THE EVIDENCE FOR SPONDYLOLYTIC DEFECTS IN
PREHISTORIC SASKATCHEWAN ABORIGINAL POPULATIONS

A Thesis
Submitted to the Faculty of Graduate Studies and Research
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Master of Arts

in the
Department of Anthropology and Archaeology

by
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Saskatoon, Saskatchewan

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ABSTRACT

Spondylolysis is a separation in the neural arch that occurs in the region of the pars interarticularis and is considered to be an acquired fatigue fracture which may have a genetic or familial element. This defect generally occurs in the lumbar vertebrae with the L5 being the most frequently affected.

The University of Saskatchewan osteology collection has 12 individuals displaying spondylolytic defects. These represent native populations of the plains and parkland areas of Saskatchewan and span the prehistoric and early historic periods. This study includes an examination of these skeletal materials as well as a thorough investigation of the literature concerning spondylolytic defects. Original research on unusual environmentally or culturally-determined habitual postures that may have lead to fatigue fractures in prehistoric and historic Plains Indians is discussed.
ACKNOWLEDGEMENTS

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Thanks must also go to my thesis committee: Dr. E.G. Walker (Supervisor), Dr. M. Marino, Dr. U. Linnamae, and Dr. C. S. Houston (External Examiner), for their assistance and support.

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1.0 INTRODUCTION

Spondylolysis is a separation in the partes interarticulares of the neural arch of a vertebra. The separation may be bilateral or unilateral, however, bilateral defects are the more common of the two types. The term spondylolysis was coined in 1892 by Neugebauer and was derived from the Greek "spondylo" meaning spine and "lysis" meaning to dissolve (Wiltse 1962). The separation of the vertebrae results in a posterior portion (neural arch, lamina, inferior articulation processes) and an anterior segment (centrum, superior articulation processes and transverse processes). The fifth lumbar vertebra is the most often affected vertebra, although other vertebrae in the lumbar area as well as cervical (Rowe et al 1987) may be affected. The clinical manifestation of spondylolysis is spondylolisthesis. Spondylolisthesis occurs when the anterior portion of a spondylolytic vertebra slips forward on the vertebral body below, while the posterior portion remains in place. The amount of slip is graded from I to IV based on four 25% increments. Spondylolysis is generally believed to be an acquired lesion, although many authors believe the lesion may have a genetic or familial element (Wiltse 1957, 1962, et al 1975, Kettlekamp and Wright 1971, Haukipuro et al 1978, Shahriaree et al 1979, Wynne-Davies et al 1979,
Ravichandran et al 1981, Fredrickson et al 1984). The incidence of spondylolysis is approximately 5-6% in the general public (Willis 1923, Batts 1939, Friberg 1939, Hitchcock 1940, Roche and Rowe 1952, Nathan 1959, Wiltse et al 1975, Merbs 1983, Eisenstein 1984) but the incidence seems to vary greatly with race and has been found to be as high as 54.8% in certain Eskimo populations (Stewart 1931). One of the most poorly studied races/ethnic groups in this regard is the North American Indian, thus the lack of information was the major impetus for writing this thesis.

The University of Saskatchewan osteology collection has 12 cases of spondylolysis ranging from bilateral separations of single vertebra, to unilateral, and multiple vertebral defects. Spondylolysis among the Plains Indians has not been studied to any great extent, therefore the purpose of this thesis was to analyse the materials found in Saskatchewan, review and analyse the literature (etiologic theories and histological appearance of the lesion) on spondylolysis with an emphasis on the possible mechanical causes of spondylolysis found in prehistoric and historic Plains Indians.

