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SINEW THREAD PRODUCTION AND STITCH PROPERTIES IN ARCTIC ALASKAN CLOTHING CONSTRUCTION

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ABSTRACT

The production and functional properties of sinew thread are integral to the creation of Arctic clothing, both in the strength of the thread itself and also how it was sewn into garments. To evaluate these properties, nineteenth-century Iñupiaq garments produced for daily wear and part of the Edward W. Nelson Collection at the Smithsonian Institution's National Museum of Natural History were examined. All clothing was constructed with only two stitch types: overcast and running stitch. Stress-bearing seams were created exclusively with overcast stitch, primarily using a Z-twist sinew thread. Conversely, only minor seams of what appear to be repairs or attachment of trim were sewn with a running stitch. To explain these differences, reproductions of historical clothing pieces using overcast-stitch seams were undertaken, and evaluation of the strength of flat and twisted sinew thread was compared to that of modern cellulose threads. While linen thread is significantly stronger than cotton and sinew, twisted sinew is equivalent in strength to cotton. Twisting sinew increases its pliability and durability, although experimentation showed that this weakens its strength compared to flat sinew. Conversely, flat sinew is stiff and tends to delaminate and tangle. Overcast-stitch seams proved to be extremely durable; when replicated using various thread types, they held up to stress tests better than the hide pieces they were securing. The hide was more likely to fail than the seams, which is a testament both to the inherent strength and durability of the sinew thread design and the method of seam construction.

INTRODUCTION

Tailored clothing—meaning cut and sewn to fit the dimensions of a specific person—is essential to survival in extreme polar environments (Gilligan 2010; Havenith 2010; Issenmann 1997; Osborn 2014). Without well-fitting, tailored garments, expertly designed to prevent frostbite and hypothermia, humans are incapable of even short forays into Arctic climates, much less year-round occupation. Clothing had to mitigate the effects of three lethal environmental factors: extreme cold, windchill, and water exposure (Havenith 2010; McElroy 1975; Moran 1981). Without properly designed apparel that was prepared to high technical standards, humans could not have settled Arctic regions over a continuum of more than 25,000 years.

Indigenous peoples of the coastal Arctic regions of northern Alaska, Canada, and Greenland today can trace their genetic and cultural ancestry to the Thule, who originated in the Bering Strait region more than 1000 years ago but then rapidly expanded eastward to Greenland during the thirteenth century (Friesen and Arnold 2008; LeMoine and Darwent 2016; McCullough 1989; Raghavan et al. 2014). Though their success is often attributed to their ability to hunt whales, catch seals, and move about the landscape through the use of dog traction, their success was arguably tied directly to the effectiveness of their clothing. Clothing had to fulfill the needs of people who made short- or long-term treks in search of game, as well as those simply working near home (McElroy 1975). Many subsistence tasks were technologically demanding on clothing. Standing still for long stretches of time by a seal breathing hole required clothing that would retain heat in extreme cold and wind, and rowing on the open seas in an *umiaq* (large skin boat) in pursuit of whales required clothing to be flexible and water-resistant. While men's hunting tasks are often characterized by these specialized garments, women produced them and were essential to successful adaptation across an unforgiving Arctic landscape (e.g., Bodenhorn 1990; Burch 2006). Women were not only seamstresses but also hide workers who prepared and preserved skins for myriad uses, be that clothing, storage, shelter, or boat hulls (Guemple 1986; Hall et al. 1995; Nakashima 2002). Communities thrived in the North American Arctic through both the skillful preparation of animal hides and the knowledge and tailoring expertise of skilled seamstresses.

Early anthropological research in the Arctic focused on the activities of men, with the roles of women often viewed as secondary. In anthropological archaeology, the door was opened to gendered research more than 30 years ago (Conkey and Spector 1984; Gero and Conkey 1991), but women's technological innovations and contributions to Arctic habitation is a relatively new field (e.g., Frink et al. 2003; Frink and Weedman 2005; Harry and Frink 2009; Harry et al. 2009; LeMoine 2003). Arctic clothing has been studied extensively for its cultural significance and artistic design elements (Driscoll-Engelstad 2005; Issenmann 1997; King et al. 2005; LeMoine and Darwent 2013; Oakes 1991; Oakes and Riewe 1996; Svensson 1992), but fewer researchers have focused on the engineering innovations of Arctic clothing (Gilligan 2010; Havenith 2010). While some researchers have addressed aspects of the functionality of an entire suit of clothing (e.g., Havenith 2010; Klokkernes and Sharma 2005), thread production and seam construction have not been emphasized.

SINEW PRODUCTION AND SEAM CONSTRUCTION: PROJECT GOALS

Understanding how thread technology affects garment construction is vital to discerning how Arctic clothing is engineered to protect people in the harsh environmental conditions faced by year-round habitation. Failure of a seam could prove fatal. To engineer clothing and boat hulls that were waterproof and sturdy, women had to design and innovate seam technology capable not only of keeping garments together but of keeping feet dry during snowmelt, keeping seafaring vessels watertight, and preventing frostbite and hypothermia during the rigors of hunting (a highly strenuous activity). Seams bear stress, movement, weight, and friction, which tests their capacity to hold hide together. Traditionally, seams are created from millimeter-thin lengths of tendon split and twisted into malleable thread and used in concert with a needle to join two pieces of hide or intestine (Issenmann 1997; Turner 2014:211–212). It is crucial to understand the physical limits of the sinew thread to be able to understand how women were able to transform tendons into supple but strong sinew threads to join animal skins and gut into high-performance Arctic survival gear.

Empirical tests were carried out to understand the tensile-strength properties of sinew thread, that is, its resistance to breakage under tension or how well the thread will perform under vigorous use (Rengasamy and Wesley 2011). For example, thread strength can demonstrate how it was possible to sew hides around the frame of a boat, put humans and gear in that boat, and not have the seams tear apart and drown the seafarers. It also tells us how clothing does not fall apart during vigorous use despite leg and arm movement constantly pulling on seams. If a thread such as sinew is weak, the thread will break and the seam joining the two pieces of hide together will split. A split seam in the Arctic environment or on the Arctic sea could easily prove fatal. By testing the material that seams were constructed from, we can not only gain a better understanding of the physical properties of Arctic sewing techniques but also develop a better understanding of how women came to design clothing. Knowing the limits of a material tells us what constraints affected women's design.

SEAM CONSTRUCTION: THE SMITHSONIAN'S ARCTIC CLOTHING COLLECTION

For this pilot study, the focus was on daily-wear clothing that would have experienced extensive wear and tear, rather than special ceremonial regalia. Everyday clothing made of seal or caribou hide (rather than gut skin) was selected that was tailored to an individual's body dimensions and produced by indigenous "Eskimo" women, who lived in arguably one of the most "Arctic" of Alaska's coastal environments. This emphasis left a limited selection of pieces in the collection: a pair of women's boot-trousers (Fig. 1), a pair of sealskin trousers, likely made for a man (Fig. 2), and a men's parka or coat (Fig. 3). Although the pieces can be found in the Smithsonian's online catalog, they have not appeared in any previously published work (e.g., Nelson 1983). We were told by museum staff that this was the first time these garments had ever been examined in this manner by a researcher.

Each of the three daily-wear clothing items was collected in Norton Sound, Alaska, between 1869 and 1888. The oldest piece, a set of Iñupiaq women's trousers attached to a pair of skin boots, was collected by William Healey Dall in Norton Bay, central Norton Sound, when

Figure 1a. Iñupiaq woman's boot-trouser combination, front (E7578-0). Collected in Norton Bay, Alaska, by William H. Dall and donated to the Smithsonian National Museum of Natural History in 1869 (photograph by D. R. Ewing, 2014).

