

# Sagittal Clefting of the Body and Other Vertebral Developmental Errors in Canadian Inuit Skeletons

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**KEY WORDS** vertebral development; notochord; segmentation error; spina bifida; Arctic Canada; Hudson Bay; Sadlermiut; Thule-Historic Inuit

**ABSTRACT** The objective of this study was to determine the expression, distribution in the column, and overall frequency of sagittal clefting of the vertebral body in the skeletons of two Canadian Inuit groups. One group, referred to as Thule-Historic, lived along the coast northwest of Hudson Bay, while the other, known as the Sadlermiut, were limited to Southampton Island and Coats Island north of Hudson Bay. The Thule-Historic people are thought to be the ancestors of the present-day Inuit of this region, whereas the much smaller, relatively isolated Sadlermiut became extinct during the winter of 1902–1903. The sagittal clefting results were also compared with those obtained for two other vertebral developmental problems, segmentation error and spina bifida. Sagittal clefting was found to occur with high frequency in the two

Inuit series, especially in the region T6–T10. Segmentation errors were found to occur in approximately the same region of the column, while spina bifida produced a completely different pattern, occurring primarily at T11 and S1. The T11 involvement is limited to females, while S1 involvement occurs primarily in males. Sagittal clefting and spina bifida occur in the same individual more frequently than sagittal clefting and segmentation error. Possibly reflecting the smaller population size and isolated location of the Sadlermiut, sagittal clefting was found with greater frequency and intensity in the skeletons of this group than in those of the Thule-Historic Inuit. *Am J Phys Anthropol* 123:236–249, 2004.

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An early study of skeletons of the Sadlermiut, a Canadian Inuit (Eskimo) group, produced an apparent high frequency of the congenital defect known as sagittal clefting of the vertebral body (Merbs and Wilson, 1962). The anthropological literature rarely mentions this condition, but whether this is due to its infrequent occurrence, or simply to the fact that paleopathologists are largely unaware of it, especially if its expression is relatively mild, is difficult to say. The Inuit finding led to a renewed interest in sagittal clefting and how it might relate to other congenital defects of the spine.

The objective of this study was to examine sagittal clefting from several perspectives: 1) to determine the frequency, expression, and distribution of the condition in Inuit of the Canadian Arctic; 2) to compare the condition in two very different Canadian Inuit groups, a large, widely distributed group representing the ancestors of the present-day Inuit, and a small, isolated group that became extinct during the winter of 1902–1903; and 3) to compare the occurrence and patterning of sagittal clefting with two other vertebral developmental problems, segmentation error and spina bifida (failure of laminar fusion), in these same groups.

## SAGITTAL CLEFT VERTEBRAE

Sagittal clefting as used here refers to an anatomical defect in the centrum (immature) or body (ma-

ture) of a vertebra related to the disappearance of the notochord during fetal development. The notochord provides the structural frame and inductive tissue for the development of the vertebral column, basioccipital, basisphenoid, and neural tube (Verbout, 1985; Barnes, 1994; Lonstein, 1995). When the human embryo is at approximately the 12-mm stage, the precartilaginous centrum is represented by mesenchymal masses situated on either side of the notochord (Colquhoun, 1986). Shortly after this stage, around the sixth or seventh week of development, chondrification centers for the centrum appear, one on either side of the midline, and the notochord begins to regress (Barnes, 1994; Scheuer and Black, 2000). The notochord tissue begins to degenerate by the sixth fetal month, to be replaced by cells from the internal zone of the annulus fibrosis. Normally the sagittal cleft between the chondrification centers is obliterated by medial extension of

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these centers at about the same time the notochord degenerates (Colquhoun, 1986). By week 12, the notochord has disappeared, except for parts which become entrapped within the sclerotomic fissures of the developing vertebral segments and develop into the nuclei pulposi of the vertebral disks (Peacock, 1951; Verbout, 1985; Barnes, 1994).

Ossification in the vertebral centrum begins at about 18 weeks, when the embryo is approximately 11 cm in length (Colquhoun, 1986). The ossification centers do not correspond with the centers of chondrification, but extend across the midline rather than lying to either side of it. As bone replaces cartilage in the developing centrum, failure of the notochord to recede can result in a sagittal defect ranging from a cleft or circular hole to complete separation of the body into lateral halves (Müller et al., 1986). The extreme condition is referred to as "butterfly vertebra" because of its radiographic appearance in anteroposterior view, with the divided halves of the body resembling a butterfly's wings and the spinous process resembling its body. In lateral view, the defect may take the form of an hourglass. The disk itself may be absent, or hypoplastic and calcified (Aufderheide and Rodríguez-Martin, 1998).

The adjacent surfaces of vertebrae above and below a defective segment often assume a shape that compensates for the missing bone (Merbs and Wilson, 1962, p. 178, Plate VI). However, compensatory changes may result in scoliosis (Aufderheide and Rodríguez-Martin, 1998). In a severe case, the anterior height of the centrum may be diminished, thus producing a wedge-shaped centrum and kyphosis. This condition may also occur later in life in response to vertical forces acting on a vertebral body weakened by missing bone. The degree of compression may reflect the severity of the original defect as well as a history of vertically directed microtrauma involving the back. Osteoporosis can be a contributing factor.

Sagittal clefting is thought to occur more frequently in males than in females (Aufderheide and Rodríguez-Martin, 1998). The condition is described as usually occurring separately, as least as far as other osteological changes are concerned, but it may occur along with related phenomena in the same individual, or as part of a syndrome. Peabody (1927), for example, described an infant with T6–T12 sagittal clefting and general centrum deformation, segmentation errors of vertebrae and ribs, L4 spina bifida, and lumbarization of S1. The condition is also seen in various syndromes such as Alagille, Crousen, Jarcho-Levin, and Pfeiffer (Sonel et al., 2001; Przkora et al., 2002). Sagittal cleft vertebrae have also been reported for nonhumans, including cattle (Moritomo et al., 1995) and horses (Doige, 1996).

Sagittal clefting is clearly due to a developmental error involving the cartilaginous precursor of the vertebral centrum, but its cause is unknown. Some genetic basis is suspected.

Not included in this study is the first cervical vertebra, because it lacks a body. Although its anterior arch is sometimes separated into two parts (clearly a developmental error producing a sagittal defect in the ventral part of the vertebra), this condition, unlike sagittal clefting of the body, appears unrelated to the notochord (Scheuer and Black, 2000).

### Segmentation error

By the third week of embryonic development, the mesoderm has differentiated from the endoderm and ectoderm (Lonstein, 1995). The mesoderm then proliferates and condenses into paired structures called somites (Verbout, 1985). By the fifth week of development, 42–44 pairs of somites have differentiated: 4 occipital, 8 cervical, 12 thoracic, 5 lumbar, 5 sacral, and 8–10 coccygeal (Lonstein, 1995). Eventually, the occipital somites form part of the base of the skull and the craniocervical articulation, the vertebral somites form the vertebrae, and the last 5–7 coccygeal somites disappear. Cells on the ventral and medial portions of the somite proliferate and migrate toward the notochord. It is from these cells, referred to as the sclerotome, that the vertebral column actually develops, but because they also give rise to spinal nerves they are considered mesenchyme (Lonstein, 1995).