Due to the nature of a skeletal analysis any genetic or familial aspect of spondylolysis can neither be proved nor disproved. Therefore, the major focus of
this thesis will be the possible behavioural causes of cyclic loading which may lead to spondylolysis.
2.0 METHODS AND MATERIALS

2.1 Materials

The University of Saskatchewan human osteology collection contains 12 individuals displaying spondylolytic defects. These individuals include both males and females with an estimated age range from 6 - 55 years of age. The location and time frame for this pathology is not restricted since the burial sites of these individuals were found throughout Saskatchewan (Figure 1) and radiocarbon dates show a time span of approximately 3,000 years (Table 1). The various burial sites involved in this study include the following:

2.1.1 Gray Site

The Gray site (EcNx-1) is located in southwestern Saskatchewan near Swift Current. Radiocarbon dates for the Gray site extend from 5100 +/- 390 years B.P. (S-647) to 2915 +/- 85 years B.P. (S-1449) (Millar 1981) (Table 1). A total of 99 burial units were excavated with 304 individuals recovered. Individuals of both sexes and all ages were interred at this site and consist of a mixture of burial forms.

Compact secondary interments were the most dominant form of interment although both primary and secondary
Figure 1: Map of Saskatchewan showing the location of the archaeological sites referred to in this study.
Table 1: Radiocarbon Dates

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<tr>
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<td>3485 +/- 195 B.P (S-706)</td>
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<td></td>
<td>3415 +/- 105 B.P (S-1450)</td>
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<tr>
<td></td>
<td>2915 +/- 85 B.P (S-1449)</td>
</tr>
<tr>
<td>BRADWELL</td>
<td>2800 +/- 75 B.P (S-441)</td>
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<tr>
<td>BRACKEN CAIRN</td>
<td>2465 +/- 85 B.P (S-912)</td>
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<tr>
<td>CABRI</td>
<td>2335 +/- 105 B.P (S-2943)</td>
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<td>BETHUNE</td>
<td>1389 +/- 40 B.P (S-1575)</td>
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<td>BUFFALO POUND LAKE</td>
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modes of interment including bundle, extended, flexed, and semi-flexed patterns, with body orientations in all directions were observed. A total of 109 artifacts and 183 faunal specimens were associated with these skeletal remains. Specific artifacts found include: 16 projectile points; 5 bifaces; 9 end scrapers; 3 specialized scrapers; 23 retouched and utilized flakes; 69 flake debitage; 11 pebble tools; three grooved mauls; two smooth stones; 28 bone artifacts (tools, beads, pendants); six shell artifacts (beads, gorgets, ornaments); four copper artifacts (three rolled copper fragments, and one copper sheet).

2.1.2 Bradwell Site

The Bradwell Burial site is situated near Bradwell Saskatchewan in the Allan Hills. The provenience of this site is Section 36, Township 32, Range 2, west of the 3rd meridian. A radiocarbon date of 2800 +/- 75 years B.P. (S-441) (Wilmeth 1978) has been established for this site (Table 1). This burial site was excavated in November, 1936. The interred individual was found in a flexed prone position. Artifacts associated with the burial include: one worked knife or scraper and some eagle claws perhaps representing a necklace or other decoration.

2.1.3 Bracken Cairn Site
The Bracken Cairn Burial site (DhOb-3) is located in the hills overlooking the Frenchman River valley in Southwestern, Saskatchewan (Figure 1). The site is radiocarbon dated at 2465 +/- 85 years B.P. (S-912, Pendree 1980) (Table 1). The site was first discovered by private collectors in 1936 and was excavated in 1948 although the majority of the remains were re-interred. Two crania and some cultural artifacts were collected. The remainder of this site was excavated in 1957. Information gathered from the original collectors in 1961 revealed that the burial was in a shallow pit approximately 1.22 m in length, .91m in width, and .76m in depth. The mode of interment was secondary and consisted of two bundles positioned at the opposite ends of the pit. In both cases, the heads faced west and both sets of skeletal remains were stained with red ochre. The remains of at least five individuals were recovered (three adult and two very immature) (Walker 1983). Stones covered the entire burial forming a cairn approximately three meters in diameter. Artifacts associated with this burial include: one Pelican Lake projectile point (consistent with the radiocarbon date); one drill; three endscrapers; seven large ovate bifaced tools; six large unifacially-retouched flakes; 14 non-retouched flakes; one ground stone implement (pestle); one small rolled copper fragment; red ochre (in both
nodular form and applied to the skeletal materials); a small quantity of limonite or yellow oxide of iron; two clam shell gorgets; an assortment of mammalian and avian materials including a series (minimum of nine) of mandibles and maxillae of the swift fox (*Vulpes velox* sp.); many bone tools; and decorative items made from bone and shells including "pseudo-elk teeth" cut from bone.