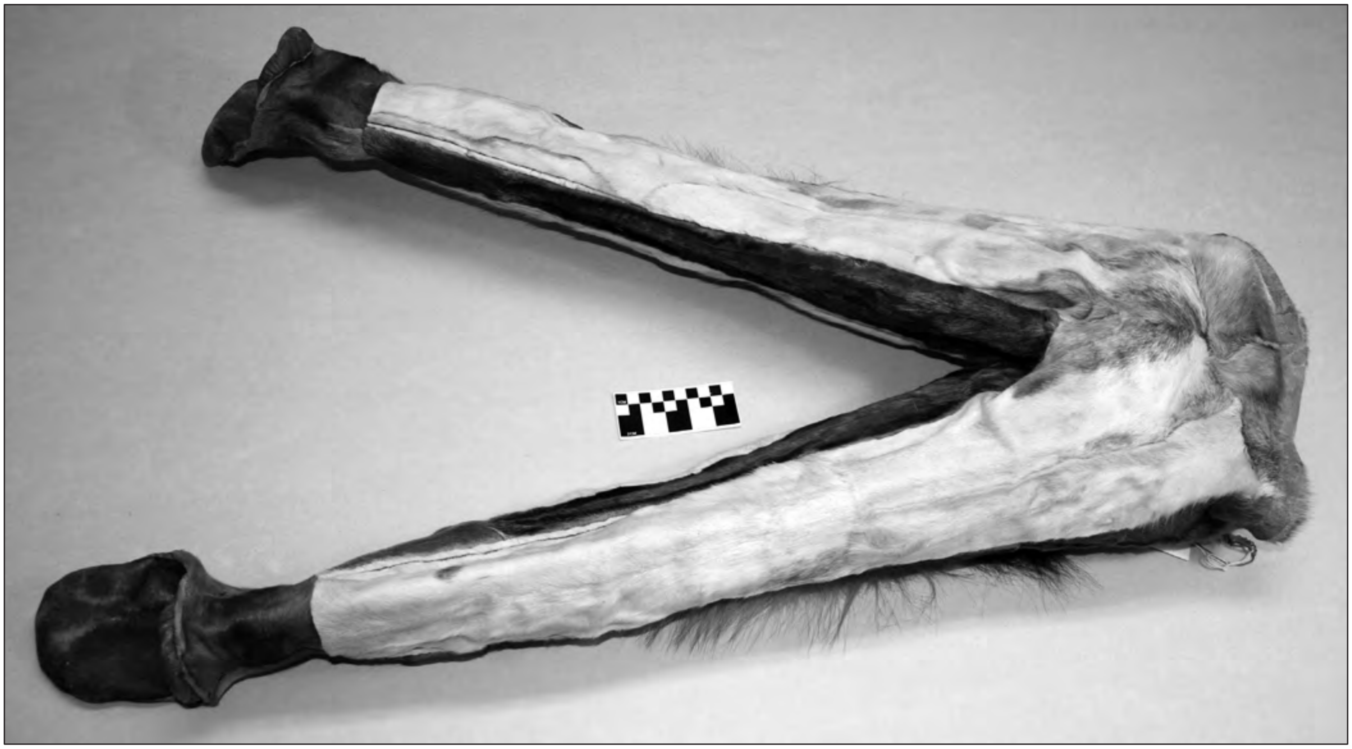

Figure 1b. Iñupiaq woman's boot-trouser combination, back (E7578-0). Collected in Norton Bay, Alaska, by William H. Dall and donated to the Smithsonian National Museum of Natural History in 1869 (photograph by D. R. Ewing, 2014).

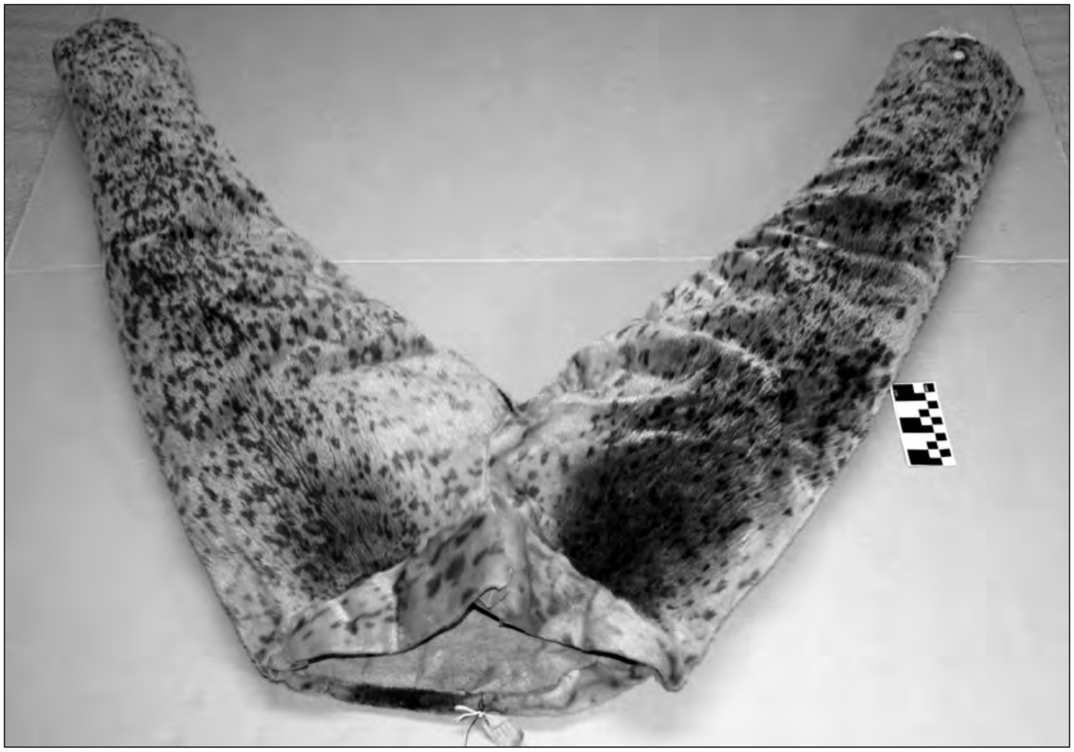

Figure 2a. Sealskin trousers (likely Iñupiaq), front (E43330-0). Collected in Golovnin Bay, Alaska, by Edward W. Nelson for the Smithsonian National Museum of Natural History in 1880 (photograph by D. R. Ewing, 2014).

Figure 2b. Sealskin trousers (likely Iñupiaq), back (E43330-0). Collected in Golovnin Bay, Alaska, by Edward W. Nelson for the Smithsonian National Museum of Natural History in 1880 (photograph by D. R. Ewing, 2014).

Figure 3a (right). Men's parka or coat (likely Yup'ik), front (E129819-0). Collected by Mildred M. Hazen in St. Michael, Alaska, and donated to the Smithsonian National Museum of Natural History in 1888 (photograph by D. R. Ewing, 2014).

Figure 3b (below). Men's parka or coat (likely Yup'ik), back (E129819-0). Collected by Mildred M. Hazen in St. Michael, Alaska, and donated to the Smithsonian National Museum of Natural History in 1888 (photograph by D. R. Ewing, 2014).

he was part of the Western Union Telegraph Expedition (1865–1867), and donated to the Smithsonian in 1869. Edward William Nelson (1983) arrived in the Bering Strait region of western Alaska as a weather observer for the U.S. Army Signal Corps in 1877. In addition to his meteorological duties, he also collected items for the Smithsonian Institution's National Museum of Natural History. While Nelson worked in the region, he collected and documented the material culture of Native Alaskans until leaving his position in 1881 (Nelson 1983). The Iñupiaq sealskin trousers were obtained by Nelson in Golovnin Bay along the Seward Peninsula in northern Norton Sound sometime during this period. The final garment, a men's parka, was obtained by Mildred M. Hazen, who likely purchased the garment in St. Michael and donated it to the Smithsonian in 1888. Given that the garment was obtained in southern Norton Sound, it was likely made by a Yup'ik seamstress. Although these items were collected well after Russian and western European colonists established trade routes and trading posts to exploit local fur resources (Ray 1975), sinew was clearly still being used to prepare hide garments.

For these pieces, the tailoring and construction details across all parts of the garments were examined, including preparing a paper pattern; documentation included hide type and method of preparation, and thread type and method of preparation (Issenmann 1997; King et al. 2005; Nelson 1983; Wilder 1976). Across all three of the everyday-use museum garments, all parts were sewn with metal sharps, or needles, as the piercings were cylindrical and placed exceptionally close together. Ivory, bone, or copper needles would have produced larger conical holes. An ivory needle thin enough to produce such a small hole would have been too fragile to pierce the leather. Metal glovers, or bladed needles, would have produced a triangular-shaped cut hole, rather than a pierced hole, and would have been prone to tearing.

Because of the age and fragility of these garments, it was not possible to turn them inside out to observe all seams. However, permission was given to carefully feel the seams with bare fingertips in locations that were less visible to determine whether or not stitches passed entirely or partially through the leather and to trace how the garment was pieced together. Light was shone down the length of the leggings, and all seams could be either seen or felt. A complete paper pattern was created for each garment, which allowed us to understand the "piecing" of leather in garment construction. In each of the garments examined, multiple pieces of hide were sewn together to create what appears from the outside to be a single piece.

A digital microscope was used to record the details of seam construction, which consisted of stitch type and the number of stitches per centimeter. The latter is important because stitch density affects the finished seam. Tightly placed stitches will create a seam without gaps or puckering, and the distance between stitches is an indication of whether air can pass through the seam or whether the material can shift against itself edge-to-edge during wear. Edge-to-edge shifting can cause a garment to buckle or pucker; it can also cause a garment to deteriorate due to friction-induced wear. All of these properties play into the functionality of a finished piece. Unfortunately, even with a digital microscope, it was impossible to confirm whether the sinew thread originated from caribou tendons as opposed to tendons from another mammal. Although it is most parsimonious to assume the sinew threads are from caribou or reindeer, as they looked microscopically identical to caribou sinew prepared for experimental research, destructive analysis (e.g., isotopic or proteomic analysis) would be needed to confirm.