The sclerotome mesenchyme in each of the united pairs of somites separates into cranial and caudal portions as the growth of intersegmental arteries forms a temporary transverse fissure between them (Barnes, 1994). The lower portion of a cranial somite then combines with the upper portion of the somite below, to form the final vertebra. The transverse fissure develops into a dense band which ultimately becomes the intervertebral disk. Failure of the fissure to form results in a continuous block of blastemal tissue and, ultimately, to the congenital union of two or more vertebrae. This condition is commonly referred to as "block vertebra." The degree of separation failure and the parts affected depend on the timing of the delay in the critical threshold event that triggers the development of the transverse fissure (Barnes, 1994).

It is important to distinguish this developmental error from vertebral fusion, where previously separated vertebrae become a single unit because of osteological changes caused by trauma, infection, degenerative changes, or other pathology (Jarcho and Levin, 1938; Gunderson et al., 1967).

The degree of segmentation failure is dependent on the timing and completeness of transverse fissure development. Usually there is complete unity between the bodies, with complete or incomplete cohesion of the neural arches (Barnes, 1994), but the condition varies considerably in terms of which vertebral parts remain attached.

Segmentation failure in the cervical region is often referred to as Klippel-Feil syndrome. Although three types of the condition are presently recog-

nized, infants born with types I and III usually suffer from multiple defects that make survival difficult (Brown et al., 1964; Gunderson et al., 1967). The cervical block vertebrae generally seen in archaeological collections are of type II, with only 2 or 3 vertebrae involved, and C2–C3 affected most frequently (Barnes, 1994). The type II category is applicable to block vertebrae in the thoracic and lumbar regions as well, and the condition generally produces no symptoms.

### Spina bifida

The term “spina bifida” refers to a failure of the laminae to fuse to complete the neural arch. The term presents a problem, however, because it can refer to specific medical conditions such as spina bifida cystica and spina bifida occulta. Hoping to avoid this problem, Barnes (1994) suggested using the term “cleft neural arch” or “bifurcated neural arch.” However, these terms refer to different manifestations of the condition, and a collective term referring to both of them would seem desirable.

During early morphogenesis of the vertebral column, sclerotome cells from the proliferating caudal part of the somite develop dorsally to form the anlage of the neural arch and its processes (Barnes, 1994). The two chondrification centers that form the dorsal part of the arch appear during the sixth fetal week, followed by the two centers forming the anterior part of the arch (Barnes, 1994). By the expansion and fusion of these four centers, along with the two forming the centrum, a cartilaginous vertebral unit is formed (Scheuer and Black, 2000). The unit is complete when fusion occurs at the spinous process during the fourth fetal month.

Three ossification centers develop to form the final vertebra, one for the centrum and one for each half of the neural arch plus a small part of the vertebral body. Although there is some controversy as to the exact sequence of appearance of these centers (Scheuer and Black, 2000), all three are present in all presacral vertebrae by at least the end of the fourth fetal month (Budorick et al., 1991). During the first year of postnatal life, the laminae of the arches fuse posteriorly, beginning in the lower thoracic-upper lumbar region toward the end of the first year, and then proceeding upward and downward. The cervical arches may not fuse until the beginning of the second year, and the lumbar may not fuse until the end of the fifth year (Scheuer and Black, 2000).

Spina bifida as considered in this study is due to a developmental delay resulting in hypoplasia or aplasia of the precursors of the neural arch. Barnes (1994) recognized two forms, “bifurcation” and “clefting.” In the bifurcation form, thought to represent a minor delay in development, the two sides come together but do not fuse, while in the clefting form, thought to represent a major delay, the two sides do not come together, leaving a cleft (gap) between them.

The condition may be symmetrical or asymmetrical, depending on the degree of hypoplasia or aplasia on the two sides. The less affected side may develop beyond its boundaries when it fails to meet the affected side at the proper time. This may even result in the unaffected side producing a spinous process with the separation between the hemiarcs located some distance from the midline toward the defective side (Barnes, 1994, p. 124, Fig. 3.43). It is also possible for the hypoplasia to be symmetrical, with both sides failing to produce a spinous process (Barnes, 1994, p. 123, Fig. 3.42). In this case, the laminae may ultimately fuse, but with aplasia of the spinous process (Merbs and Wilson, 1962, p. 179, Plate VII-B; Anderson, 1996).

Simple spina bifida is reported to occur primarily in the border regions (Barnes, 1994), particularly at the lumbosacral border. The last lumbar exhibits a bifid defect more frequently than any of the other lumbar vertebrae, while clefting at the S1 level is particularly common. Clefting of C1 has been reported for about 5% of adults, while the lower end of the cervical column is affected less frequently (Barnes, 1994). Involvement of the thoracic region is rare, with the lower border affected most frequently. According to Willis (1923, p. 105), however, “the eleventh thoracic (the eighteenth pre-sacral) segment frequently, and the twelfth more rarely, show a posterior fusion of the laminae but lack a spinous process. This defect is of course a very imperfect form of spina bifida and should be so recognized.”

### SAGITTAL CLEFT IN THE ANTHROPOLOGICAL LITERATURE

In an early study of the vertebral column in the South African Bantu, Shore (1930) noted an unusual fifth thoracic vertebra in a 40-year-old Basutu male. He described the vertebral body as wedge-shaped, its anterior height reduced by approximately 6.5 mm (40%), and he felt that it clearly represented a “developmental phenomenon.” He also noted that this apparent expression of sagittal clefting was the only one observed in 1,936 Bantu vertebrae studied.

An example of sagittal clefting was reported for the skeleton of a middle-aged adult recovered from Krasnojarski Kray near the village of Podgornoe in eastern Siberia (Rokhlin, 1965). The site is dated to the sixth to fifth centuries BC. Although the affected vertebra is identified in the text as lumbar, the specimen illustrated (Rokhlin, 1965, p. 162, Fig. 80) is clearly lower thoracic. The body has a deep sagittal groove in its upper and lower surfaces, and a “scar” on its anterior surface. To the left and adjacent to the groove is a semicircular aperture that extends vertically through the body. A small opening in the dorsal wall of the body makes the defect continuous with the neural canal.

In South America, sagittal clefting of T8 was found in a 20–30-year-old female from Pacatmu, Peru, dating to the 11th–15th centuries AD (Mann and Verano, 1990). The body contains a large circu-

lar aperture that extends for approximately one-third of the body's transverse diameter and communicates with the neural canal. The affected body has a reduced anterior height, and the body surfaces of the contiguous vertebrae show compensatory overgrowth congruent with the defective segment. Also present in this individual is a segmentation error involving the neural arches of T4, T5, and T6, resulting in a block vertebra. Absence of a costal facet on the left transverse process of T5 suggests a segmentation error of the left ribs as well. Another Peruvian example involves an adult midthoracic vertebra from Huacho, Peru, part of the Hrdlička Paleopathology Collection at the San Diego Museum of Man (Merbs, 1980, p. 148–149, Figs. B, C). Sagittal clefting involving the dorsal one-third of the body appears as a shallow groove on the superior, dorsal, and inferior surfaces of the body.

A sagittal cleft vertebra was observed at the Henderson Site, a late prehistoric Puebloan population in the Pecos Valley near Roswell, New Mexico (Rocek and Speth, 1986). The burial of a young adult, probably male, includes a T6 with a large anterior portion of its body missing, and a dorsal cleft that divides the body into distinct halves (Rocek and Speth, 1986, p. 144, Fig. 117). The body surfaces immediately above and below the defective vertebra are described as "slightly deformed to partially fill the gap" (Rocek and Speth, 1986, p. 142). The sixth and seventh ribs on both sides are fused together by bony bridging adjacent to their vertebral articulation (Rocek and Speth, 1986, p. 143, Fig. 116). Two vertebrae with sagittal clefting are present in an adolescent skeleton (sex unknown) from Schoolhouse Point Mound, a Salado site dated to AD 1150–1450 located near Roosevelt Lake in central Arizona (Regan et al., 1996). Although listed in the inventory as C4 and C5, they are more likely C3 and C5, with C4 missing. Both vertebrae have a defect involving the dorsal surface of the body, which reduces the posterior body height in the midline by about 50%.