2.1.4 **Cabri Site**

The Cabri Burial site (EdOa-14) is situated 13 miles west of Cabri Saskatchewan, at 50 36' 10" North Latitude, and 108 08' 45" West Longitude (Figure 1). The provenience of the site is SE 1/4 SW 1/4 Section 15, Township 19, Range 16, west of the 3rd meridian. This site was excavated July 17, 1986. The Cabri site dates 2335 +/- 105 years B.P. (S-2943) (Walker, personal communication) (Table 1). The burial was placed in a semi-flexed position with the upper limbs flexed at the elbow so that the hands were positioned in the head region. The individual was in the supine position with the head to the southeast and the feet to the southwest. Artifacts associated with the burial include: one shell bead; one right mandibular symphyseal fragment of a canid (*Canis sp.*), one molar tooth fragment (possibly fox or small canid), and a quantity of red ochre.
2.1.5 Bethune Site

The Bethune Burial site (EeNg-6) is situated northeast of the town of Bethune, at 50 46’ 50" North Latitude and 105 07’ 10" West Longitude (Figure 1). The provenience of the site is southwest 1/4, Section 15, Township 21, Range 23, west of the 2nd meridian. The site was originally excavated in May, 1972 as a salvage operation by the Saskatchewan Museum of Natural History. A radiocarbon date places the site at 1389 +/- 40 years B.P. (S-1575) (Dawson and Walker 1989) (Table 1). Due to the site location on a frequently cultivated knoll and looting during excavation, the resultant disturbance made it difficult for the excavators to precisely determine the stratigraphy and the mode of the burial. Stones found in the vicinity of the burial may indicate a stone cairn. Seven individuals were recovered from the Bethune site. Flexed and semi-flexed interments were observed while evidence of bundle burials was also noted. Artifacts associated with the burial include: one Avonlea projectile point (consistent with the radiocarbon date); one biface; one endscraper; one curvilinear drill; one retouched flake; one bone tool made from the proximal end of a deer metatarsal (Odocoileus sp.); a number of carapace fragments from a Western Painted Turtle (Chrysemys picta belli); and scattered bison elements found around the burial site.
2.1.6 Buffalo Pound Lake Site

The Buffalo Pound Lake Burial site (EdNi-5) is located on the south shore of Buffalo Pound Lake on residential property, Lot 11, Block 24 of the Buffalo Pound Lake Subdivision (Figure 1). The provenience of the site is NE 1/4 SE 1/4 Section 9, Township 19, Range 25, west of the 2nd meridian. The material was found by a private collector and no documentation was recorded regarding the nature of the site. This site dates to 920 +/- 90 years B.P. (S-2944) (Walker, personal communication) (Table 1). Artifacts associated with the burial include: one shell ornament, one projectile point (unavailable), and large quantities of red ochre.

2.1.7 White City Site

The White City Burial site (EcNc-10) is located one mile north of White City, Saskatchewan (Figure 1). The provenience of the site is SW 1/4, section 36, Township 17, Range 18, west of the 2nd meridian. The site was excavated on October 17, 1968. A single individual was interred in the prone position and was placed in a red ochre lined burial pit at a depth of 3 feet. A radiocarbon date was not attempted for this individual because the remains were covered with lacquer. Thus, a date of "prehistoric" was assigned for this individual
The Silver Burial site (FhNj-12) is located three miles east and one mile north of Prince Albert, Saskatchewan at 53° 13' 30" North Latitude and 105° 33' 45" West Longitude (Figure 1). The provenience of the site is NW 1/4, Section 25, Township 48, Range 25, west of the 2nd meridian. Due to extensive bulldozer destruction, only the basal portion of one coffin was left in situ. The estimated dimensions of the coffin were 1.6m in length by .35m in width. Approximately 4 to 6 coffins were buried on top of this knoll and from the number of left humeri and right ulnae recovered, a minimum of seven individuals were interred at this site. All of the skeletal material recovered were those of subadults. Artifacts associated with the burial include: one ironstone saucer dated between 1890-1907; one ironstone shallow bowl dated between 1880-1891; one porcelain human bust; one complete "Perry Davis Pain Killer" bottle, circa late 1800’s; one Lea and Perrins glass stopper; one clear glass stopper; three clear glass fragments; 13 white glass buttons commonly found on underclothing in the late 1800’s; one extremely corroded ferrous metal button; three marbles (one glass