WOMEN AS AGENTS OF TECHNOLOGICAL INNOVATION: ARCTIC CLOTHING PRODUCTION

In Arctic societies known to ethnographers, it was predominantly women who prepared hides of mammals, birds, and fish and who processed tendons into usable sinew for thread and rope to construct clothing, footwear, summer tents, and skin-boat covers (e.g., Frink 2006; Hall et al. 1995; Turner 2014; VanStone 1989). They also made food storage containers and floats from seal hides and intestines (Frink and Giordano 2015; Issenmann 1997). Usually, a new suit of caribou clothing was constructed annually as the garments would wear and develop holes because of the caribou's easily breakable hollow hair that was prone to shedding (Burch 2012:38; Meeks and Cartwright 2005:42–44; Turner 2014:78). While repairs were made year-round, caribou clothing, in particular, was seasonally constructed primarily because "the only time of year that adult caribou skins are prime for clothing—in terms of skin thickness and hair quality—is from late July to early September" (Burch 2012:38; see also Turner 2014:83). Although Nelson (1983:35; emphasis added) notes that "during the summer the men usually wear a light frock made from the skins of marmot, mink, muskrat, *fawns* of reindeer, or the *summer* reindeer with its light coat of hair," the main period of clothing construction was late summer and fall. If the outer layer for a northern garment was made from seal skin, the inner layer was often constructed of caribou hide, as it provided not only thermal properties but also the ability to wick moisture from the body—both critical factors for an active life in the north.

Indigenous North American Arctic clothing is well known to have exceptional cold-weather performance characteristics. While European-manufactured pieces may allow for greater freedom of movement, Inuit-style clothing provides better heat retention (Havenith 2010). Interestingly, both Robert F. Scott in his expedition to the South Pole and George Mallory on his climb of Everest did not survive their expeditions while wearing modern European ensembles of the day. Roald Amundsen survived his South Pole journey in a combination of Inuit-style outerwear and European-style undergarments.

Many ethnographers have photographed, discussed, and documented clothing designs and general production of garments across the Arctic (e.g., Nelson 1983; Rasmussen 1999; VanStone 1980); it is rarer for attention to be paid to the process of stitching itself (e.g., Bockstoce 1977; Hall et al. 1996; Issenman 1997; Oakes 1991; Oakes and Reiwe 1995). Turner (2014:231) describes, for example, waterproof seam construction on a Labrador *umiaq* "as such as may be termed a lap seam, that is by the edge of one skin lapping beyond the edge of the other so far that it may be turned over the edge and stitched to the other skin, the thread not appearing on the outer side." This particular method is also known as a mock flat-felled seam and is documented across the north for waterproofing not only boat hulls but gut parkas that served as a water-repellent anorak (see Bockstoce 1977:93–94, Fig. 72b, c) and for the soles of kamiks (see Oakes and Riewe 1995). It was Betty Kobayashi Issenman (1997), however, who first brought awareness to the importance of thread and seams in her book *Sinews of Survival*. Overcast or whip stitching is documented by Issenman (1997:90) as the most commonly used seam stitch for fur garment production across the Arctic, yet she is one of the only researchers to provide a detailed diagram of how the stitch is actually produced. This stitch type is simple to execute but challenging to execute well.

The entanglement of gender and Arctic clothing production is part of a much broader anthropological concept of women as agents or gender as agency (Conkey and Gero 1997). The question of agency depends a great deal on how it is defined. The dominant views of agency depend on a definition that either posits agency as operating in many ways at once both consciously and unconsciously, or that sees agency as the intentional actions of individual agents (Dobres and Robb 2000:10). For the purpose of investigating technological innovation, the latter definition applies, where agency must be approached primarily as the intentional action of the women innovators. When examining agency through the lens of "methodological individualism," this distinction of decisional action, where "the attempt" is made to reconcile "the causal relationship between constraining institutions and individual decision making" (Dobres and Robb 2000:4), fits well within the context of engineered technology.

Garment construction in Inuit societies is a gendered activity in that the creation of garments and other sewn items is undertaken by persons in the community considered women (Billson and Mancini 2007; Brumbach and Jarvenpa 2006; Burch 2006). As Conkey and Gero (1997:420) point out, technology is a gendered labor practice and can be "reassessed" through the lens of agency. Here we would point out that gender can be added to the list of constraints within which innovation in clothing technology must have taken place for indigenous Arctic women. Using this definition of agency and applying it to the gendered task of clothing construction, without which neither gender could perform tasks in the Arctic environment year-round, it allows us to assess the engineering choices made by women creating the technology necessary for cultures to flourish in the Arctic. This use, coupled with an understanding of the physical properties of the materials with which women made clothing, will lead to a more nuanced understanding of precontact Arctic lifeways. Women were, and are, recognized for their expertise (Burch 2006:73). These skills gave women agency within communities, especially where matters of survival such as food processing, shelter, and clothing were concerned. As Billson and Mancini (2007:58) point out, women had "autonomy" within their "sphere of responsibilities," which, while not as visible in early-contact accounts as that of men, nevertheless gave Inuit women a greater status than has been traditionally assumed (Bodenhorn 1990).

When applying such agency to the question of women's construction of Arctic clothing, specific parameters must be considered. Women had authority over clothing production, and the task was such an interlaced part of the community as a whole. For example, decisions may have been made related to the type of materials to use and in which manner, perhaps through the constraints of cultural taboo (Oakes and Riewe 2007), environmental conditions (Havenith 2010), and the physical properties of available raw materials. The importance of sewing to northern Alaska Iñupiaq peoples is underscored by cultural taboos associated with when sewing could be undertaken. Sewing at certain times was considered dangerous. For example, sewing could not take place when anyone in the settlement was sick; if they did sew, it would result in the sick person's death (Burch 2006:212). Likewise, sewing was forbidden when men were out whale hunting or the seamstress would die. Regardless of these constraints, the woman as agent not only had to develop the skill set to execute the task of garment construction, but she also had to take into account the rigors of active life in a hunting (seafaring) and gathering lifeway and develop knowledge and discernment tied to harvesting these resources. These clothes had to not only keep a person warm and dry but perform well during strenuous and repetitive activities that had a high impact (i.e., wear and tear) on materials and clothing construction points.

With the exception of stone scrapers in Arctic assemblages and rarely preserved bone scrapers, the tools of women's work, such as small bone needles, sinew, and hides, rarely survive taphonomic processes. Large projectile points or decorated harpoons tend to capture the imagination while decomposed leather and sinew threads lack visual appeal for most archaeologists. This penchant has helped to perpetuate what Brumbach and Jarvenpa (2006) refer to as "women's exclusion," a concept they apply to interpretations of gendered division of labor within a culture as well as by researchers investigating that culture. Women's exclusion also refers to women being left out of activities and spheres of influence often considered prestigious, such as big-game hunting and politics, and to their exclusion in terms of study by anthropologists (Brumbach and Jarvenpa 2006). In Inuit cultures, however, women were not excluded, nor were their contributions undervalued (Billson and Mancini 2007; Bodenhorn 1990; Brumbach and Jarvenpa 2006). In fact, women and men worked in concert to thrive in the Arctic (e.g., Briggs 1974; Burch 2006; Stopp 2002). Task differentiation between genders allows for the intense specialization and expertise needed for Arctic survival.

GARMENT CONSTRUCTION TERMINOLOGY

Understanding the terminology inherent to elements of clothing design and manufacture is important to this analysis. Much of this knowledge comes from the senior author's 20 years of experience as a professional seamstress and historical-costume designer, which includes the preparation of hides and sewing of leather.

Thread is the filament that lashes parts of a garment together to create stitches. Traditional sinew thread is made from animal tendons, and its manufacture and use in the production of stitches contributed directly to successful Arctic adaptation (Issenman 1997). Sinew is typically prepared from "shredded . . . fibers obtained from the legs and back of caribou" (VanStone 1989:34). While the preferred Arctic species was, and is, caribou, sinew can be made from any species of mammal or even bird (Burch 2006:230), including the esophagus of seal or waterfowl, the rectal canal of sea mammals and bears, or the covering of a whale's tongue (Issenman 1997:32).

Stitches are the individual lash points between two or more pieces of material and the particular style in which that lashing is executed to create a seam. *Seams* are the connecting points between two or more pieces of material from which a garment is constructed. *Knots* are entanglements of thread used to prevent the seam from unraveling or falling apart and can be either bulky, above the surface of the garment material, or flush with the stitches.

Seam construction is how the pieces of a garment are sewn together: the material used for thread, the preparation of the thread material, the stitch type chosen to join the pieces, and the knots used to keep stitches from coming loose during wear. The choice of thread material, how the thread is prepared (twisted or not twisted), the size of needle used (as evidenced by the size of holes in the material where the needle passes through), and the chosen stitch type all affect how the garment wears on the human body. Poor choices made in leather preparation, thread manufacture, stitch type, or knots could result in irritation to the wearer through abrasive friction during movement.

Leather usually constitutes the material used to make Arctic clothing. To be suitable for garment construction, its preparation must involve creation of a material soft enough to minimize friction during wear. Finished leather should be supple and move with the body. Proper tanning accomplishes this, but unskilled or careless preparation will create rough, stiff patches unsuitable for wear.

