers 1B and 1A), Siberia (Yana RHS), Central Asia (Aghitu-3, layer IIId), and China (Shuidonggou Locality 2, layer 2, Zhoukoudian Upper Cave, layer 1, and Shizitan Locality 29, layer 7) indicate this tool type was part of the East Eurasian toolkit since the very beginning of the Upper Paleolithic in Central Asia, and the Late Paleolithic in East Asia (for details on the debate surrounding the

Figure 2. Needles found at (a) Xiaogushan, (b) Zhoukoudian Upper Cave, China, and (c) Strashnaya Cave, Siberia. Scales = 1 cm.

subdivision of the Paleolithic in East Asia, see Gao and Norton, 2002; Yee, 2012; Gao, 2013; Qu et al., 2013; Li, 2014; Seong and Bae, 2016). The specimens from Xiaogushan, layer 3 should likely be added to this body of evidence owing to the similarities shared between the industry found in this layer and that yielded from Zhoukoudian Upper Cave, layer 1 (Zhang et al., 1985; Huang et al., 1986), although the precise chronology of the site remains to be established (see Norton and Jin, 2009 for a review). Subsequently, bone needles are found in Gravettian and Gorodtsovian contexts from Eastern European sites such as Eliseevitchi, Gagarino, Kostienki, Mezine, Mezirič, Moldova V, and Sungir.

In Western and Southern Europe, the earliest bone needles are found at Solutrean (c. 26–23 ka BP) sites in France and Spain. After the Solutrean, this tool type continues to be manufactured in this region during the Badegoulian (*c.* 23.5–20.5 ka BP) and becomes almost ubiquitous at Magdalenian (*c.* 20.5–14 ka BP) sites from Western, Southern, and Central Europe. Some occurrences are reported from Creswellian (c. 13–11 ka BP) contexts in the British Isles. At Le Mas-d'Azil, two bone needles were found in Proto-Azilian (c. 12 ka BP) layers (Stordeur-Yedid, 1979). Some specimens are described from the Azilian (c. 12–10 ka BP) occupations at the Pégourié, Troubat, and Tourasse sites in the Pyrenean region

Table 3
Archaeozoological and taphonomic data on SDG 12 bone needles, preforms, blanks, and blocks.

Catalog no.	Species	Animal size	Element	Artefact type	Completness	Root etching	Conservation	Fracture type	Figure no.
327	undet	ML	LB	preform	mesial	yes	AF, RF	W	SOM Fig S2b; SOM Fig S8a
3263	*Equus przewalskii*	L	rib	block	mesial	yes	AF	W	SOM Fig S3a; SOM Fig S9a-b
3421	*Equus przewalskii*	L	rib	block	mesial	yes	AF, RF	W	SOM Fig S3b
4003	*Equus przewalskii*	L	rib	block	mesial	yes	AF	W	SOM Fig S3c; SOM Fig S9c-e
133	undet	ML	LB	flat needle	proximal	yes	RF	W	Figure 3b; SOM Fig S5a-c
300	undet	ML	LB or rib	flat needle	distal	yes	AF	F	Figure 3f; SOM Fig S6c-d
1206	undet	ML	LB or rib	flat needle	mesial	yes	AF	F	Figure 3c
1207	undet	L	LB or rib	flat needle	complete	yes	na	na	Figure 3a; SOM Fig S4
1216	undet	ML	LB or rib	sub-circular needle	distal	yes	AF	W	Figure 4a; SOM Fig S7b
1829	undet	ML	LB or rib	flat needle	distal	yes	AF	F	Figure 3d; SOM Fig S5d
2851	undet	ML	LB or rib	flat needle	distal	yes	AF	W	Figure 3e; SOM Fig S6a-b
3089	undet	ML	LB or rib	flat needle	mesial-proximal	yes	AF, RF	F, W	Figure 3g; SOM Fig S7a
3098	undet	M	LB or rib	sub-circular needle	mesial-distal	yes	AF, RF	W	Figure 4c
3100	undet	M	LB or rib	sub-circular needle	mesial-proximal	yes	AF	F, W	Figure 4b
3101	undet	M	LB or rib	sub-circular needle	mesial	yes	AF	F, W	Figure 4d; SOM Fig S7c
94	undet	ML	LB	preform	mesial	yes	AF, RF	W, F	SOM Fig S2a; SOM Fig S7d
2865	*Struthio* sp.	M	LB	preform	mesial	yes	AF	W	SOM Fig S2e; SOM Fig S8c
2868	undet	ML	LB	blank	mesial	yes	AF, RF	W	SOM Fig S2d; SOM Fig S8b
3102	undet	ML	Metapodial	preform	mesial	yes	AF, RF	W	SOM Fig S2c

Undet: undetermined; M: medium; L: large; LB: limb bone; na: not applicable; AF: ancient fracture; RF: recent fracture; W: weathered; F: fresh.