A case of sagittal clefting of T11 is reported for the Trigg site in Virginia that dates to AD 1610–1620 (Barnes, 1994, p. 39, Fig. 3.2). Separation of the lateral halves is complete, with hypoplasia of the left half. The affected body shows extreme anterior wedging, and the adjacent body surfaces show compensatory increased anterior height.

The Uxbridge Ossuary, an Iroquois site in southern Ontario, produced two adults with sagittal cleft vertebrae (Pfeiffer et al., 1985). In one, the body of T12, described as a true butterfly vertebra, is completely divided into lateral halves, each forming a wedge. This vertebra is solidly fused (segmentation error?) to the one above through the zygapophysial joints and the ends of the spinous processes (Pfeiffer et al., 1985, p. 87, Fig. 5). Another thoracic vertebra (T8 or T9) from the same individual shows abnormal modeling of the inferior body surface similar to that on T11, suggesting that the vertebra below (not re-

covered) was also a butterfly vertebra. An unidentified thoracic vertebra from a second individual also showed evidence of sagittal clefting. A juvenile mid-cervical vertebra from the Fairty Ossuary in Ontario, Canada, showed a wide defect that separated the body into right and left sides (Anderson, 1963, p. 84–85, Plate XI-A). A thoracic vertebra from this same site has a wedge-shaped body attributed to compression fracturing, but the cause may be sagittal clefting. A view of the vertebra (Anderson, 1963, p. 84–85, Plate XI-C) shows a deep groove on its superior body surface. The reduction in anterior body height may be a direct result of sagittal clefting, or may have been caused by compressive forces acting on a body weakened by congenital clefting.

Complete sagittal clefting with a circular defect was observed in a transitional lumbosacral vertebra by Frets (Schmorl and Junghans, 1971), but the source of the specimen, whether from an archaeological site or an anatomy collection, is not indicated. The affected segment is fused with the sacrum on the left side and separate on the right. If its description as the "last presacral vertebra" is correct, it is a case of L5 sacralization (cranial shift) (Barnes, 1994).

It is likely that other examples of sagittal clefting of the vertebral body exist in osteological reports, but, as just one of many phenomena included, the term does not show up among the key words. A search of the paleopathology bibliography (Elerick and Tyson, 1997) and its supplements for the terms "sagittal" and "cleft" turned up several references to premature closure of the sagittal suture and numerous references to cleft lip and cleft palate, but no references to sagittal cleft vertebrae.

## RESEARCH COLLECTIONS

The Inuit series identified as Thule-Historic is from sites located on the mainland northwest of Hudson Bay (Fig. 1). Five sites produced a total of 218 skeletons with observable vertebrae as follows: Silumiut = 114, Kamarvik = 67, Kulaituijavik = 15, Inuksivik = 13, and Naujan = 9. The series primarily represents the Thule culture (beginning ca. AD 1200), but includes some historic (late 1800s–early 1900s) material (McCartney, 1977). The Sadlermiut series is from Southampton Island, which forms the northern boundary of Hudson Bay. The observable vertebrae for this series come from 115 skeletons: 111 from Native Point (Tunermiut), and 4 from Prairie Point. With one exception, the study material is currently curated by the Archaeological Survey of Canada at the Canadian Museum of Civilization (Hull, Quebec). The exception is the Naujan series, which was studied at the Panum Institute (Copenhagen, Denmark), but has since been returned to Canada.

The Thule-Historic series represents a basic continuity of Canadian Inuit from the arrival of the Thule culture from Alaska around AD 1200 to the present. Although centered on the mainland west



Fig. 1. Map of region north (Southampton Island = Sadlermiut) and northwest (mainland = Thule-Historic) of Hudson Bay, showing locations of sites that produced skeletons used in this study.

and northwest of Hudson Bay, these people appear representative of the general Inuit population that occupied most of the Canadian Arctic. The Sadlermiut, in contrast, were a small isolated group that occupied Southampton Island and nearby Coats Island north of Hudson Bay until they became extinct during the winter of 1902–1903 as a result of infectious disease introduced by the crew of a Scottish whaling ship (Merbs, 1983). Although these islands lie very close to the Thule-Historic mainland sites, separated only by Roes Welcome Sound, the geography of the area (primarily winter ice conditions) and distinct cultural differences appear to have effectively kept the Sadlermiut from sharing many cultural traits or genes with their mainland neighbors. The Sadlermiut thus represent a much smaller, more inbred genetic isolate.

#### METHODS

Using standard anthropological procedures (Buikstra and Ubelaker, 1994), age at death and sex had

already been recorded by the author as part of the general study of the two series. The following vertebrae were examined for each of the conditions studied: C2–S1 for sagittal clefting, occipital–S1 for segmentation error, and C1–S1 for spina bifida. The location of the vertebrae in the column was noted along with the form of the defect. Multiple defects in the same column were also noted.

Because of the extreme preservation differences between the two series, the study dealt primarily with affected vertebrae rather than affected individuals. In the case of sagittal clefting, for example, the Sadlermiut series produced 115 columns with 2,361 observable vertebrae, for an average of 20.5 vertebrae per column, compared with the Thule-Historic series, which produced 218 columns with 1,610 vertebrae, for an average of only 7.4 vertebrae per column. The abundance of complete or nearly complete (>90%) Sadlermiut columns (107) makes it practical to record frequencies of affected individuals for this series. In contrast, the Thule-Historic series pro-

TABLE 1. Classification of sagittal clefting of vertebral body used in this study

Form	
L,	linear defect with anteroposterior orientation
C,	circular (approximate) defect in end-plate surface or aperture extending through body
T,	triangular defect (usually a severe defect with apex of triangle toward neural canal)
Anteroposterior location	
A,	defect communicates with anterior (ventral) margin of body
M,	defect in middle of body (communicates with neither ventral nor dorsal margin)
P,	defect communicates with posterior (neural canal) margin of body
Transverse location	
L,	defect to left of midsagittal line
S,	defect approximates midsagittal line
R,	defect to right of midsagittal line
Degree of expression	
1,	defect visible on only one body surface (superior, inferior, or dorsal)
2,	defect visible on superior and inferior body surfaces, but does not extend through body (traces visible on radiographs not considered here)
3,	defect clearly extends through body, but for less than 50% of body's anteroposterior diameter
4,	defect forms large gap, with partial separation of body (over 50%) into right and left parts
5,	defect completely separates body into right and left sides (full butterfly vertebra)

duced very few complete or nearly complete columns (21): too few, it was judged, to make a valid comparison between the two series based on frequencies of affected columns. Nevertheless, the Sadlermiut column results are included in the study to complete the profile for this group and as a basis for comparison in future studies.

Sagittal clefting was classified according to its general form, position in the vertebral body, and degree of expression (Table 1). Three defect forms were recognized, based on the shape of the defect: linear (L), circular (C), and triangular (T). In the L form, the defect is linear, usually narrow, and sometimes with a sharply folded appearance, and its margins are well-corticated (Fig. 2A). The defect may be visible on one or both end plates, and in severe cases it may continue onto the ventral surface of the body, where it is said to resemble a scar. The defect may lie in the midsagittal plane or a parallel plane, or it may angle away from the sagittal plane. The defect is usually visible on radiographs directed vertically through the vertebral body (Fig. 2B), and its presence may be associated with an anterior height reduction of the body.