Tanning the hide is the first step in hide-garment construction, followed by patterning or piecing the leather.

Patterning is the way in which the garment material is cut into particular shapes so that when sewn together they form three-dimensional apparel that fits the human body. This process is sometimes referred to as piecing, as each shape cut out of the material is called a "piece." For Arctic clothing, it is important that the pieces be cut to fit an individual in such a way as to minimize heat loss and to avoid gaps at the wrists, ankles, neck, and waist where wind can enter the garment and chill the wearer. When cutting leather that still has fur intact, one must cut from the inside surface; this "wrong side" cutting allows the fur (or feathers) to lie properly at the seams without gaps in the finished garment. Fitting a garment to an individual is called *tailoring* and is essential to the engineering of Arctic clothing.

Stitch style or type is critical in garment construction. Each type of stitch creates a different resulting seam. Some create bulk, some are flush, some are created with the garment material overlapping, and yet others are prepared with the material edge-to-edge. Another aspect of stitching is the direction and angle at which the needle passes through the material and whether or not the thread passes back through or over previous passes through the material. Each of these differences can change the final stitch, lending it a different appearance and altering the functional application. For example, a bulky seam is created when a stitch is passed through previous stitches, creating tiny loops in the previous stitch, but this method of stitching is functionally useful on a loosely woven fiber cloth prone to unraveling, as it will prevent the material from fraying and deteriorating. However, this method of stitching is impractical on a tough material like leather.

Stitches must also be constructed of thread strong enough to endure the rigors of wear. For a garment to be functional, the thread cannot break, or the seams will not remain intact. The thread must also be malleable enough to move with the garment as the seam stresses with wear. If the thread is stiff and immobile, it can become a point of friction on the wearer or garment. Friction on the seam where the stitches pass through leather can tear out a seam, while friction on the wearer will cause irritation. By documenting the seam construction and stitch style, replica seams can be created to test for properties such as strength, abrasiveness, and weathertightness.

In order to evaluate these various properties, we explored two avenues of research: (1) examination of museum garments created in the late 1800s by indigenous women in Norton Sound Alaska; and (2) experiments on sinew thread and seam strength compared to modern cellulose thread material commonly used to sew leather garments (i.e., cotton and linen).

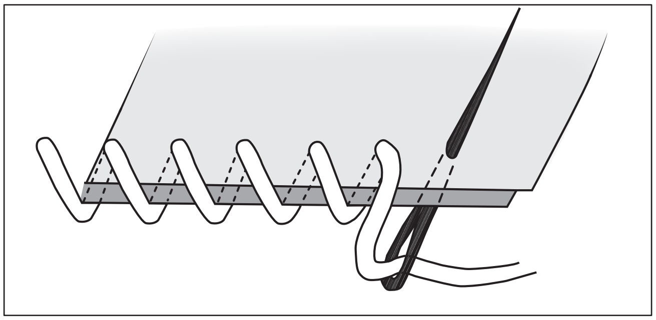

Figure 4. Overcast stitch, also referred to as whip stitch.

STITCH TYPES

Garment analysis revealed that only two stitch types were used to construct these Arctic clothing items, which is consistent with Issenman (1997): (1) overcast stitch and (2) running stitch. Overcast stitch, also known as whip stitch (Fig. 4), is a technique that is highly conservative of materials. It creates a seam where the material seats edge-to-edge smoothly and has no folds or puckers when executed correctly. It not only takes less material than seam construction often used in modern cloth garments but also creates a smooth interior surface. Overcast stitch is created by looping the thread material in a circular motion while

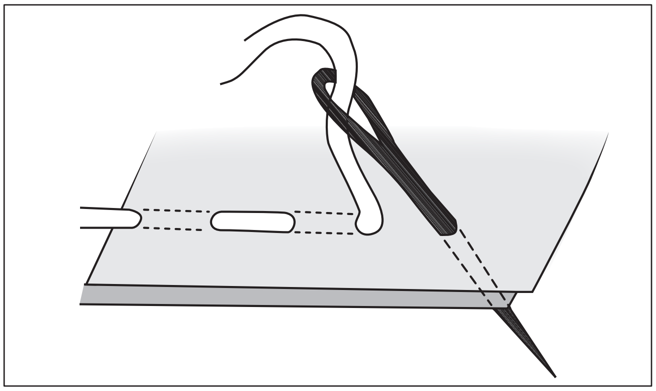

Figure 5. Running stitch, also referred to as tacking.

simultaneously piercing the edges of the garment pieces that are being joined.

Running stitch, also known as tacking (Fig. 5), joins two or more overlying pieces of the garment (i.e., two material pieces overlap one another). Running stitch, when completed, looks similar to modern machine stitches where every other stitch is "missing." The knots used in these garments appear to be a figure-eight-style knot with the tail encased in the ensuing stitches or tucked back into the seam (Fig. 6). Two examples of these knots show the tail tucked into the seam on both the parka and the leggings (Fig. 7).

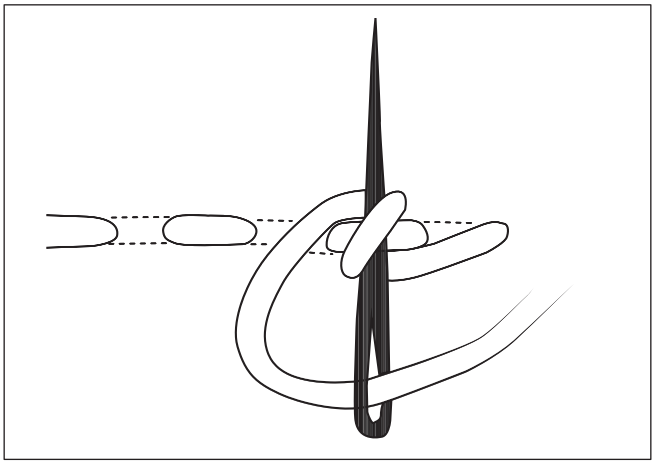

Figure 6. Figure-eight knot.

The stress-bearing seams of all garments examined were created with an overcast stitch. Only a few minor seams of what appeared to be repairs on trim were created with a running stitch. These running stitches were never stress bearing but rather were only used to attach fur-trim pieces to the parka hood edge (Fig. 8). All running-stitch seams were made with either flat sinew thread (as opposed to twisted) or, in some cases, what appeared to be cotton or linen thread. The running stitches were sloppy and of uneven lengths. The lack of precision in these stitches suggests that they may have been expedient repairs or possibly an undocumented museum repair to the item after collection.

The sewing strategy for leatherworking, such as the choice to pierce the hide through with the needle or to just "catch" part of the leather with the needle, affects the function of a garment. According to ethnographic accounts (see Oakes and Riewe 1996 and refer-

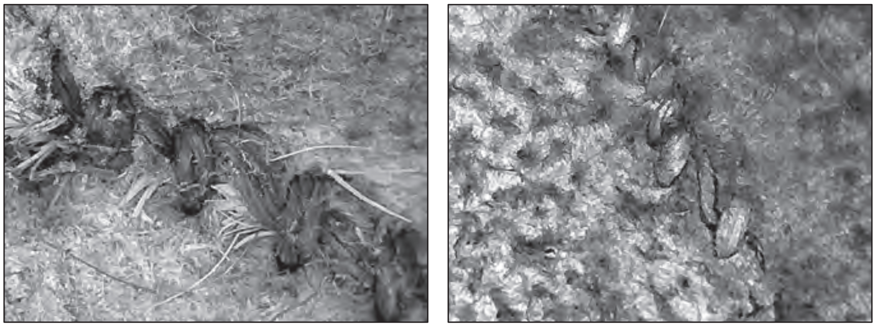

Figure 7. Sinew thread overcast stitch, finishing knot and tuck on parka, left (E129819-0), and trousers, right (E7578-0). Ethnology Collections, Smithsonian National Museum of Natural History (photograph by D. R. Ewing, 2014).

Figure 8. Running stitches on parka hood (E129819-0). Ethnology Collections, Smithsonian National Museum of Natural History (photograph by D. R. Ewing, 2014).

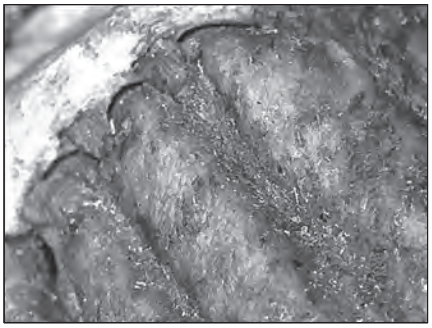

Figure 9. Overcast stitch on soles of leggings (E7578-0) showing detail of crease tucks to fit soles. Ethnology Collections, Smithsonian National Museum of Natural History (photograph by D. R. Ewing, 2014).

ences therein), the soles of leggings would *not* have been pierced through both sides of the leather's epidermis. In so doing, a seamstress created a more waterproof garment (Moran 1981). For example, this type of waterproof overcast stitch is visible where the soles of the leggings are attached to the upper portion; here, the overcast stitches did not pass entirely through the leather of the soles, and crease tucks were used to fit the soles (Fig. 9).