2.1.8 Silver Burial Site

No artifacts were based on the abundance of red ochre. No artifacts were found.
and two clay); a number of beads (13 circular "wound" beads, several barrel shaped beads, and a large number of seed beads); one arm of a pair of scissors; the corroded outer portion of a pocket watch; four machine stamped nails; a cut section of an unidentified bird bone diaphysis encased in a corroded copper sheath; leather fragments; ribbon fragments; pieces of red and white cloth; and a piece of thin braid trim.

2.1.9 Prince Albert Site

The Prince Albert Burial site (EhNk-1) is located in the city of Prince Albert, Saskatchewan (Figure 1). The mass burial site was discovered during the construction of a sewage treatment plant. Excavation of the site was carried out during the summer of 1971 by the Prince Albert Police and excavation notes were taken for only one individual. The skeleton was oriented in a North-South direction with the head to the north and the arms crossed over the pubic region. A total of 12 individuals were recovered from this site. Three individuals were reinterred while nine were donated to the University of Saskatchewan. Artifacts associated with the burial include both mid-nineteenth century trade items and native artifacts. The trade items found include: one wooden-handled household knife minus the blade; one light blue glazed egg cup; one wooden-handled awl, or
pick surrounded by a perforated lead frame; and 56 glass trade beads. The native artifacts recovered include: one complete polished steatite stone pipe bowl; one shell gorget; four small pieces of leather; 21 pieces of birch bark; one hair ornament made up of 20 closely knit rings; and three small animal bones.

2.1.10 Saskatchewan Landing Site

The Saskatchewan Landing Burial site is located five miles east of Empress, Alberta at the junction of the Saskatchewan and Red Deer Rivers (Figure 1). This was a historic burial interred in the flexed position. The individual was interred in a 3-4 foot pit in a supine, flexed position with the knees tucked up near the chest and the arms placed at the sides of the body. The remains were oriented with the head directed north and the feet to the south. The skull was slightly tipped to the right. Artifacts associated with the burial include: seven bone buttons (three on top of the body; and four large buttons in the pubic region); two "shoe type" buckles found in the vicinity of the feet; one leather fragment found at one side of the waist; one clay trade pipe; and a number of chokecherry seeds.
2.2 Methods

The first step in the analysis of the materials was to derive demographic data from the specimens. The time lapsed since death and the cultural affiliation, where possible, were obtained via radiocarbon dating, bone analysis and grave items. The estimated age at death and the sex of the individuals were investigated using the following methods.

2.2.1 Age Determination

In the prepubescent individual, the most accurate method of age determination is to correlate the length of the long bones with dental development (Ubelaker 1978:46; Shipman 1985:255). Dental development (calcification) and dental eruption are the most reliable means of aging children between 0-10 years. Dental development is particularly reliable because tooth calcification is under genetic control and has a minimal environmental influence (Shipman 1985:225, Stewart 1979:140, Ubelaker 1978:46). Age estimations based on skeletal remains alone tend to be very subjective due to the variation in growth among populations as well as individuals. However, when the skeletal remains are compared with the dental development a fairly reliable age estimation can be obtained.

In order to determine the stage of dental
development, a radiograph of the subadult's maxilla and mandible was taken. Both the dental formation and the eruption of the teeth were noted. The radiograph was compared to a pictorial sequence of the formation and eruption of teeth among American Indians (Ubelaker 1978:47) and an estimated age was established. The canine teeth were avoided in the age estimation because these teeth show the greatest sex difference (Ubelaker 1978:47).