The C form of defect appears as a roughly circular depression, in or near the midsagittal plane, or some distance from it. The defect may be shallow or deep, and may be visible on one or both horizontal body surfaces. Frequently the defect extends vertically entirely through the body, thus producing an aperture. In young individuals the defect appears more circular or oval in outline (horizontal), and the transition from the body surface to the aperture surface is gradual and smooth (Fig. 3), while in older indi-

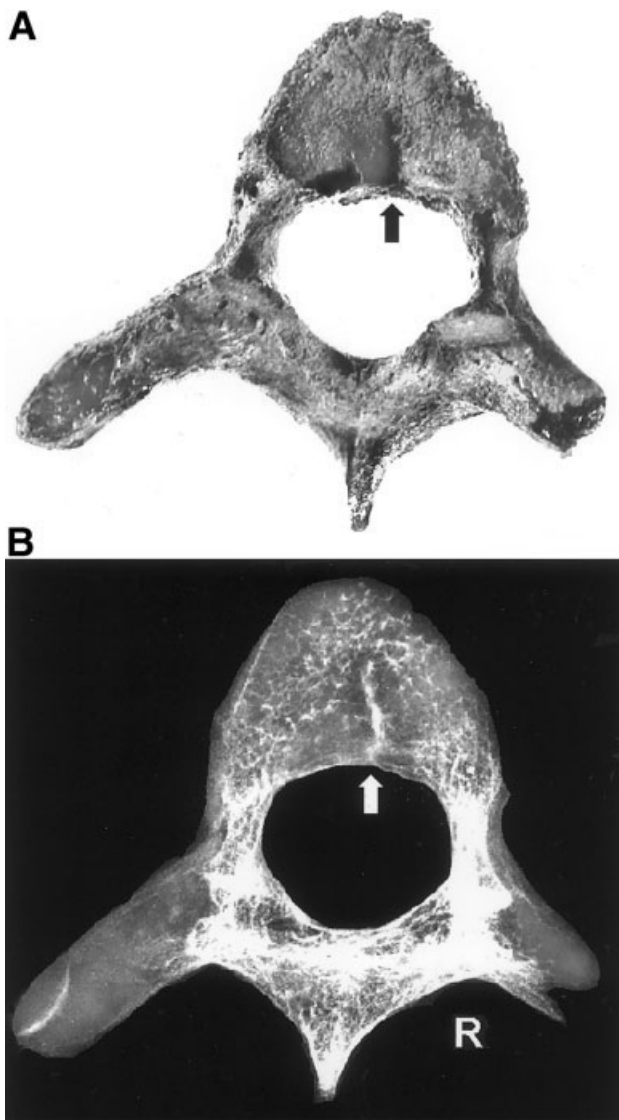


Fig. 2. Fourth thoracic vertebra, with a linear defect (arrow) to right of midsagittal line that communicates with neural canal. **A:** Superior view. **B:** Radiograph (view from above). Middle-aged adult female from Inuksivik. Table 2, case 25.

viduals the outline of the defect is more irregular, with relatively sharp margins (Fig. 4A). When viewed radiographically from the side, the defect may look like an hourglass or the letter X (Fig. 4B). L and C defects may occur in the same vertebra, and when they do, they are generally contiguous. Where this happened in the present study it was classified as C(L) and scored as C, giving preference to what was interpreted as the more severe defect (Fig. 5).

The T category, in which a significant portion of the body is missing, is the form most easily identified (Fig. 6). The apex of the triangle is toward the neural canal, and the margins are well-corticated. In its most extreme form, the lateral parts of the body are completely separated, producing the classic butterfly vertebra when viewed radiographically. This form of the defect is most likely to be associated with



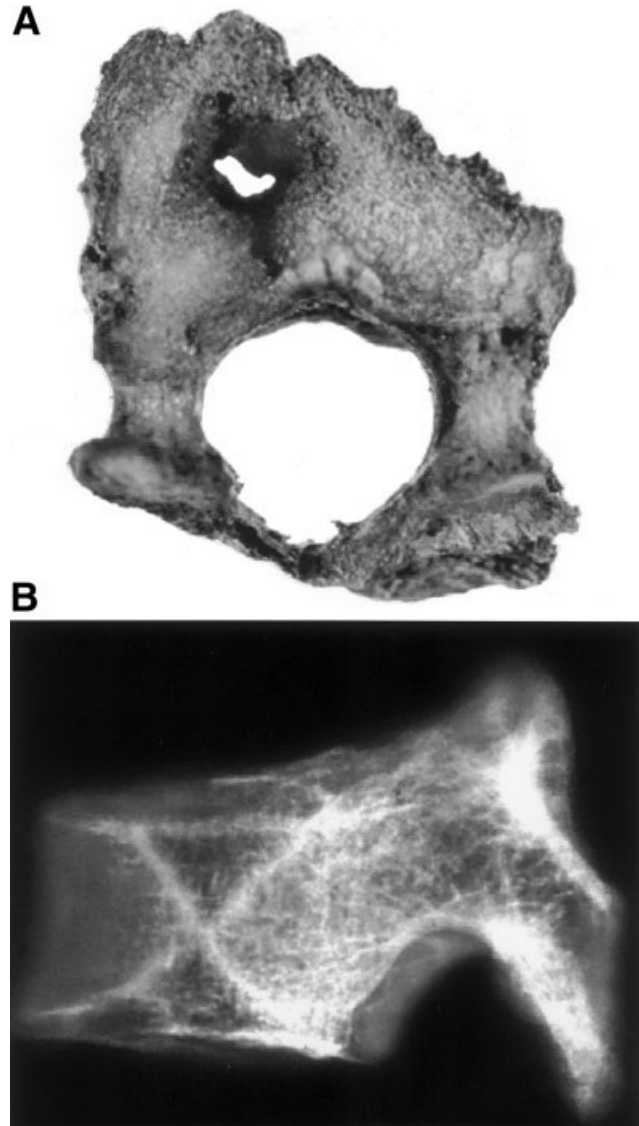
**Fig. 3.** Ninth thoracic vertebra, with a circular defect (arrow) to left of midline that communicates with neural canal. Young adult male from Native Point. Superior view. Table 2, case 14.

compensatory changes in the body shape of the vertebrae above and below the defective vertebra (Fig. 7). In young individuals, the margins of the defect merge smoothly with the end-plate surfaces of the body. With age, however, the edges of the defect become sharp and may develop osteophytes. This is also the form most often associated with simulated or real compression fracturing of the defective body.

The defect was also defined according to its location in the anteroposterior plane of the vertebral body (Table 1). A defect that does not communicate with either the anterior or posterior margin is defined as middle (M); when communication does occur, it is described as anterior (A) or posterior (P). The defect is also described according to its location in the transverse plane of the body as midsagittal (S), or to the left (L) or right (R) of the midline. Some defects were found to occur some distance from the midsagittal line.

A scoring system ranging from 1 (least) to 5 (most) was devised to measure the degree of expression within individuals, and between the Thule-Historic and Sadlermiut series (Table 1). The system is based entirely on appearance, and any clinical significance it might have is unknown.