STITCH PLACEMENT

In order to understand how the stitches joined pieces of hide together, and what effect that may have had on the wearer, the number of stitches per centimeter was counted. The overcast-stitch seams of the parka and leggings both had stitch counts of between seven and nine stitches per centimeter, with a maximum count of 11 stitches (Fig. 10) and an average of seven. A stitch count this tight is exceedingly difficult to achieve in material as tough as leather. Despite the senior author's considerable experience sewing hide, during experimental work, it was only possible to consistently achieve approximately five sinew stitches per centimeter in leather. The stitches in all but one of the museum garments were so carefully executed that the gap between pieces of hide was nearly imperceptible without magnification. Such careful stitchwork created a garment that was smooth on the side closest to the wearer. Unlike seam construction typically found in modern leather garments, there were no puckers or excess material. Similar tight overcast stitches have been documented on a sock from a well-preserved 4000-year-old site in West Greenland (Persson 2017).

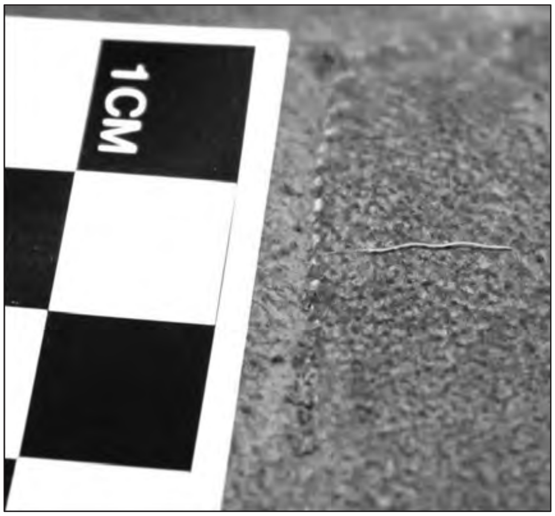

Figure 10. Overcast stitch with scale showing seven stitches per centimeter on parka (E129819-0). Ethnology Collections, Smithsonian National Museum of Natural History (photograph by D. R. Ewing, 2014).

An exception to the consistent quality of work in the examined museum-collection garments was the stitching in the sealskin trousers collected by Nelson. This garment was not as carefully executed, having only three to four stitches per centimeter, with a maximum of five stitches. The piece was also overcast stitched on a slant, which resulted in the edges of the hide not pulling together evenly but instead being under tension. This factor, coupled with low stitch count per centimeter, created some gaps and puckers in the completed garment (Fig. 11) and indicates hasty or unskilled construction when compared to the care taken with the seams of the other garments (see also

Figure 11. Puckered seams on trousers (E43330-0). Ethnology Collections, Smithsonian National Museum of Natural History (photograph by D. R. Ewing, 2014).

LeMoine and Darwent [2013:217] for a comparative example of experienced and inexperienced stitching).

SINEW THREAD

The use of sinew as a thread material is of interest in the study of the construction of these garments. Sinew is a material created from processed tendon and must be split by hand to the desired width. To do this task, a strip of sinew is first softened by soaking in water, or with saliva, and then it is split to the desired thickness. At this point, the sinew can be left flat and used as thread; however, sinew is often twisted before it is used in stitching in order to create a stronger material (Issenmann 1997:85). Most of the sinew used in the museum garments was precisely split and twisted, although some seams were created with flat (nontwisted) sinew thread. Using a handheld digital microscope, a Z-twist was identified for sinew-thread preparation for use in construction of the parka (Fig. 12). Z-twists on a thread mean the fibers or filaments are twisted in a clockwise direction. No S-twisted sinew threads were observed.

Figure 12. Twisted (Z-twist) sinew thread in trousers (E43330-0) under magnification. Ethnology Collections, Smithsonian National Museum of Natural History (photograph by D. R. Ewing, 2014).

Sinew can be split to any desired width using only one's fingernails, and then tapered at one end to fit through the eye of a needle. If the selected needle size has a similar diameter to that of the thread, it is possible to create stitches that are the same size as the holes pierced by the needle. If the thread end that passes through the needle eye is tapered narrower than the bulk of the thread, it can be the same width or larger than the needle. This ability to taper sinew to fit through a smaller eyehole, catching only one side of leather's epidermis when sewing, along with the ability of sinew to swell when wet, is what accounts for the waterproof nature of sewing techniques, such as those used on boat skins or boot soles (Gilligan 2010; Oakes and Riewe 1996).

SEAM CONSTRUCTION: EXPERIMENTAL ANALYSIS

Experimental analysis involves replication to evaluate the feasibility of particular materials or suites of materials in order to test hypotheses about artifact production and function. For archaeologists, this approach can enable the production of a more nuanced understanding of the archaeological record (Mathieu 2002). While analysis of museum pieces can tell us what an object was and how it may have been used, experimental analysis allows us to test functional properties without the risk of damaging the artifact (e.g., Ferguson 2010; Sholts et al. 2017). Not only can we explore functional properties, but also we can evaluate labor costs and the level of expertise needed to create an object or complete a task. Experimental analysis allows for a holistic understanding of technology—that is to say not just what an object is or does but how an object may have affected the life of the maker and/or the life of the user (Sholts et al. 2017). It provides a glimpse into both the process of creating and the place of that object within a human technological context. It allows the cost of production and use to be evaluated, giving a better understanding of the lifeways of the individuals for whom these items were not just tools of survival but parts of a cultural landscape (Brumbach and Jarvenpa 2006; Darwent 1998).

By conducting this set of replicable experiments, we can not only evaluate the tensile properties of sinew in comparison to modern materials, but we can also better understand the means by which humans culturally and technologically adapted to the Arctic. Time investment in creating thread and stitching seams allows for a better understanding of traditional indigenous lifeways. The balance of time management between tasks is not directly addressed here, but the time-consuming nature of sewing technology has implications for understanding the labor of women in Arctic environments. Such data can also be used to extrapolate sewing technology in other times and places where sinew was also likely used, as tendons of other cervids will react in a highly comparable way.

To be able to test the functional properties of seam construction—specifically, the strength of threads and seams—the stitch techniques observed in the selected museum garments were replicated by the senior author. For comparison, short stretches of stitches using both flat and twisted sinew were replicated, as were stitches using modern commercial threads. Details such as how close stitches are to one another and the thickness of the thread used to create the stitches determine how much puckering, give, or tearing will occur when seams are stressed. These experiments focused on the technical aspects of seam construction, as this determines the clothing's functionality. We specifically examined how sinew acts as a thread and how sinew compares to commercial thread in weighted stress tests. Replicated sample seams were tested for breakpoint strength by attaching them to a bar that was hooked to a digital scale and applying weight following methods similar to those presented by Rengasamy and Wesley (2011; see also Hsu 1976), but with less expensive equipment. The strength of thread material was tested similarly. Lengths of prepared flat and twisted sinew were tested individually on the same digital scale. The breakpoints were compared to the breakpoints of modern thread materials cut to the same length.

Reindeer (*Rangifer tarandus*) hide from Finland and farmed whitetail deer (*Odocoileus virginianus*) tendons were chosen as a proxy for Alaska caribou because the former is the same species and the latter is in the same family (Cervidae). Both of these products are legal to purchase, whereas caribou are a restricted wild game species. Both leg and back tendons of whitetail deer were used to produce sinew. Seams were created in reindeer hide with sinew, cotton, and linen thread to evaluate differences in functionality between sinew and readily available modern threads most commonly made from cellulose fibers. Sewing with modern materials was obviously less time-consuming, as these materials are prepared before purchase and require no special treatment. Gutterman mercerized cotton, a common, high-quality thread available at local fabric stores and online retailers, was selected. This brand of cotton thread is manufactured in multiple diameters, making it possible to purchase a comparably sized thread to the handmade sinew threads. For linen thread, Londonderry was selected, which is a brand of flax-based, pure linen thread. This brand is the only one still in production that sells multiple thicknesses, which allowed selection of a comparable thickness to the sinew threads used in the museum-collection garments.

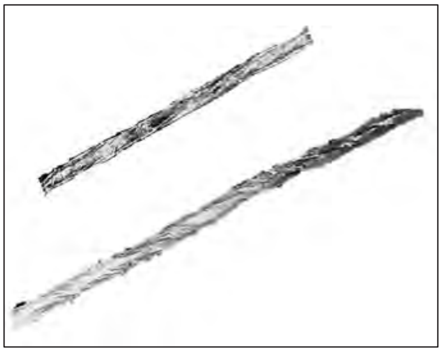

Figure 14. Flat (above) and twisted (below) sinew thread under magnification (photograph by D. R. Ewing, 2015).

Figure 13. Raw whitetail deer tendon (photograph by D. R. Ewing, 2015).