The age determination of subadults based on skeletal remains was established by measuring the maximum diaphyseal length of the long bones. A chart that correlates maximum diaphyseal length with chronological age was consulted and an estimated age was obtained (Ubelaker 1978: 46-47). Age standards in the literature are derived from living children and not from prehistoric dry bone (Stewart 1979: 140, Ubelaker 1978:46-47). However, the age standards used in this investigation are believed to be most accurate for the Arikara and related Plains Indians (Ubelaker 1978:48). Both age estimates, dental formation and maximum diaphyseal length, were derived separately and then combined to arrive at a single age estimate for the individual.

Another method of determining skeletal age involves epiphyseal fusion. Individual vertebrae from mass burial sites were assessed for the amount of epiphyseal fusion
in order to obtain a very rough age estimate. As well, epiphyseal fusion of other bones was used to determine whether a young adult was in the upper or lower region of an age range.

Age determination of the adult specimens was done on a multifactoral basis. Whenever possible, three skeletal features were used to assess the individual’s age at death. The pubic symphysis, dental wear morphology, and the morphology of the auricular area were assessed independently based on the appropriate criterion for each. After each feature was assessed, the results were combined to arrive at a single age estimate for the individual.

The methods used to age the pubic symphysis were those by McKern and Stewart (1957) and Suchey (1986) for the males, and the Gilbert and McKern (1973) for the females. The McKern/Stewart method assesses age by examining the age-related metamorphic changes in the pubic symphysis. The age range covered by this method is 17-50 years. The symphyseal face is broken into 3 components: the dorsal demiface, the ventral demiface, and the symphyseal rim. In turn, each of these 3 components is broken into 6 (0-5) subdivisions or stages. Each of the 6 stages represents morphologic changes which have been translated into chronological terms. Each component is studied separately and a stage is
assigned to the component. The stages are then combined as a formula (3-4-4), the sum of the 3 components is calculated, and subsequently translated into an age via a table provided by the authors.

The Suchey method is based on a 6 phase system. A single pattern is used rather than component analysis as seen in the McKern/Stewart method. The Suchey model consists of 12 plaster male pubic symphyseal casts arranged as 6 phases. Each phase has 2 examples: one early; and one advanced. The terms early and advanced do not necessarily correspond to age (younger/older). The six phases are not sequential and the age ranges overlap although the system is designed so that the mean ages differ. Pubic symphyses are examined and compared to the plaster models provided. A phase is determined for the symphysis and the estimated age is established by means of a table.

The Gilbert/McKern (1973) method was devised because "females are absolutely different from males in the rate and locality of age-related metamorphic changes in the os pubis" (Gilbert/McKern 1973:31). Gilbert/McKern based their method on the McKern/Stewart system of 3 components: the dorsal demiface, the ventral demiface, and the symphyseal rim, with 5 stages each. The age range of this method is 17-55 years, because no regular metamorphic activity can be found beyond 55 years (Gilbert/McKern 1973:34).
The teeth were the second skeletal feature used to age the individuals. The degree of dental attrition is the result of both physical and cultural aspects of lifestyle. The inclusion of abrasives in food coupled with the strength and amount of mastication are the primary factors causing dental wear, yet, certain cultural practices may also attribute to permanent dentition attrition (Brothwell 1981:71). Brothwell devised a method of age determination based on the molar occlusal wear of Neolithic and medieval British skulls. The resulting dental chart has an approximate age range of 17-45 years. Individuals older than 45 years are lumped into the 45+ category. Age estimation is established by comparing the specimen to Brothwell's chart.

Lovejoy et al's (1985) method of occlusal attrition is derived from a sample of 332 adult dentitions from the Libben population in Ohio. The Libben people were a hunter and gatherer society with extremely regular dental wear in both form and rate due to their relatively short time of occupation (approximately 200-300 years), the homogeneity of the population and because no major dietary shifts occurred during the occupation period (Lovejoy et al 1985:47). In this method, the maxilla and the mandible are aged separately. Modal wear patterns are broken into "modal groups" A-I depending on the
degree of attrition (A-least; I-greatest). The dental wear pattern of each individual is then compared with the chart provided. The chart translates occlusal attrition into a chronological age sequence.