(Seddas, 2012). A single bone needle is reported from the Late Azilian occupation of the Grotte du Bois-Ragot, layer 3 (Célérier et al., 1997). Specimens from Tardiglacial contexts represent the latest occurrences of this tool type in Western Europe prior to the Holocene.

At the very end of the Late Pleistocene, bone needles are found in Caucasus (Mezmaiskaya), Siberia (Biriusa I, Bolshoi Yakor, Denisova, Maina, Novoselovo VI, Oshurkova, and Ust-Menza 1), Northern China (Shizitan Locality 9 and Shuidonggou Locality 12), and in North American Paleoindian sites (SOM Table S1). In Southern China, bone needles were recovered at Bailiandong, Liyuzui, and Zengpiyan in association with core and flake lithic technologies and ceramic sherds. A similar toolkit was also recovered at the Northern Chinese site of Nanzhuangtou, Hebei Province. The first two sites are, however, problematic. The single needle from Bailiandong comes from a disturbed context with ^{14}C ages spanning 39 to 6.9 ka BP (Jia and Qui, 1960; Lotus Cave Science Museum et al., 1987). In the case of Liyuzui, the specimen was found in a cultural layer dated between 21 and 12 ka BP (Liuzhou Museum and Guangxi Wenwu Gongzuodui, 1983; Jiang and Liu, 2004). The two needles from Zengpiyan, layers 1 and 2, dated respectively to 12 and 10 ka BP (Chinese Academy of Social Sciences Institute of Archaeology, 2003), and the single specimen found at Nanzhuangtou, layer 5, dated to 11 and 11.5 ka BP (Li et al., 2010), nonetheless suggest this artefact type was part of the prehistoric toolkit alongside the earliest instances of pottery in Southern China and in the eastern regions of Northern China, a period contemporaneous with the human occupation of SDG12.

3.2. *SDG12 needles*

SDG12 (Tables 3 and 4) has yielded 11 needles, four preforms, one blank and three partially modified bone fragments interpreted as blocks from which blanks could have been extracted. A bone tool with an elongated eye may have also been used in sewing activities (Yi et al., 2013; Zhang et al., 2018). This latter specimen along with the other osseous artefacts found at the site (wedges, projectile points, knife handle, etc.) have been analysed in a separate study (Zhang et al., 2018).

State of preservation The needles include a complete specimen, one proximal, two mesial-proximal, three mesial, and four distal fragments (Table 3). Both ancient and post-depositional fractures are recorded (Table 3). The former occurred on both fresh and weathered bone (Table 3; see below). Although root etching is present on all specimens, surfaces not affected by this agent show an excellent state of preservation and allow a precise identification of anthropogenic modifications. No traces produced by other non-human taphonomic factors were detected.

SDG12 reduction sequences Technological (Figs. 3 and 4; SOM Figs. S2–S9; see SOM Text S1.3 for a detailed description) and morphometric analysis of needles, preforms, blank and blocks (Fig. 5; Table 4) indicate that the manufacture of sewing implements at SDG12 followed two distinct reduction sequences leading to the production of flat and sub-circular needles. Flat needles were mainly produced by cleaning by scraping and subsequently splitting in half the distal portion of large herbivores ribs. The edges of the resulting blanks were regularised by marginal retouch and both aspects ground to flatten the periosteal surface and remove the trabecular bone. Grooves detected on the sides of flat needles reveal that the blanks were deeply grooved in order to detach a preform similar in morphology to the final shape of the needle. In one instance, the needle preform was extracted from a long bone diaphysis. Preforms were first shaped by scraping, then probably by grinding to regularize the proximal end, and finished by

Table 4
Technological and morphometric data on SDG 12 bone needles, preforms, blanks, and blocks.