SINEW THREAD PREPARATION

The sinew thread was prepared by soaking the deer tendons in warm water, then gently pounding flat the leg tendons (Fig. 13). The back tendons are naturally flat and thus required one less step in production. Once flat, widths of sinew were pulled from the tendon in strips as close as possible to the sizes observed in the museum-collection garments. Some of the strips were left flat, and the others were prepared by twisting (Fig. 14). It took 43 minutes to split a presoaked strip of back sinew into 154 threads of usable length. Similarly, it took 94 minutes to split one presoaked leg tendon into 281 usable sinew threads, but in this case, the leg tendon had to be pounded with a mallet first to release the sinew fibers before it could be split into threads.

Sinew thread, in either flat or twisted form, is relatively stiff compared to linen or cotton thread. The twisted sinew was found to perform better as a thread material because the sinew became more pliant after twisting, while the nontwisted sinew was far more stiff or rigid, thus making it difficult to execute uniform stitches. This pliability made the twisted sinew easier to manipulate during the sewing process and easier to knot. The flat sinew did not tie into knots as easily, was more challenging to sew with because it did not readily conform to the stitch, and had a tendency to kink or buckle as sewing progressed. This qualitative difference in ease of use underscores the purpose of twisting the sinew before using it as a thread. Also, as the flat sinew dried, it tended to delaminate and further split at the ends or sometimes along the length or shaft of the thread, which caused threads stored together to knot up or break. The twisted sinew threads did not split or tangle when stored together. This difference in storability of prepared threads also indicates a qualitative advantage to the use of twisted sinew, which would have been useful for highly mobile people. Twisted sinew could be stored and transported for production or repairs at any time.

When documenting the Arctic garments at the Smithsonian, what appeared to be incidental twisting in the stitches in some seams was noted. Perhaps this was produced by sewing with flat sinew and simply not being careful of the stitch work. Given personal experience with this incidental twisting of flat silk thread (i.e., if you do not take care to keep the flat silk untwisted, the circular motion of stitching can twist the thread slightly as you work), we wondered if something similar had happened with the sinew. However, when experimental stitching was undertaken, incidental twisting never occurred when sewing with flat sinew. Nevertheless, when the senior author first began twisting sinew threads, initial attempts at twisting the sinew created a thread that appeared similar to that used in the stitches observed in some of the museum garments that appeared to have an incidental twist in the thread. Initial attempts at twisting sinew were not as tight or as even as later attempts, which resulted in replicated stitches indistinguishable from those documented in the Iñupiaq garments (Fig. 15). There is a skill to twisting sinew, and that skill (or lack thereof) is visible in the stitches made with that thread. While the tightness and evenness of the sinew twist changed the experimental thread's appearance, there was no appreciable difference in the pliability of the thread that was less or more evenly twisted.

THREAD BREAKAGE TESTS

The breakpoint of twisted and flat sinew threads was tested because both flat and twisted sinew varieties were used in the museum garments. We wanted to understand why one style would be chosen over the other and if that choice was a functional one (Table 1). In general, twisted sinew was far more commonly observed, as flat sinew only appeared in a few seams, and thus we hypothesized that twisted thread was superior for construction.

A total of 33 lengths of twisted sinew and 36 lengths of flat sinew thread were prepared and tested following methods used by the industry to test tensile strength. The average length of flat sinew used in this test was 23 cm, and the average length for twisted sinew was 27 cm. Attempting to mimic the width of thread needed to create five to seven stitches per centimeter, the average thickness of all 69 sinew threads created was 0.25 mm. Flat sinew threads averaged a breakpoint of 3.14 kg (SD = 1.61). The

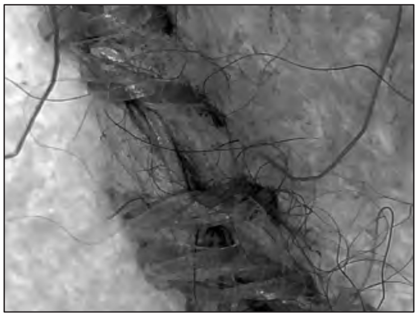

Figure 15. Replicated twisted-sinew (Z-twist) overcast-stitch seam joining reindeer-hide pieces under magnification (photograph by D. R. Ewing, 2015).

Table 1. Experimental breakage of sinew thread.

Thread Material	Thickness (mm)	Breakpoint (kg)	Thread Material	Thickness (mm)	Breakpoint (kg)
Flat sinew	0.38	1.09	Twisted sinew	0.21	1.18
Flat sinew	0.39	1.13	Twisted sinew	0.29	2.68
Flat sinew	0.39	2.18	Twisted sinew	0.17	0.82
Flat sinew	0.27	1.68	Twisted sinew	0.19	1.45
Flat sinew	0.25	6.62	Twisted sinew	0.37	3.13
Flat sinew	0.25	4.45	Twisted sinew	0.31	1.95
Flat sinew	0.25	3.40	Twisted sinew	0.29	2.40
Flat sinew	0.26	2.36	Twisted sinew	0.38	3.22
Flat sinew	0.25	4.22	Twisted sinew	0.29	2.77
Flat sinew	0.24	3.81	Twisted sinew	0.15	1.27
Flat sinew	0.23	2.95	Twisted sinew	0.35	3.90
Flat sinew	0.39	7.67	Twisted sinew	0.39	10.02
Flat sinew	0.44	5.53	Twisted sinew	0.17	1.18
Flat sinew	0.16	1.91	Twisted sinew	0.29	3.76
Flat sinew	0.21	2.31	Twisted sinew	0.19	2.36
Flat sinew	0.13	1.18	Twisted sinew	0.24	1.68
Flat sinew	0.39	3.72	Twisted sinew	0.21	1.95
Flat sinew	0.21	1.77	Twisted sinew	0.16	1.77
Flat sinew	0.19	1.22	Twisted sinew	0.34	6.67
Flat sinew	0.23	2.90	Twisted sinew	0.22	3.90
Flat sinew	0.13	2.45	Twisted sinew	0.26	3.31
Flat sinew	0.15	2.99	Twisted sinew	0.22	2.59
Flat sinew	0.31	3.58	Twisted sinew	0.17	1.86
Flat sinew	0.25	2.31	Twisted sinew	0.13	0.95
Flat sinew	0.19	1.59	Twisted sinew	0.26	1.59
Flat sinew	0.22	2.86	Twisted sinew	0.15	1.22
Flat sinew	0.35	6.62	Twisted sinew	0.39	3.90
Flat sinew	0.19	3.81	Twisted sinew	0.27	1.45
Flat sinew	0.15	2.36	Twisted sinew	0.19	1.86
Flat sinew	0.25	3.49	Twisted sinew	0.15	1.00
Flat sinew	0.18	2.13	Twisted sinew	0.22	1.54
Flat sinew	0.29	3.08	Twisted sinew	0.20	1.18
Flat sinew	0.32	5.26	Twisted sinew	0.26	1.50
Flat sinew	0.17	1.63	**Min**	**0.13**	**0.82**
Flat sinew	0.29	2.81	**Max**	**0.39**	**10.02**
Flat sinew	0.21	1.41	**Avg**	**0.25**	**2.65**
Min	**0.13**	**1.09**	**SD**	**0.07**	**1.80**
Max	**0.44**	**7.67**			
Avg	**0.26**	**3.14**			
SD	**0.08**	**1.61**			

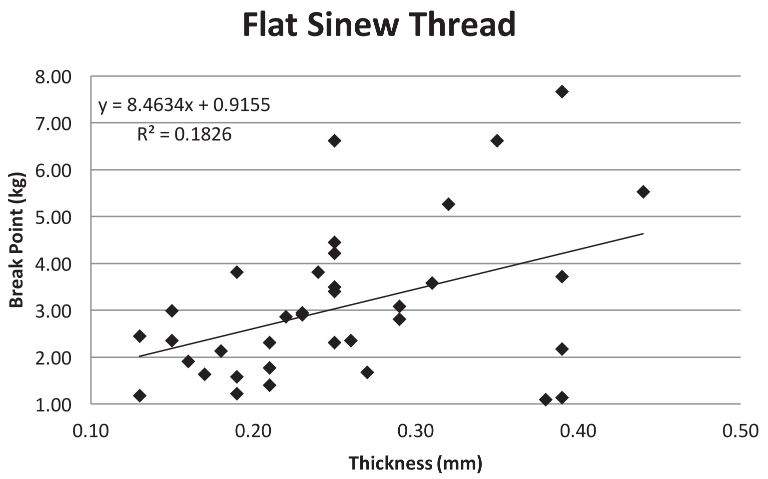

Figure 16. Comparison between thickness and breakpoint for flat sinew thread.