Care was taken to avoid conditions that could mimic or mask sagittal clefting, the most obvious of these being disk herniations (Schmorl's nodes) and bone-destroying infection (e.g., tuberculosis). The C-type defect can usually be distinguished from the effects of disk herniation, for example, by its regular appearance, the relatively smooth cortication of its surface, and its location in or near the midsagittal plane. Each of the other conditions was found to



**Fig. 4.** Ninth thoracic vertebra, with circular defect (deformed by degenerative processes) to left of midline. Middle-aged adult female from Silumiut. **A:** Superior view. **B:** Radiograph (transverse view) shows defect resembling letter X. Table 2, case 24.

have distinguishing features, and no confusion was encountered. It is possible, however, that minor sagittal defects could be masked by severe degenerative changes in older individuals. Unusual anatomical features were sometimes observed that might be related to sagittal clefting, but they were not included in the study since an actual relationship could not be established. These features were limited to children.

A potential for error is the large bore hole occasionally encountered in the center of a vertebral body. In the past, cancellous bone from these holes was used for chemical analysis and blood typing. A recent example of this approach is described by Cattaneo et al. (1992) in their attempt to identify albumin in ancient bone. They described the damage caused to vertebral bodies by their boring as "small,"

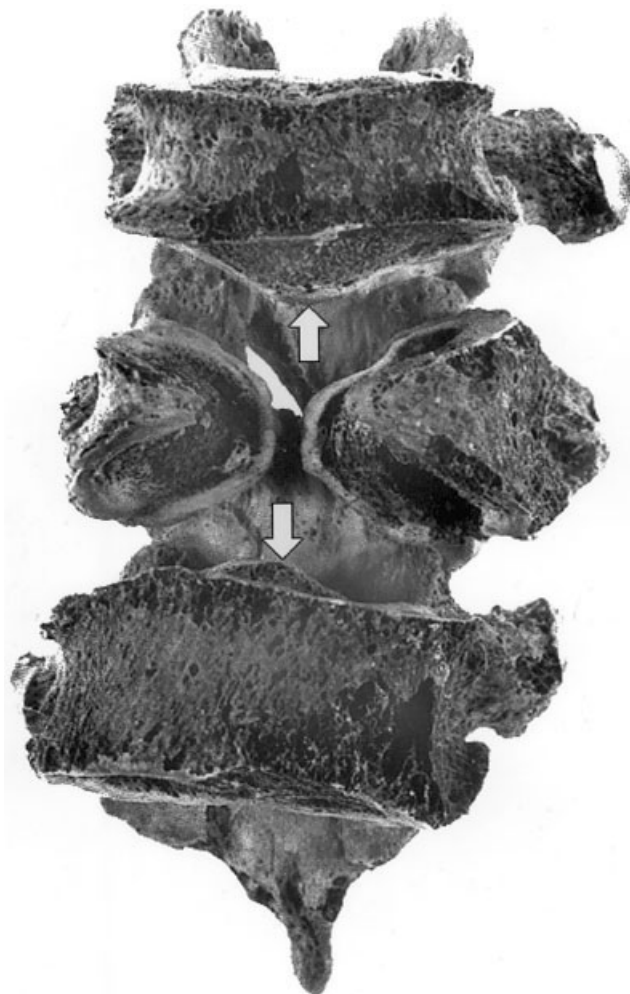


**Fig. 5.** Fifth thoracic vertebra, with combined circular (mid-sagittal) and linear (right) defects. Young adult male from Native Point. Superior view. Table 2, case 1.



**Fig. 6.** Seventh thoracic vertebra, with triangular defect that divides body into two separate parts (butterfly vertebra). Middle-aged adult female from Native Point. Superior view. Table 2, case 10.

leaving intact “the morphological features likely to be of most value to palaeopathologists” (Cattaneo et al., 1992, p. 368, Fig. 2). Although the general appearance and location of these holes can mimic sagittal clefting, their extreme regularity, sharp edges, and total absence of cortication should make them



**Fig. 7.** Sixth, seventh, and eighth thoracic vertebrae (same case as Fig. 6), showing compensation (arrows) by T6 and T8 for defect in T7. Anterior view. Note that in T7, ring epiphyses which normally would encircle superior and inferior surfaces of body are divided by defect into right and left sides, but are continuous on each side between superior and inferior surfaces.

obvious. The possibility that their removal resulted in the destruction of clefting evidence is potentially a more serious problem. Fortunately, none of the Inuit skeletons in this study had been exposed to boring.

All examples of fused vertebrae were examined, but they were recorded as segmentation error only if pathology (e.g., trauma, arthritis, or infection) could reasonably be eliminated. The total sample size was determined by the number of intervertebral spaces represented, whether by two contiguous vertebrae, or just the vertebrae above or below a space. This is based on the principle that if two vertebra had not segmented but had broken apart postmortem, this would be detectable even though only one was available for study.

Cases of spina bifida included separations between the laminae that occurred in the midline, or to either side of the midline. Included are examples where a spinous process developed entirely from the

TABLE 2. *Sagittal cleft vertebrae in canadian inuit skeletons*<sup>1</sup>

Case	Burial	Age	Sex	Vertebra affected	Form of defect	Location		Degree of severity
						A-P	Trans.	
1	NP-14	Young adult	Male	T5	C(L)	P	S(R)	3
				T8	T	A	R	4
2	NP-15	Child	?	S1	<i>Spina bifida</i>			
				T8	L	P	L	2
				T10	L	P	S	3
3	NP-16	Old adult	Male	T11	<i>Spina bifida</i>			
				C2	L	P	S	1
4	NP-48	Middle-aged adult	Female	T6	C	M	L	3
5	NP-75	Child	?	T8	L	P	R	2
				T10	T	A	R	5
				T11	<i>Spina bifida</i>			
6	NP-78	Young adult	Female	L5	L	P	S	1
7	NP-127	Young adult	Female	T6	L	A	L	2
8	NP-146	Middle-aged adult	Male	T8	T	P	S	4
				S1	<i>Spina bifida</i>			
9	NP-156	Child	?	C2	L	P	S	1
				C3	L	P	S	2
10	NP-175	Middle-aged adult	Female	T7	T	A	S	5
11	NP-182	Middle-aged adult	Female	T4	C	M	L	1
				T3-T4	<i>Segmentation error</i>			
12	NP-C20	Young adult	Male	T8-T9	<i>Segmentation error</i>			
				T9	C	M	S	1
13	NP-C22	Young adult	Female	T8	C	M	R	1
14	NP-C28	Young adult	Male	T8	C	M	R	3
				T9	C	P	L	3
				T12	C	M	R	2
15	PP-2	Adult	Female	L2	C	P	S	2
				T6	C	M	S	2
16	KA-3	Old adult	Male	T2	L	M	R	1
				T3	<i>Spina bifida</i>			
17	KA-5	Old adult	Female	T3-T4	<i>Segmentation error</i>			
				T5	C	M	S	1
18	KA-51	Middle-aged adult	Female	T6-T7	<i>Segmentation error</i>			
				L1-L2	<i>Segmentation error</i>			
19	KA-88	Old adult	Male	T6	C(L)	M	S	2
20	KA-115	Young adult	Male	T10	L	P	S	1
				T11	L	P	S	2
21	SIL-30	Young adult	Male	S1	<i>Spina bifida</i>			
				T3	L	M	S	2
22	SIL-75	Middle-aged adult	Male	T7	C	M	S	1
				T11	C	M	S	1
23	SIL-138	Child	?	T3-T4	<i>Segmentation error</i>			
				T4	<i>Spina bifida</i>			
24	SIL-148	Middle-aged adult	Female	C2	L	P	S	1
25	IN-7	Middle-aged Adult	Female	T9	C	M	L	3
26	NAU-5	Old adult	Female	T4	L	P	R	2
				C4	L	P	S	1
				C2-C3	<i>Segmentation error</i>			

NP, Native Point (Sadlermiut); SIL, Silumiut (Thule-Historic); PP, Prairie Point (Sadlermiut); IN, Inuksivik (Thule-Historic); KA, Kamarvik (Thule-Historic); NAU, Naujan (Thule-Historic). See Table 1 for defect codes.