Catalog no.	Artefact type	Cross-section	Proximal end morphology	Length (mm)[a]	Width (mm)[a]	Thickness (mm)	Modification (%)	Techniques of manufacture			Location of use-wear	Type of use-wear	Figure no.
								Grinding	Scraping	Other			
327	preform	na	na	(24)	4.6	3.2	50	partial					SOM Fig S2b; SOM Fig S8a
3263	block	na	na	(63.5)	(21.9)	3.8	70	partial					SOM Fig S3a; SOM Fig S9a-b
3421	block	na	na	(33.6)	(8.5)	3.1	100	entire					SOM Fig S3b
4003	block	na	na	(34.6)	16.9	3.7	30	partial	partial	ret			SOM Fig S3c; SOM Fig S9c-e
133	flat needle	sub-rectangular	rounded	(21.6)	6.2	2.3	100		entire	po, heat, engr	b, e	po	Figure 3b; SOM Fig S5a-c
300	flat needle	sub-rectangular	na	(17.3)	3.8	1.6	100		entire	po			Figure 3f; SOM Fig S6c-d
1206	flat needle	sub-rectangular	na	(18)	5.1	1.5	100		entire		b	po	Figure 3c
1207	flat needle	sub-rectangular	rounded	51.7	4.8	1.9	100	partial	entire	po, dri, gro, res	t, b, e	po	Figure 3a; SOM Fig S4
1216	sub-circular needle	quadrangular	na	(28.3)	3.5	2.1	100	partial	entire	po, res	t, b		Figure 4a; SOM Fig S7b
1829	flat needle	sub-rectangular	na	(28.8)	5	2.1	100		entire	po, gro	t, b		Figure 3d; SOM Fig S5d
2851	flat needle	sub-rectangular	na	(29.7)	4.4	1.9	100		entire	po	t, b		Figure 3e; SOM Fig S6a-b
3089	flat needle	na	na	(15.4)	(2.5)	1.6	100		entire	po, dri	b		Figure 3g; SOM Fig S7a
3098	sub-circular needle	circular	na	(20.6)	2.2	1.6	100		entire	po	b		Figure 4c
3100	sub-circular needle	sub-rectangular and sub-circular	na	(15.9)	1.9	0.9	100		entire	po, dri	b		Figure 4b
3101	sub-circular needle	circular	na	(27.1)	2.2	1.9	100		entire	po	b		Figure 4d; SOM Fig S7c
94	preform	na	na	(20.4)	3.2	3	30	partial		fla			SOM Fig S2a; SOM Fig S7d
2865	preform	na	na	(17.2)	4	2.3	30		partial				SOM Fig S2e; SOM Fig S8c
2868	blank	na	na	(39)	4.3	3.2	20		partial				SOM Fig S2d; SOM Fig S8b
3102	preform	na	na	(39.9)	4.1	3.7	50	partial	partial	fla			SOM Fig S2c

Na: not applicable; heat: heating; fla: flaking; gro: grooving; dri: drilling; po: polishing; engr: engraving; res: resharpening; ret: retouching; t: tip; b: body; e: eye.
[a] Minimum value owing to damage between parantheses.

Figure 3. Flat needles found at SDG12. (a) Specimen SDG12-1207; (b) Specimen SDG12-133; (c) Specimen SDG12-1206; (d) Specimen SDG12-1829; (e) Specimen SDG12-2851; (f) Specimen SDG12-300; (g) Specimen SDG12-3089. Scale = 1 cm.

Figure 4. Sub-circular needles found at SDG12. (a) Specimen SDG12-1216; (b) Specimen SDG12-3100; (c) Specimen SDG12-3098; (d) Specimen SDG12-3101. Scale = 1 cm.

prolonged polishing. For the flat needle eye, the SDG12 artisan either drilled the preform on just one side, which produced a conical perforation, or took advantage of a foramen present on a long bone diaphysis without modifying it. The resulting needles are subrectangular in cross-section, have a rounded proximal end, symmetrical outlines, clean edges, and are highly polished. Scraping was occasionally used to resharpen the apex. Traces of use wear indicate these needles were intensively utilised and certainly curated.

The sub-circular needles were manufactured out of weathered long bones. The periosteal surface of these bones was first cleaned by scraping, then blanks were extracted by longitudinally splitting the bone by percussion. The ends of the ensuing elongated splinters were occasionally pointed by flaking, before being shaped by grinding and scraping. The eye was obtained by drilling both sides of the object. The needles thus produced are asymmetrical, display irregular outlines and are seldom polished. Their cross-section, sub-circular or quadrangular, varies along their main axis. Worn apexes were resharpened by scraping and grinding.

The morphometric analysis of the SDG12 needles and manufacturing by-products is consistent with the results of the technological analysis (Fig. 5). The thickness of the ground rib