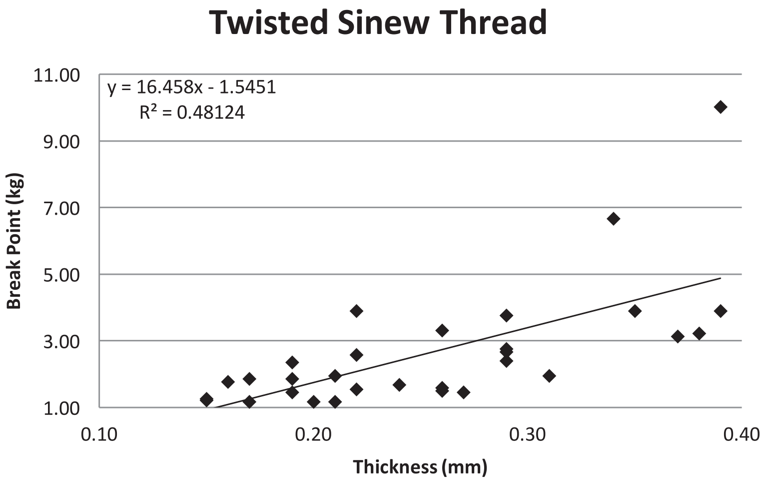

Figure 17. Comparison between thickness and breakpoint for twisted sinew thread.

lowest flat sinew breakpoint was 1.09 kg, yet this thread was thicker than average at 0.38 mm. The strongest flat thread was 0.39 mm thick, and it broke when 7.67 kg of weight was applied; neither of these threads broke at the knot. Only three (or 8.3%) of the flat sinew threads broke at the knot. A regression analysis of flat sinew thickness to breakpoint produced a Pearson's R-value of 0.43 (Fig. 16). While technically a positive correlation, the relationship between the variables is weak, and thus breakpoint is not entirely explained by thread thickness. If there is no significant difference in strength to using thicker sinew strips, resources of animal tendon can be split finer and thus produce more threads per individual piece, thus conserving resources. Through seamstress experience, the senior author knew finer threads will produce a seam that lies flatter to the material being sewn, thus producing a more comfortable garment. If thicker threads do not create an appreciable difference in the strength and durability of the finished garment, there is no reason to risk scratchy raised seams and waste material.

The average breakpoint for twisted sinew was 2.65 kg (SD = 1.80). The twisting process had a distinct learning curve. If the twist was created using uneven pressure along the length of the thread, then this created a weak point. In fact, when the senior author first began twisting the sinew, numerous pieces were broken simply by twisting too much and snapping through the thread. Twisted sinew is much more flexible than flat sinew, but also more prone to breakage at weak points such as knots. A total of nine twisted sinew threads broke at the knot where it attached to the weight machine (27.3%), which is approximately three times the knotted breakage rate for flat sinew threads.

The strongest twisted sinew thread was 0.39 mm thick; it broke at 10.02 kg. The weakest twisted sinew thread was 0.13 mm thick; it broke when 0.95 kg of weight was applied. This thin thread was not as evenly twisted and possibly twisted too tightly, which weakened the thread. Neither of these threads broke at a knot. We used a regression analysis to test for any correlation between thickness and breakpoint for twisted sinew (Fig. 17). A Pearson's R-value of 0.69 indicates there is a moderately positive correlation between these two variables. The stronger correlation between thickness and breakpoint for twisted sinew compared to flat likely relates to the twisting process. Thus, there is a benefit to twisting in that the thread is more pliable and less prone to delamination and fraying, but the thread is weaker, particularly if the twist is too tight or at a knot.

A total of 46 cotton and linen threads, each 20 cm in length, were subjected to strength tests (Table 2). To find the thread's breakpoint, a knot was tied to create a loop at one end. This loop was hooked onto the hanging digital scale, and weight was applied by pulling on the thread until the thread broke. The number on the scale at the point the thread broke was recorded, thus giving the

Table 2. Experimental breakage of commercially produced cotton and linen thread.

Thread Material	Breakpoint (kg)	Thread Material	Breakpoint (kg)
Cotton	2.36	Linen	4.58
Cotton	2.40	Linen	4.49
Cotton	2.27	Linen	4.58
Cotton	2.09	Linen	4.63
Cotton	2.40	Linen	4.45
Cotton	1.95	Linen	4.72
Cotton	2.40	Linen	5.13
Cotton	2.09	Linen	2.95
Cotton	2.09	Linen	0.95
Cotton	2.31	Linen	4.63
Cotton	2.59	Linen	4.45
Cotton	2.18	Linen	4.67
Cotton	2.22	Linen	4.40
Cotton	2.09	Linen	2.90
Cotton	2.49	Linen	4.94
Cotton	2.59	Linen	4.63
Cotton	2.81	Linen	5.22
Cotton	1.91	Linen	4.45
Cotton	2.40	Linen	4.31
Cotton	2.36	Linen	3.45
Cotton	2.40	Linen	4.76
Cotton	2.31	Linen	5.31
Cotton	2.49	Linen	4.49
Cotton	2.31	Linen	4.63
Cotton	2.40	Linen	4.49
Cotton	2.68	Linen	4.40
Cotton	2.13	Linen	2.40
Cotton	2.36	Linen	5.03
Cotton	2.40	Linen	4.85
Cotton	2.31	Linen	4.26
Cotton	2.36	Linen	4.49
Cotton	2.49	Linen	4.67
Cotton	2.68	Linen	3.40
Cotton	2.31	Linen	4.45
Cotton	2.40	Linen	4.58
Cotton	2.40	Linen	4.72
Cotton	2.45	Linen	4.40
Cotton	2.22	Linen	2.04
Cotton	2.36	Linen	5.26
Cotton	2.31	Linen	4.72
Cotton	2.54	Linen	4.63
Cotton	2.36	Linen	4.35
Cotton	2.36	Linen	4.45
Cotton	2.31	Linen	4.31
Cotton	2.22	Linen	4.67
Cotton	2.59	Linen	4.85
Min	**1.91**	**Min**	**0.95**
Max	**2.81**	**Max**	**5.31**
Avg	**2.35**	**Avg**	**4.28**
SD	**0.18**	**SD**	**0.84**

failure point of each thread. The same style knot and slow method of pulling were applied to each thread of all material types to give as accurate a measure as possible. The cotton and linen threads were highly consistent in thickness, as is expected from commercially produced thread. All lengths of cotton and linen thread were 20 cm long and prepared to hang from a loop on the scale in the same manner as the sinew. Cotton averaged 2.35 kg test weight before breaking (SD = 0.18). The strongest cotton length tested broke at 2.81 kg, and the weakest broke at 1.90 kg. Interestingly, the Londonderry linen thread proved the strongest, with an average breakpoint of 4.28 kg (SD = 0.84). The strongest breakpoint for linen was 5.31 kg, and the weakest linen thread broke at 0.95 kg. Although linen was the most variable in terms of minimum and maximum breakage, as reflected in the standard deviation, both cellulose threads are much less variable than their animal tendon counterparts.

Additional statistical analyses were undertaken using a Student's T-test to assess the difference among all four thread types (Table 3) in terms of breakage. Comparison of flat to twisted sinew and twisted sinew to cotton showed no significant difference. Given that cotton thread requires no preparation, is as thin as sinew threads, is pliable, and is not significantly different in terms of strength to sinew (with linen being nearly twice as strong), it is not surprising that cotton thread has replaced sinew in many applications. However, sinew thread has a distinct ability to swell when moist, thus sealing the stitch piercings and creating a more watertight seam than either cotton or linen.

It is well known from ethnographic accounts in the Bering Strait region of Alaska (Ray 1975) and elsewhere in the north (LeMoine and Darwent 2013) that metal

Table 3. Statistical comparison of thread material breakpoints using a Student's T-test. No significant difference between flat and twisted sinew, and between twisted sinew and cotton.

	Flat Sinew	Twisted Sinew	Cotton	Linen
Flat Sinew	—	1.40	2.96*	–4.51*
Twisted Sinew	1.40	—	0.50	6.02*
Cotton	2.96*	0.50	—	–15.44*
Linen	–4.51*	6.02*	–15.44*	—

*significant difference at p < 0.01

needles and thimbles were highly sought-after trade items and replaced ivory, bone, and copper almost immediately. The Arctic garments from the Smithsonian's collection were produced between 1869 and 1888, which is well after the Russian-American trading post was established at St. Michael in 1833, but metal implements were already major items of trade as early as 1816–1820 (Ray 1975:68, 101). By 1898, cotton cloth and thread was especially prized by indigenous seamstresses in order to create cotton covers for their parkas, and at one local feast, 80% of the European redistributed goods were cloth items (Ray 1975:242). That being the case, however, constituent performance is crucial to the creation of functional finished garments. Women would have taken, and continue to take, the performance of materials and their preparation cost into the highest consideration when deciding whether to accept or reject particular materials for use in the construction of sewn garments. Sinew appears to have been retained as a thread filament long after the availability of commercial thread.

SEAM BREAKAGE TESTS

Thirty-nine sample seams were created using overcast stitch in each thread type (Table 4), using brain-tanned reindeer hide with fur remaining intact. Overcast stitch was the only stitch type identified on stress-bearing seams in the museum collections, and thus this was the only type replicated. It took an average of 25 minutes to create each sample seam. After construction, each finished seam was manipulated for two minutes each to see if the stitches puckered or if the seam lay flat during movement. It is essential for seams to lie flat as the material could cause friction, which may lead to chafing or blistering for the wearer or material rubbing if under- or overgarments are worn with the clothing item. All of the senior author's sample seam stitches stayed flat, and the hide pieces remained parallel during and after manipulation. All knots held.