<sup>1</sup> Included are cases of spina bifida and segmentation error occurring in these same individuals.

left or the right lamina, developed from both (divided process), or failed to develop on either side. Also included are cases (all T11) where the laminae eventually fused, but with no development (aplasia) of a spinous process. Not included are vertebrae in juveniles where laminae may normally be unfused at the individual's particular stage of development.

Possible relationships between sagittal clefting and the other conditions observed were studied in terms of whether they involved the same vertebra or adjacent vertebrae, whether they occurred in the same individual but at distant levels in the column, or whether they occurred in different individuals but had a similar pattern of involvement with respect to vertebral level.

Based on their origin as the costal element of a vertebra and the occurrence of fused ribs along with sagittal clefting at the same level in a New Mexico Pueblo skeleton (Rocek and Speth, 1986), the ribs in both Inuit series were also examined for segmentation error.

## RESULTS

Examination of 3,964 vertebrae in the two Inuit series produced 26 individuals with sagittal clefting: 4 children and 22 adults (12 female, 10 male) (Table 2). In total, 34 vertebrae are affected, for a frequency rate of 0.86% (Table 3). The overall frequency of affected vertebrae in individuals where sex was determined is slightly higher in males (0.82%;

TABLE 3. Canadian Inuit vertebrae with sagittal clefting<sup>1</sup>

Vertebra	Sad.	T.-H.	Total	Series	Sex
C2	97	84	181	■ ■ □	♂ ○ ○
C3	84	51	135	■	○
C4	85	52	137	□	♀
C5	88	58	146		
C6	96	58	154		
C7	100	46	146		
T1	94	52	146		
T2	99	55	154	□	♂
T3	96	51	147	□	♂
T4	100	52	152	■ □	♀ ♀
T5	102	56	158	■ □	♀ ♂
T6	104	65	169	■ ■ ■ □	♀ ♀ ♀ ♀
T7	105	56	174	■ □	♀ ♂
T8	103	64	167	■ ■ ■ ■ ■ ■ ■ ■	♀ ♂ ♂ ♂ ○ ○
T9	103	73	176	■ ■ □	♀ ♂ ♂
T10	99	75	174	■ ■ □	♂ ○ ○
T11	103	73	176	□ □	♂ ♂
T12	95	72	167	■	♂
L1	100	75	175		
L2	103	79	182	■	♂
L3	101	76	177		
L4	100	76	176		
L5	102	89	191	■	♀
S1	102	101	203		
Totals	2,361	1,610	3,964	34 vertebrae	12, ♀; 15, ♂; 7, ?

<sup>1</sup> Sad, total Sadlermiut vertebrae observed; T.-H., total Thule-Historic vertebrae observed; Sagittal clefting: ■, Sadlermiut cases; □, Thule-Historic cases. ♀, female; ♂, male; ○, sex not determined.

15/1,832) than females (0.68%; 12/1,775). Each of the adult females has just one vertebra affected, while the average for adult males is 1.5, and that for children is 1.75.

Seventy-one vertebrae from 10 Sadlermiut infants were also examined, but produced no recognizable evidence of sagittal clefting. The infant results are not included in the totals because identification of the condition is more difficult than in adults, and no Thule-Historic infant vertebrae were available for comparison.

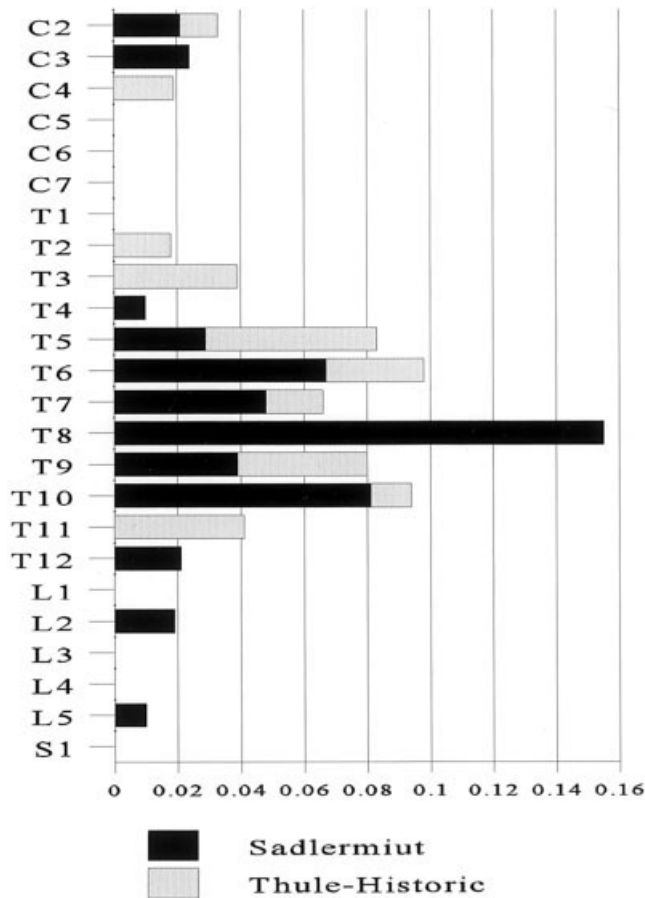
The frequency of affected vertebrae is highest in the thoracic region (1.38%; 27/1,960), followed by the cervical (0.53%; 5/949) and lumbar (0.22%; 2/901) regions (Table 3). The 34 affected vertebrae are divided by region as follows: 5 cervical (14.7%), 27 thoracic (79.4%), 5 lumbar (5.9%), and 0 sacral. The prevalence is particularly high in the region T6–T10 (2.09%; 18/860), and this where the more extreme expressions (scores of 3–5) were found.

Defect totals by category for the Canadian Inuit are as follows (Table 2): shape: L = 15, C = 13, C(L) = 2, and T = 4; anteroposterior position: A = 4, M = 14, and P = 16; transverse position: L = 6, S = 20, and R = 8; and degree of expression: one = 13, two = 12, three = 5, four = 2, and five = 2. The same four vertebrae (Table 2: cases 1, 5, 8, and 10) account for all examples of T and A, with scores of 4 or 5. Reflecting the greater multiple-vertebrae involvement in males, the average degree of expression per affected individual is 3.1 for males and 2.0 for females. The highest average, 4.3, is seen in children.

A comparison between the two series based on affected vertebrae produced only a slight difference: 0.93% (22/2,361) for the Sadlermiut, compared with

0.75% (12/1,610) for the Thule-Historic (Table 3). When degree of expression is taken into consideration (Fig. 8), the difference between the two series is greater. Scoring each of the affected vertebrae from 1–5, the expression value is twice as high for the Sadlermiut, i.e., 0.022 (53/2,447) compared with 0.011 (18/1,699) for the Thule-Historic. The difference is greatest in the region T6–T10 (0.078 vs. 0.021). Based just on affected vertebrae in the two series, the average score (scale of 1–5) for the Sadlermiut is 2.41 (53/22), compared with 1.50 (18/12) for the Thule-Historic. A difference in the form of the defect between the two series was also observed, with 75% (9/12) of the Thule-Historic defects occurring in the midline, compared with only 50% (11/22) of those of the Sadlermiut.