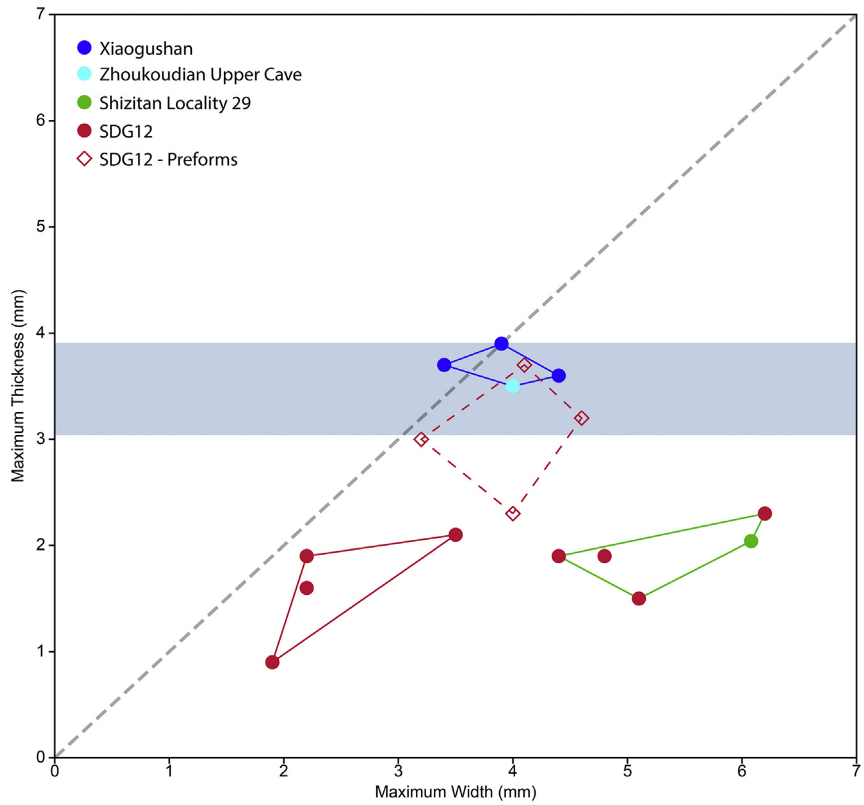

Figure 5. Scatterplot of width and thickness for needles found at Xiaogushan, Zhoukoudian Upper Cave, Shizitan Locality 29, and Shuidonggou Locality 12 (SDG12). The blue band highlights the thickness range of preforms from SDG12 made of ribs. The empty diamonds represent preforms made of weathered long bone. Convex hulls were added *post hoc* to aid visualization.

fragments is compatible with that of the flat needles. The splinters extracted from weathered bones, interpreted as needle blanks and preforms, have widths and thicknesses adapted to the production of sub-circular needles. They would be too narrow to manufacture the flat needles found in the same layer. The finished needles from the two groups differ remarkably from one another in their width/thickness ratio.

3.3. Morphometric comparisons

Width and thickness comparison of SDG12 specimens with needles from other Chinese Paleolithic sites shows the single specimen from Shizitan Loc. 29 falls within the variability of the flat needles. In contrast, Xiaogushan and Zhoukoudian Upper Cave needles (Fig. 2a,b) are circular in section, and more robust than those from SDG12 and Shizitan Loc. 29 (Fig. 5). The PERMANOVA confirms a significant difference between these three groups (Table 5).

Width and thickness comparison at a broad geographic scale identifies interesting trends (Figs. 6–7; Table 5; SOM Fig. S10). The few specimens from Siberia and Caucasus for which metric data are available show that the first known needles from these regions present similar size ranges. They are however significantly thinner than the earliest needles found in China. In both Siberia and Caucasus, no significant difference in width/thickness ratio is observed between these early needles and those found at Epipaleolithic sites. The persistence of needles of similar sizes is paralleled, in Siberia, by continuity in decoration. A longitudinal sequence of dots bored close to the perforation is present on needles from Siberian sites attributed to different periods (Derevianko and Shunkov, 2004, 2009; Pitulko et al., 2012). Needles from the French Upper Paleolithic show comparable width and thickness during the Solutrean and the Badegoulian, followed by a substantial reduction in size during the Magdalenian. The needles of this last technocomplex are also characterized by broader size variability with a number of robust needles overlapping the range of variation of the needles from Xiaogushan and Zhoukoudian Upper Cave. The sub-circular needles from SDG12 fall in the lower tail of variability observed for Magdalenian needles. Specimens from the Moravian Magdalenian are significantly wider than their French counterparts (Fig. 8; SOM Fig. S10), and include a homogenous sub-set of needles with a thickness ranging from 1 to 1.7 mm and a width ranging from 2.2 to 3.4 mm. Mixture analysis suggests the frequency distributions for the width and thickness of both French and Moravian needles comprise two distinct size groups (SOM Table S2). This supports technological analysis according to which Magdalenian needles can be divided into two sub-groups, i.e., small thin needles relatively homogeneous in size and robust needles heterogeneous in size (Treuillot, 2012). The Paleoindian needles are the smallest. Their size variability only partially overlaps with sub-circular needles from SDG12, and the smallest needles from French and Moravian Magdalenian sites.