The final method used in adult age determination was auricular surface aging (Lovejoy et al 1985). Auricular aging is based on chronological changes in the auricular surface of the ilium. Advantages of this form of aging are: first, the auricular surface has a high archeological preservation rate; and second, the age-related metamorphosis continues beyond the fifth decade (Lovejoy et al 1985: 20). Although this method is more difficult to apply than other age determination methods, Lovejoy et al believe that this method is as accurate as the pubic symphyseal aging and offers a greater age range (Lovejoy et al 1985: 19).

Auricular aging is based on changes in the "general nature" of the auricular surface, such as changes in the amount and density of the grains, macroporosity, striations, and billowing. A list of definitions is provided by the authors. Five basic phases may be isolated in the age transformations of the auricular surface: (1) Early Post-Epiphysyal phase (puberty to mid 20's); (2) Young Adult phase (mid 20's to mid 30's); (3) Mid - Adult phase (mid 30's to mid 40's); (4) Early Senescent phase (mid 40's to mid 50's); and (5) Breakdown
phase (mid 50's - 60+). Auricular specimens are compared to photographs/illustrations, and a "modal age" phase is established. There are eight modal age phases: (1) 20-24; (2) 25-29; (3) 30-34; (4) 35-39; (5) 40-44; (6) 45-49; (7) 50-60; and (8) 60+. Each modal age phase has its own specific aging criteria. Auricular aging may be used equally well for males and females except when a female innominate has a well defined pre-auricular sulcus (Lovejoy et al 1985: 27). In these females, the age changes of the apex and the inferior margin must be discarded since they tend to increase the age estimation.

2.2.2 Sex Determination

Sex determination of the prepubescent subadult can be attempted via a combination of dental development and the maturation of the post-cranial skeleton (Hunt and Gleser 1955). This method relies on the fact that males mature more slowly than females post-cranially although the rate of tooth ossification is approximately the same. To arrive at an estimation of sex, one must age the individual separately by both tooth calcification and postcranial development and then compare the results. Most of the standards developed are based on males. If the two sets of results compare closely with the standards, the child is probably male. If, however, the skeletal age is in advance of the dental age, the child
is probably female. Some authors believe that the sexing of a subadult should not be attempted unless the complete skeleton is available (Ubelaker 1978:42). Non-metric traits may also indicate sexual dimorphism, yet, these traits are extremely subjective and unreliable in young individuals.

Sexing of the adult skeletons was based on an evaluation of skull and innominate morphology. Although "ultra-female" and "ultra-male" individuals do exist, a vast number fall within these two extremes. Hence, a multitude of morphological features were examined in order to assess the sex of the remains. The morphological features examined in the skull were: supraorbital ridges, muscle attachment sites, the nasal aperture, orbital margins, zygomatic flaring, glabellar prominence, forehead contour, mastoid process size, supramastoid crests, occipital protuberance, foramen magnum, occipital condyles, palatal breadth, teeth, and the mandible. When all these features are combined, a fairly reliable sex estimation can be established from the skull alone. However, to further the accuracy of sex determination the pelvis was examined and the results were correlated with those of the skull. The pelvis is the most accurate skeletal feature in sex determination. The morphological features used to assess sex were: the pelvic inlet; the subpubic angle; the greater sciatic notch; and the preauricular sulcus.
X-rays and photographs of each spondylolytic specimen were taken at the University Hospital, Saskatoon, Saskatchewan, through the Departments of Medical Imaging, and Medical Photography respectively.
3.0 ETIOLOGY OF SPONDYLOLYSIS

Since 1855, when Robert de Coblenz first described spondylolysis, several etiological theories have been put forward. The following is a review of the most prominent theories to date.

3.1 Developmental / Congenital Theories

The first major theory regarding the etiology of spondylolysis was developed by Schwegal in 1859 and revolved around the idea that the pars interarticularis contained two centers of ossification. He claimed that he observed two separate centres of ossification in each half of the neural arch in several fetuses. From these observations, Schwegal concluded that the failure of these two centres to fuse explained the origins of neural arch defects.