Examination of the equivalent of 4,712 intersegmental spaces produced 17 examples of segmentation error, for a frequency rate of 0.36%. Fifteen individuals are involved: 13 with a single pair affected, and 2 with two pairs each. Different parts of the vertebrae are involved, but most frequently it is the bodies and the zygapophyseal joints, followed by the laminae and spinous processes. The errors occur at C2–C3, and in the region T3–T4 to T10–T11 (Table 4). Females are affected more than males, at a ratio of 12 to 5. The two individuals with multiple examples of segmentation error (Table 2, cases 11 and 17), adult females from Native Point (T3–T4 and T8–T9) and Kamarvik (T6–T7 and L1–L2), also display sagittal clefting. Segmentation error rates for the two Inuit series are very similar: 0.38% (10/2,602) for the Sadlermiut, and 0.33% (7/2,110) for the Thule-Historic.



**Fig. 8.** Intensity of sagittal clefting in Thule-Historic and Sadlermiut series.

Although the youngest individual with fused S1 laminae was judged to have been 13 years of age, 15 years was used as a more reasonable dividing line to record spina bifida at this level of the column. This accounts for the lower number of total observations at S1 compared with those for sagittal clefting and segmentation error (Table 5). The two Inuit series produced 33 vertebrae with unfused laminae or aplasia of the spinous process, for a total frequency of 0.80% (33/4,135). None of the 184 atlases examined had a defect in the anterior arch. Only one individual, an adult male Sadlermiut, has spina bifida in more than one vertebra (C7 + T1). The affected vertebrae in the two series are proportionately divided among the various age categories, but they occur more frequently in males than in females, i.e., 0.94% (18/1,917) to 0.59% (11/1,854), respectively. The sex difference becomes more apparent when the level of the affected vertebra is considered. All 7 of the 9 individuals with T11 spina bifida for whom sex could be determined are female, while all 5 cases occurring above T11 are male. Also, 13 of the S1 spina bifida cases are male; only 4 are female.

The T11 spina bifida cases show considerable variability, as follows: separation in midline with spi-

nous process agenesis = 2; cleft to left of midline, spinous process formed by right lamina = 3 (Merbs and Wilson, 1962, p. 179, Plate VIIB, left); cleft to right of midline, spinous process formed by left lamina = 2; and laminae fused but with spinous process agenesis = 2 (Merbs and Wilson, 1962, p. 179, Plate VIIB, right).

The spina bifida frequency for the Thule-Historic series is higher than for the Sadlermiut series, at 0.95% (16/1,685) to 0.68% (17/2,488), respectively. There is also a sex difference between the two series at S1, with 88.8% (8/9) of the affected Sadlermiut being male, compared with 62.5% (5/8) of the affected Thule-Historic.

In 5 individuals, sagittal clefting occurs with spina bifida; in 2 it occurs with segmentation error; and in 2 it occurs with both spina bifida and segmentation error. In no case did spina bifida and segmentation error occur together in the same individual without sagittal clefting.

Two Sadlermiut children (Table 2, cases 2 and 5) have similar patterns: mild clefting of T8, more serious clefting of T10, and spina bifida of T11 (Fig. 9). The two also show differences, primarily with respect to side. In case 2, a linear defect in T8 is to the left of the midline and communicates with the neural canal, while in case 5 the defect, also linear, is to the right of the midline and terminates dorsally at the division between the developing centrum and neural arch. The T10 defect in case 2 is essentially in the midline and continuous with the neural canal, while the defect at this level in case 5 is to the right of the midline and completely divides the body into two parts. The spina bifida of T11 affects opposite sides of the arch in the two cases, the gap occurring to the left of the spinous process in case 2, and to the right in case 5.

Because fused ribs occurred at the same level as sagittal clefting in a skeleton from New Mexico (Rocek and Speth, 1986), rib fusion was included in the present study. Only one example of fused ribs was found, in a Thule-Historic column. The skeleton was poorly preserved, and no vertebrae were recovered.

The overall frequency of individuals with sagittal clefting in the Sadlermiut series (based on reasonably complete columns) is 14.0% (15/107), with the rate in children and adolescents being 20.0% (3/15) compared with 13.0% (12/92) for adults. Segmentation errors were found in 7.5% (8/107) of the Sadlermiut columns, in 8.76% (8/92) of adults, and in 0% (0/15) of subadults. The frequency of columns with spina bifida occurring above the sacrum is 5.6% (6/107) overall, 3.3% (3/92) for adults, and 20.0% (3/15) for subadults. The inclusion of S1 cases, which essentially limited the series to adult columns, produced a frequency of 13% (12/92). Too few columns in the Thule-Historic series were complete enough to produce comparable figures.

TABLE 4. Canadian inuit vertebrae pairs with segmentation error<sup>1</sup>

Vertebrae	Sad.	T.-H.	Total	Series	Sex
Oc/C1	95	89	184		
C1/C2	107	115	222		
C2/C3	105	92	197	■□□	♂ ♀ ♀
C3/C4	98	63	161		
C4/C5	97	69	166		
C5/C6	103	74	177		
C6/C7	107	68	175		
C7/T1	106	67	173		
T1/T2	105	67	172		
T2/T3	102	67	169		
T3/T4	104	66	170	■□□□	♀ ♂ ♂ ♂
T4/T5	104	65	169	■	♀
T5/T6	107	75	182		
T6/T7	107	84	191	■□	♀ ♀
T7/T8	107	80	187	□	♀
T8/T9	107	83	190	■■	♀ ♀
T9/T10	107	91	198	■	♀
T10/T11	104	95	199	■■	♀ ♂
T11/T12	107	90	197		
T12/L1	106	92	198		
L1/L2	104	97	201	□	♀
L2/L3	104	92	196		
L3/L4	103	93	196		
L4/L5	103	107	210		
L5/S1	103	129	232		
Totals	2,602	2,110	4,712	17 pairs	12, ♀; 5, ♂

<sup>1</sup> Sad., total Sadlermiut vertebrae observed; T.-H., total Thule-Historic vertebrae observed. ■, Sadlermiut; □, Thule-Historic. ♀, female; ♂, male.