Multivariate analysis (see SOM Text S1.2 for details) of French and Chinese needles highlights interesting differences. Of the 26 variables recorded, the six variables identified as the most informative to synthetize the proximal morphology of needles (SOM Text S1.2) are the width and thickness at the proximal margin of the perforation, the distance between the left (or right) margin of the perforation and the needle edge, the width and length of the perforation, and the distance between the proximal margin of the perforation and the needle edge. The first three eigenvectors of the PCA obtained with these six variables (Fig. 9) explain 95.86% of the variance (PC1 = 76.25%; PC2 = 15.89%; PC3 = 3.72%). The needles from China clearly stand out from their French counterparts for

Table 5
Result from the PERMANOVA post hoc pairwise comparison between regions and cultural affiliations. *P*-values are presented in the top-right section with statistically significant differences in bold. *F*-statistics are presented in the bottom-left section. Total sum of squares = 267.1; within-group sum of squares = 144.7; $F = 18.44$; $p = 0.0001$.

	France - Solutrean	France - Badegoulian	France - Magdalenian	Moravia - Magdalenian	Caucasus - EUP	Caucasus - EPP	Siberia - EUP	China - Cores & Flakes	China - Microlithic (Flat)	China - Microlithic (Sub-circ.[a])	North America - Paleoindian
France - Solutrean		0.9790	**0.0149**	**0.0001**	0.8488	0.1918	0.3795	**0.0004**	**0.0001**	**0.0133**	**0.0001**
France - Badegoulian	0.02		0.1117	**0.0045**	0.9463	0.2566	0.3304	**0.0012**	**0.0008**	**0.0403**	**0.0001**
France - Magdalenian	5.46	2.36		**0.0138**	0.1625	**0.0150**	0.9692	**0.0002**	**0.0001**	0.3457	**0.0001**
Moravia - Magdalenian	17.13	8.06	5.36		**0.0054**	**0.0022**	0.3118	**0.0001**	**0.0001**	0.1518	**0.0001**
Caucasus - EUP	0.16	0.05	1.85	7.13		0.2946	0.7136	**0.0019**	**0.0004**	0.0915	**0.0001**
Caucasus - EPP	1.65	1.43	5.67	12.42	1.48		0.2544	0.1958	**0.0238**	0.0599	**0.0001**
Siberia - EUP	1.02	1.01	0.02	0.95	0.36	1.81		**0.0280**	**0.0161**	0.4887	**0.0004**
China - Cores & Flakes	11.34	15.05	16.92	37.82	9.19	1.75	22.09		**0.0072**	**0.0285**	**0.0001**
China - Microlithic (Flat)	26.81	25.61	30.30	49.74	18.46	5.83	18.44	22.50		**0.0077**	**0.0001**
China - Microlithic (Sub-circ.[a])	5.34	4.91	0.90	1.71	2.65	4.51	0.82	25.92	24.80		**0.0150**
North America - Paleoindian	90.23	62.58	43.57	74.42	48.81	53.37	15.15	137.20	178.00	5.60	

[a] Sub-circ.: sub-circular.