The first overcast-stitch seam tested for strength (breakpoint) was 6 cm in length. The stitches were approximately five per centimeter, and the seam was created with twisted sinew. This seam was then lashed to a one-half-inch dowel with perlé-cotton thread, which is a 6-mm-thick twisted cotton thread. Three lash-point stitches were used to attach the piece. The test failed at 22.1 kg. Interestingly, it was not the seam that failed; instead, the hide tore in a straight line at the lashing. The average seam length for all test samples was 7.4 cm, with a maximum length of 10 cm. In every test conducted, the hide gave at the lashing even when increased to 20 lashing stitches. The overcast-stitch seams all held without damage. This pattern repeated across every thread medium (average breakpoint of 22.5 kg). Statistical comparison of overcast-seam breakpoints using a Student's T-test not surprisingly resulted in no significant difference across all material types. The reindeer hide broke before any

Table 4. Experimental breakage of overcast-stitched seams.

Thread Material	Breakpoint (kg)	Thread Material	Breakpoint (kg)	Thread Material	Breakpoint (kg)	Thread Material	Breakpoint (kg)
Flat sinew	22.1	Twisted sinew	21.9	Cotton	21.0	Linen	21.6
Flat sinew	26.9	Twisted sinew	21.0	Cotton	21.9	Linen	22.3
Flat sinew	22.5	Twisted sinew	21.3	Cotton	23.2	Linen	23.0
Flat sinew	20.5	Twisted sinew	20.7	Cotton	22.4	Linen	22.0
Flat sinew	21.4	Twisted sinew	23.3	Cotton	27.3	Linen	22.1
Flat sinew	18.5	Twisted sinew	28.5	Cotton	21.6	Linen	25.5
Flat sinew	22.2	Twisted sinew	20.0	Cotton	28.7	Linen	25.3
Flat sinew	21.0	Twisted sinew	21.4	Cotton	21.3	Linen	25.4
Flat sinew	19.2	Twisted sinew	21.7	Cotton	22.1	Linen	20.3
		Twisted sinew	21.5	Cotton	23.9	Linen	22.0
Min	**18.5**	**Min**	**20.0**	**Min**	**21.0**	**Min**	**20.3**
Max	**26.9**	**Max**	**28.5**	**Max**	**28.7**	**Max**	**25.5**
Avg	**21.8**	**Avg**	**22.5**	**Avg**	**23.6**	**Avg**	**22.9**

of the seams. In other words, all seams produced with overcast stitch, regardless of thread type, are stronger than the leather being held together. Thus, the stress test proved the overcast stitch to be extremely sturdy as well as conservative of raw material, as the leather pieces can be placed edge-to-edge. It is a stitch engineered for both comfort and strength.

DISCUSSION

Barbara Bodenhorn (1990) quoted an Iñupiaq hunter in the title of her paper discussing gender roles in northern Alaska: "I'm not the great hunter, my wife is." She wanted to dispel the Western notion of gender roles in relation to hunting prowess and women's roles as spiritual hunters. However, one part of this article clearly emphasizes the importance of having a wife to prepare the husband's clothing. Men could make repairs, but the skill to create Arctic-adapted clothing is a highly specialized one and solely the domain of women (Billson and Mancini 2007; Gilligan 2010; Guemple 1986; Nakashima 2002; Oakes 1991; Oakes and Riewe 1996). It was women who developed the clothing technologies necessary for humans to survive and thrive in harsh Arctic environments. It was women who developed the hide working, thread, stitch, piecing, and tailoring that all worked in concert to create various garments and other leather items like boats and floats. It was women who created these items and passed on the knowledge of how to do so from generation to generation. Due to "women's exclusion," women's roles in the development and creation of these items have historically been downplayed or ignored, and the study of how women developed these essential technologies has been overlooked (Brumbach and Jarvenpa 2006). The agency of women in concert with the constraints of culture, environment, the physical properties of raw materials as explored in this study, and gender (Conkey and Gero 1997; Dobres and Robb 2000; Havenith 2010; Oakes and Riewe 2007; Williamson 2006) provide the conditions in which indigenous Arctic women perfected the technology of clothing engineered for the Arctic environment.

The processing of hides and the sewing of clothing is highly skilled labor, and in coastal Arctic communities, these tasks were traditionally the responsibility of women. Contemporary peoples of the Arctic have continued to meet the challenges of their environment with the addition of market goods (Firestone 1994; King et al. 2005; LeMoine and Darwent 2013; Wilder 1976). Most clothing items in coastal Alaskan villages are purchased retail goods one could find anywhere else in North America or are available to purchase online. Handmade traditional clothing has become, in many parts of Alaska, special occasion attire (Issenmann 1997; King et al. 2005). We noted while working near the Native village of Shaktoolik, Alaska, in 2014 that traditional sewing materials are on the decline in this region. A few women still sewed animal hides, but none produced sinew thread. Cloth sewing, however, is popular. In contrast, traditional skin-clothing production, particularly in the eastern Canadian Arctic, remains a dynamic and important part of Inuit identity (e.g., Oakes and Riewe 1996; Kassam 2017).

As market goods have replaced traditional clothing for Iñupiaq people in Alaska, the skills needed to create these remarkable items have diminished (Firestone 1994), making it difficult or impossible to ethnographically observe the construction of traditional garments by Native peoples. Additionally, these hide and thread items, and the tools used to make them, tend to survive poorly in the archaeological record, leaving only ethnographic museum pieces to examine. These items, some of which are well over 100 years old, are too valuable and too fragile to be tested for their quantitative properties. Not only is it highly likely that their functional properties have diminished with age, but the process of testing those properties would be destructive. This leaves the close examination of those pieces, followed by careful experimental replication, as our best course of action for discovering exactly how these garments were made and why they were made the way they were. For example, it is important not only to test seams that were reproductions of the museum garment seams but to test plausible alternatives to achieve a better understanding women's decision-making when it comes to sewing. Testing modern alternatives is necessary to understand better why clothing construction and use may have changed after the introduction of market goods and to understand better the quantitative properties of the traditional techniques in relation to materials and techniques that are in common modern use.

As this research has demonstrated, clothing production starts with the thread and the stitch. Seam construction is critical to the final fit, wear, and thermal properties of any garment. There are hundreds of ways to create a seam, but only one stitch and two thread types were used in weight-bearing seams on the museum garments studied. This was not random or artistic preference. Without skillfully created seams, no garment would be capable of allowing humans to survive in the harsh environment of the Arctic (Havenith 2010; Turner 2014:211–212). To better understand exactly how the observed seams allowed for year-round habitation, experimental replication was necessary.

Based on the daily-wear clothing produced by indigenous women living in Norton Sound in the late nineteenth century in the Smithsonian's collections, it appears that the overcast stitch was used for stress-bearing seam construction and usually Z-twisted sinew was employed. The overcast stitch is highly conservative of materials and, when executed correctly, can be waterproof and comfortable to the wearer. However, just as necessary, as demonstrated here, the stitch is stronger than the leather it is used to sew. The use of twisted sinew in the stitching process not only makes the sewing task easier to complete but creates a more pliable thread. Seam construction that manages edge-to-edge material is frugal and also creates a more comfortable garment. While twisted sinew and cotton showed no significant difference during strength tests, linen is much stronger than either. The main difference between sinew and modern spun threads is convenience and cost; among commercially produced thread, cotton is far less expensive and convenient than linen. Sinew is time-consuming and must be hand-prepared by the user. Sinew, however, has properties unique from both linen and cotton. Threads made of sinew can be tapered, that is to say, trimmed thinner at one end to more easily thread through a needle so that the thread is thicker than the hole produced. If one tries to taper trim any spun cellulose fiber thread, the thread will unravel and become useless. In addition to the ability to be tapered, sinew will swell when wet, virtually self-sealing the puncture holes of the needle and producing a watertight seam (Hall et al. 1995; Issenmann 1997; Oakes 1991; Turner 2014:211–212; Wilder 1976).

The traditional sinew seams are preferable for functional qualities of many traditional garments, especially relating to watertightness, but they do require more skill and time to create (Fienup-Riordan 2007). This study found no correlation between stitch type and garment type specific to the location of the seam within the garment, in that overcast, waterproof-style stitching was used throughout. The only example of a different stitch type, running or tacking style, was for the attachment of fur trim decorating the front of the parka hood opening. Trim would not have needed to endure the same level of stress as other parts of a garment, and thus a faster tacking stitch could be used. Similarly, modern regalia garments created solely for formal and ceremonial use—the most common application of traditional garments by modern Alaska Iñupiaq—do not need to withstand wear and tear from daily use, thus making the convenience of modern thread materials more appealing. These traditional-style garments used in a modern context do not need to make use of all traditional sewing technologies developed by Iñupiaq women, but these innovations of seam construction are pivotal in the design and execution of comfortable and functional hide clothing for survival in the unforgiving Arctic environment and are a testament to the ingenuity of indigenous women.

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