TABLE 5. Canadian inuit vertebrae with spina bifida<sup>1</sup>

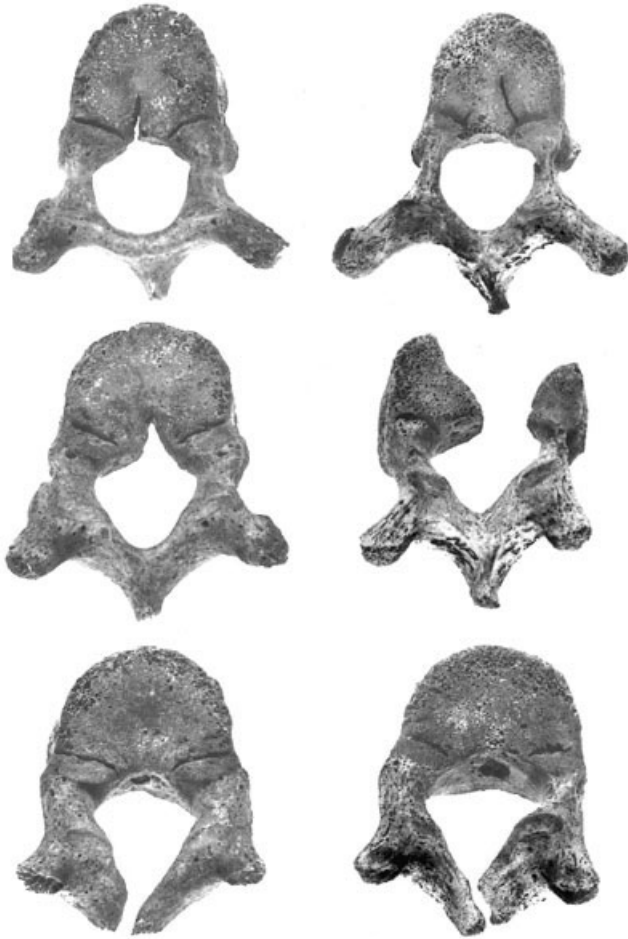
Vertebra	Sad.	T.-H.	Total	Series	Sex
C1	95	89	184		
C2	97	84	181	□	♂
C3	84	51	135		
C4	85	52	137		
C5	88	58	146		
C6	96	58	154		
C7	100	46	146	■	♂
T1	94	52	146	■	♂
T2	99	55	154		
T3	96	51	147	□	♂
T4	100	52	152	■	♂
T5	102	56	158		
T6	104	65	169		
T7	105	69	174		
T8	103	64	167		
T9	103	73	176		
T10	99	75	174		
T11	103	73	176	■■■■■□□□□	♀ ♀ ♀ ○ ♀ ♀ ♀ ♀
T12	95	72	167		
L1	100	75	175		
L2	103	79	182		
L3	101	76	177		
L4	100	76	176		
L5	102	89	191	■□	○ ○
S1	94	95	191	■■■■■■■■■■	♀ ♂ ♂ ♂ ♂ ♂ ♂ ♂
Totals	2,448	1,685	4,135	□□□□□□□□ 33 vertebrae	11, ♀; 18, ♂; 4, ○

<sup>1</sup> Sad., total Sadlermiut vertebrae observed; T.-H., total Thule-Historic vertebrae observed. ■, Sadlermiut; □, Thule-Historic; ♀, female; ♂, male; ○, sex not determined.

**DISCUSSION**

The first objective of the study was to determine the frequency, expression, and distribution of sagittal clefting in Canadian Inuit skeletons. Population frequencies are rare, and those that do exist probably exclude mild expressions of the condition. Although the overall frequency of affected

vertebrae relative to total vertebrae in the two Canadian Inuit series is less than 1%, this prevalence appears high compared with other figures presently available. The individual frequency of 14% for the Sadlermiut also appears high, but again comparable figures for other skeletal series are difficult to find.



**Fig. 9.** Two children from Native Point, with similar patterns of defects: mild sagittal clefing of T8 (top), more severe clefing of T10 (middle), and spina bifida of T11 (bottom). Table 2, cases 2 (left) and 5 (right).

Most of the defects observed are linear or circular in shape. Most involve the middle or posterior part, and most occur approximately in the midline or close to it. In general, the level of expression is relatively low, with 74% (25/34) cases in the 1 or 2 range, and only 12% (4/34) in the 4 or 5 range. Affected vertebrae occur in all three regions of the column above the sacrum, but 79% (27/34) are in the thoracic region. Just five vertebrae (T6–T10) account for 18 of the thoracic cases, and manifestations of the condition are especially severe in this part of the column.

In the Sadlermiut, the frequency of sagittal clefing is higher in children and adolescents than in adults, at 20% (3/15) to 13% (3/92), respectively. The difference may represent a selective disadvantage, with those having it being more likely to die at a younger age. This is based on a sample of just 15 children, however, and the difference is not statistically significant ( $\chi^2$ ).

Although more Inuit females (12) are affected than males (10), the females have just one affected vertebra per individual, while the males average 1.5. The overall frequency of affected vertebrae is thus slightly greater in males than in females (15:12).

The second objective was to compare sagittal clefing in two different Canadian Inuit series. We found only a slightly higher overall frequency in the Sadlermiut compared with the Thule-Inuit. Based on degree of expression, however, the difference is greater, at approximately 2:1. Unfortunately, the small numbers involved make it impossible to establish any statistical significance for this difference, but it is interesting that the higher frequency, and especially the higher degree of expression, occur in the small, inbred Sadlermiut group rather than the larger, more broadly distributed Thule-Historic Inuit.

The third objective was to compare the occurrence and patterning of sagittal clefing with segmentation error and spina bifida in these same groups. The distribution of segmentation error in the column was found to closely resemble that of sagittal clefing, with the greatest involvement in the mid- to lower thoracic region. This is in contrast to the distribution observed for spina bifida, where all but a few cases are concentrated at just two levels, T11 and S1.

Little difference was found in the distribution of segmentation error and its frequency in the two Inuit series. The condition occurs more frequently in females (0.6%) than in males (0.3%), and both individuals with multiple involvement are female. No examples were found in the small child-adolescent series available for analysis.

The frequency and distribution of spina bifida in the column are also very similar for the two Inuit series. All T11 cases are female, and most of those at S1 are male. In general, spina bifida of the type considered here would appear to be a hypo-ostotic condition, and thus more likely to occur in females (Hauser and De Stefano, 1989); this is indeed the case at T11. Involvement of S1 may be a separate phenomenon, perhaps related to later skeletal maturation in males. Incomplete development of the cartilage anlage may be the key factor at T11, while incomplete ossification of that anlage or malalignment of developing parts may be the critical factor at S1.

Sagittal clefing occurs more often in the same individual with spina bifida than segmentation error (6 to 3); in one case, all three occur in the same individual. In no case did spina bifida and segmentation error occur together in the same individual without sagittal clefing also present. In terms of occurrence in the same individual, there is thus a closer relationship between sagittal clefing and spina bifida than between sagittal clefing and segmentation error. Especially interesting are the two Sadlermiut children with virtually identical patterns: mild clefing of T8, more serious clefing of T10, and spina bifida of T11. Although the osteological expression in these individuals looks relatively benign, the young age at death suggests it might have been more severe, perhaps part of a syndrome affecting other parts of the body which left no identifiable evidence in the skeleton. Although the two

burials were located in the same general area of the site, it could not be determined from their archaeological context if they were members of the same lineage.

### CONCLUSIONS

Although comparative data are meager, the Canadian Inuit skeletons studied here appear to show an unusually high frequency of sagittal cleft vertebrae. Linear and circular defects occur more frequently than triangular defects, and most cases are relatively mild in expression. The part of the column affected most frequently and with greatest intensity is T4–T11.

Although the frequency of sagittal clefting in females was found to be slightly higher than in males, males occasionally had more than one vertebra affected, while in females it was always a single unit. Segmentation errors were more than twice as numerous in women than in men (12:5). Spina bifida produced an unusual sex distribution, occurring more frequently in males generally, but not at T11, where all seven affected individuals for whom sex could be determined were female. This pattern is intriguing and certainly worthy of additional research.

The results obtained for the two Inuit series for all three traits are very similar in terms of frequency and distribution in the column. However, one difference does stand out: the greater intensity of sagittal clefting in the Sadlermiut compared with the Thule-Historic. This could reflect the much smaller, more isolated nature of the Sadlermiut population.

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