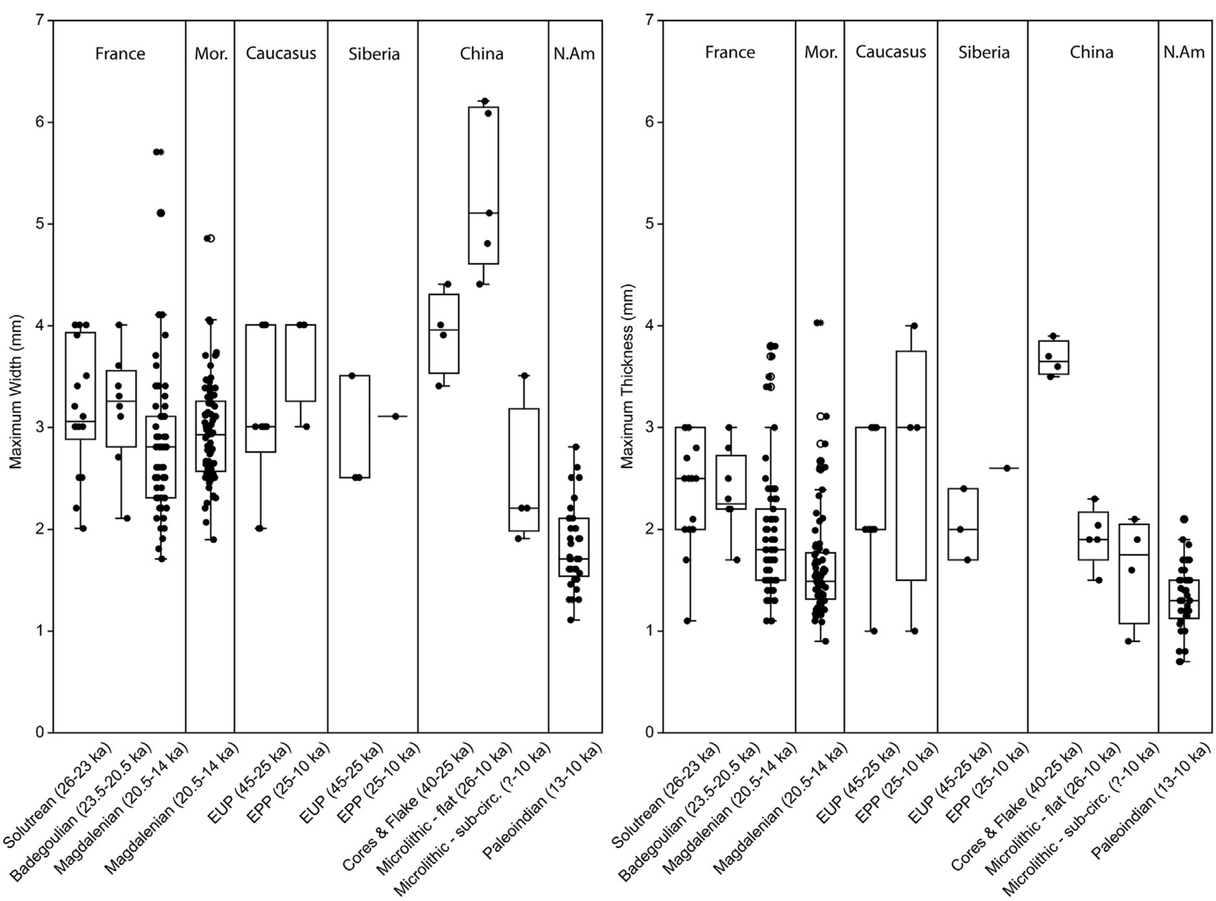

Figure 6. Width and thickness boxplot for needles by region and cultural attribution. Mor.: Moravia; N.Am.: North America.

their large perforations. Most of the Magdalenian needles have comparatively large perforations made on very small and thin bases. This is also observed on the only Badegoulian specimen, while this tendency is somewhat less manifest on the Solutrean needles considered in the PCA. However, the perforation on Solutrean specimens from Badegoule and Combe-Saunière (Fig. 10) show similarities with Magdalenian needles.

4. Discussion and conclusion

This study represents a first attempt to document the origin and follow the evolution of sewing technology at a global scale. Identifying with certainty the earliest evidence for needle production and use is problematic. The single specimens found at Denisova Cave, East Gallery, layer 11, and at Strashnaya Cave, layer 3_3, Siberia possibly represent the earliest instance of this tool type. However, new supporting data would certainly make the evidence more robust. It is difficult to attribute the absence of needles at older sites solely to taphonomic processes that would have deprived us of earlier instances of this tool. Needles are small and often fragmented, and their absence at some sites could potentially be explained by recovery biases. They have been, nonetheless, found at a number of pioneer excavations from China and Europe including those where sediment was not sieved. The discovery of

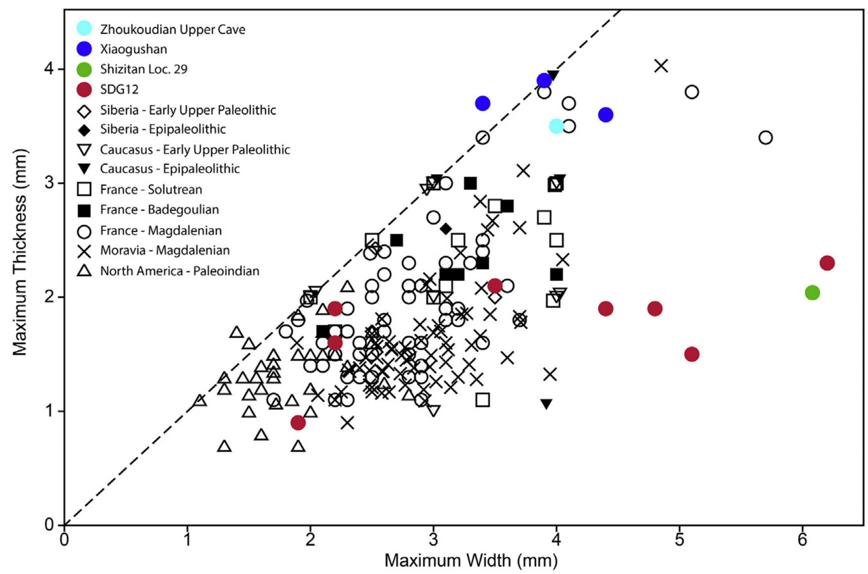

Figure 7. Scatterplot of width and thickness for needles from selected sites, regions and cultural attributions.

Figure 8. Magdalenian needles from (a) Laugerie-Haute Est (left), Laugerie-Basse (top right), La Madeleine (bottom right), France, and (b) Pekárna, Moravia. Scale = 1 cm.

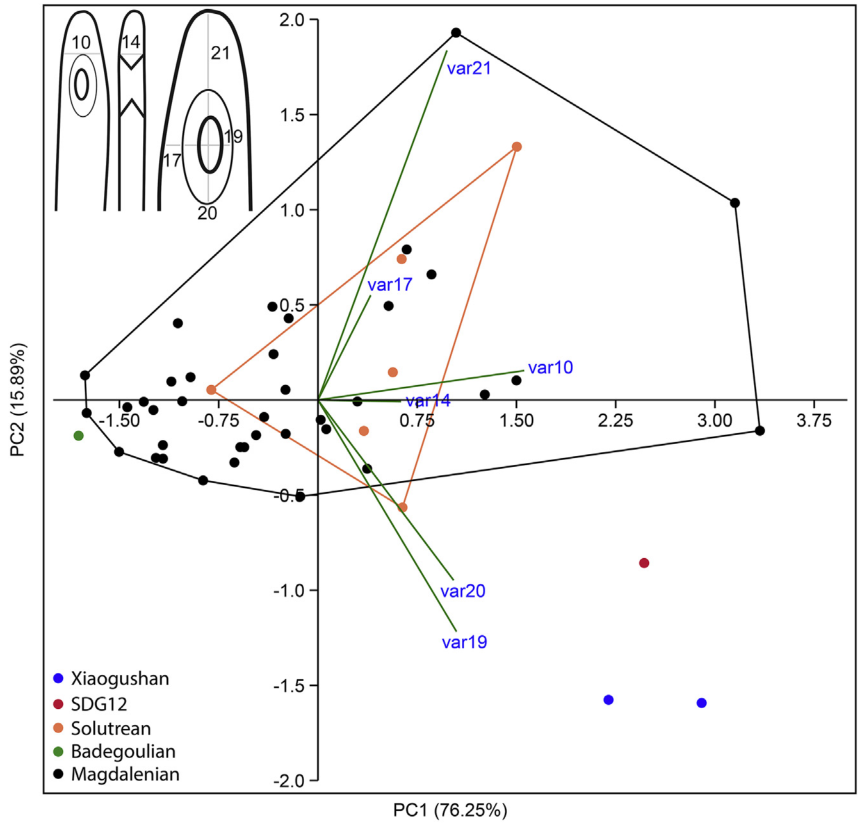

Figure 9. PCA comparing the proximal morphology of Chinese and French needles. Convex hulls were added *post hoc* to aid visualization. Green lines denote the strength of influence of morphometric variables on the first two PCA axes (width [var10] and thickness [var14] at the proximal margin of the perforation; distance between the left margin of the perforation and needle edge [var17]; width [var19] and length [var20] of the perforation; distance between the proximal margin of the perforation and the needle edge [var21]).

thin, delicate bone awls at Châtelperronian and Uluzzian sites in Europe (d'Errico et al., 2003, 2012b), and at Middle Stone Age sites from Africa (Henshilwood et al., 2001; d'Errico et al., 2012a), not to mention utilized bone fragments from the early hominin sites of Swartkrans and Sterkfontein (Robinson, 1959; Brain and Shipman, 1993; Backwell and d'Errico, 2001; d'Errico et al., 2001), suggests that small bone tools can survive in the archaeological record. This implies that bone needles are an original cultural innovation that emerged in Asia around 45 ka BP. This raises the question as to how archaic hominins survived in middle/high latitude cold environments without specialized sewing technologies. As Gilligan (2010) clearly points out, physiological and epigenetic adaptations, culturally embodied dispositions, and high caloric intakes appear insufficient to explain the intermittent peopling of those latitudes without some form of clothing. We know little about these early insulation devices but, given these issues, they must have been effective thermoregulators. The absence of needles implies the existence of alternative technologies to cope with low temperatures and wind chill, substantially different from cultural adaptations known historically to face these challenges. Such systems may have entailed ingenious combinations of clothes assembling and wrapping techniques, perhaps in conjunction with the use of animal fat to protect the body, as has been documented for populations from Tierra del Fuego (Albes, 1917) and Tasmania (Lloyd, 1862). Neanderthal know-how for the production of tar from birch bark (Kozowyk et al., 2017) suggests assembling animal and/or vegetal materials to manufacture insulating clothes was fully in the realm of their cognition and technological abilities.

Although the prehistory of sewing is still to be written owing to discrepancies in the nature and representativeness of presently available information, the data assembled here identify trends that can be interpreted in the light of the theoretical framework elaborated in the introduction of this paper. The significant differences in size between early specimens from Caucasus and Siberia on the one hand, and China on the other hand indicate that needles may have been invented independently in Central and East Asia. This is consistent with differences in lithic technologies between these two regions. In Siberia and Caucasus, the earliest needles are associated with blade-dominated Early Upper Paleolithic assemblages. In China, the first needles are found alongside cores and flake technology. It has been argued that the continuity in lithic technology recorded in China reflects the persistence of local traditions until the later appearance of blade technology circa 26 ka BP (Zhang, 1990; Gao, 2000; Gao and Norton, 2002; Li and Bodin, 2013). Blade technology is considered a reliable proxy for modern human dispersal in northern China from the west across Siberia and Mongolia (Brantingham et al., 2001; Gao and Norton, 2002; Wang, 2017). In this context, the earliest occurrences of bone needles in north-eastern China, which predates by more than 10 millennia the appearance of blade technology in this region, are difficult to interpret as resulting from diffusion of this innovation and fit better the hypothesis of independent invention. More data are necessary to follow the evolution of sewing technology in Siberia and Caucasus. However, the available information seems to indicate no major differences in needle size range were introduced throughout the Upper Paleolithic of these regions, which is consistent with a scenario of moderate cultural drift. In China, on the contrary, significantly smaller and flatter needles start to be produced between 26–23 ka BP, as exemplified by the specimen from Shizitan Loc. 29. Associated with the spread of the

Figure 10. Solutrean needles from (a) Badegoule and (b) Combe-Saunière. Scale = 1 cm.

microblades/microcores toolkit, the appearance of these small and flat needles likely signals a population replacement, possibly combined with a new function. Future discoveries may establish whether, already by 26–23 ka BP, needles were produced with two reduction sequences leading to the production of two needle types substantially different in size and morphology, as observed at the 11.2 ka BP site of SDG12. The SDG12 evidence supports a diversification of tasks requiring needles for two different functions. Small sub-circular specimens may have been devoted, for example, to embroidery, appliqué, or the sewing of more delicate furs for the production of underclothes, while flat sturdier needles could have been used to assemble winter clothes.

The needles that appear at a few Gravettian and Gorotsovian sites from the Russian Plains may represent either an independent invention or a geographic extension of earlier Caucasian and Siberian sewing traditions. More technological and morphometric data are necessary to favor one hypothesis over the other. The fact that no needles have been found at the numerous Gravettian sites from Central and Western Europe between ~30–25 ka BP, in spite of the abundant evidence of clothing and garment use during this period (Soffer et al., 2000; Riel-Salvatore and Gravel-Miguel, 2013; d'Errico and Vanhaeren, 2015), suggests a probable gap in the manufacture and use of this specialized bone tool type. The first needles appear in Western Europe during the Solutrean, and this tool type is continuously found in archaeological contexts of this region from the LGM until the Late Tardiglacial. The fact that Solutrean and Badegoulian needles are comparable in size advocates for continuity and cultural drift. The wider size range seen with the Magdalenian in Western and Central Europe best fits the idea that the sewing pouch of these Late Glacial hunters-gatherers contained, for the first time, needles of different sizes dedicated to a broad variety of tasks (cf., Stordeur-Yedid, 1979). Embroidery of ornaments with a small perforation, such as *Dentalium* sp. shells, requires very small standardized needles that are circular in section such as those found in association with the child burial of La Madeleine (Vanhaeren and d'Errico, 2001). Considering similarities observed in other aspects of material culture, this difference between French and Moravian Magdalenian needles can be attributed to cultural drift.

The narrow size range of Paleoindian needles reflects a never previously achieved mastery in the production of such tools. The production of these small needles must have been instrumental to adapt to the challenges of the environments of North American mid/high latitudes. The human groups who migrated through the Arctic during the Late Pleistocene must have had tailored clothing and needles to produce them. The occurrence of needles at some of the earliest sites in the New Word, e.g., Broken Mammoth (Holmes, 1996; Osborn, 2014; Lyman, 2015), supports this idea. One can wonder, however, whether narrow needles were already part of the cultural repertoire of the human groups who colonized North America or were developed after their arrival on this continent. No evidence is available at this time supporting the first hypothesis, i.e., that of a cultural drift occurring in North East Asia for which we are missing an intermediate stage. Both hypotheses entail a concomitant shift in the way tasks involving needles were performed. This new way of using needles may have led to the production of more effective, multi-layered clothes.

The morphological and morphometric variability of the needles' base and perforation probably reflect, as suggested by the results of our exploratory multivariate analysis, stylistic variations that we are, for the moment, unable to grasp to their full extent. When extensively documented in the future, they may help to disentangle cultural drift from population replacement, and cultural influence. Experimental manufacture and use of bone needles may facilitate the identification of the tasks in which they were involved, which is key information for assessing shifts in function.

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Supplementary Online Material

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