Support for the idea of two centres of ossification came in 1864 with the embryological publication by Rambaud and Renault entitled "Origin et Developpement des OS". At the time of publication, most anatomists believed that there were only three primary centres of ossification in vertebrae, one in the body and one on either side of the neural arch. Rambault and Renault, however, disagreed with their colleagues and wrote that each side of the neural arch has two centres.
of ossification one for the superior articular process and the pedicle and one for the inferior articular process, laminae, and half of the spinous process. These authors used a study of transparencies and a study of the ossification centers dissected out of their cartilage matrix in order to substantiate the theory of two ossification centres in the neural arch.

The major argument against the two centers of ossification theory is the fact that no accessory centers have been found. Research aimed at duplicating Schwegel’s and Rambault and Renault’s results spanned the early 1900s up to 1963 (Mall 1906, Willis 1931, Chandler 1931, Friberg 1939, Hitchcock 1940, Sensing 1949, Roche and Rowe 1953, Wiltse 1963). In all, hundreds of fetuses and stillborns were dissected and examined and only one accessory centre of ossification was found, a right unilateral defect in an L3 vertebra, by Batts (1939). In his study, Batts examined 200 fetal spines ranging in age from 3 months to full term newborns. Batts stated that it was impossible to tell whether in the event of non-fusion to the remainder of the ossification center on that side, the defect would have been at the isthmus or pars interarticularis (Batts 1939:883).

The ossification of a typical vertebra is as follows:

**Prenatal Period.** Three primary centers appear by the end of the embryonic period: one in the centrum
and one in each half of the vertebral arch. At the birth each vertebra consists of three bony parts connected by cartilage.

Postnatal Period. The halves of the vertebral arch usually fuse during the first year. The vertebral arch articulates with the centrum at cartilaginous "neurocentral joints" which permit the vertebra to grow as the spinal cord enlarges. These joints disappear when the vertebral arch fuses with the centrum during the third to sixth years. Shortly after puberty five secondary centres appear: one for the tip of the spinous process, one for the tip of each transverse process, and two "annular epiphyses", one on the upper and one on the lower surface of the vertebral body.... All secondary centers unite with the rest of the vertebra at about 25 years

(Moore 1977: 306)

A second congenital theory was put forward by Willis in 1931. He believed that the separation of the arch was the result of imperfect ossification either by failure of the ossification process itself or by a defect in the pre-existing cartilage (Willis 1931). Two problems with the congenital theory soon became apparent. First, if spondylolysis was truly congenital, then the 5% incidence (Batts 1939, Hitchcock 1940, Roche and Rowe 1953, Stewart 1953, Newman 1963) found in the adult population must also be found in the newborn population. Not one case of spondylolysis has been found at birth. The youngest case of spondylolysis was reported by Borkow and Kleiger in 1971. A case study revealed a bilateral defect in the L4 of a 4 month old child. There was no known history of trauma during delivery or after
birth. Wiltse et al (1975) presented a case of an 8 month old child whose family members also displayed spondylolysis. The first documented case of spondylolysis in a young child was Kleinberg (1934) who described a spondylolytic 17 month old child. Again, there was no history of trauma and the child had only been walking a few months. Subsequent research has shown that spondylolytic defects generally do not appear until after children begin to walk. More common still is the development of spondylolysis around the age of 5-6 years (Stewart 1953, Wiltse et al 1975, Frederickson et al 1984).

If spondylolysis is congenital, then the incidence should not increase with age. Stewart found that spondylolysis appears around the age of 5-6 years and increases in frequency through adolescence up to the age of thirty. The incidence of spondylolysis increases again after thirty in conjunction with the onset of hypertrophic arthritis but tends to stabilize at approximately 40 years of age (Stewart 1953). Physical anthropologists Lester and Shapiro, found an increased incidence with age while studying the northern Alaskan peoples of Tigara and Ipiutak (Lester and Shapiro 1968). Wiltse also agrees with Stewart that spondylolysis increases with age although he found the greatest increase in incidence between 5.5 and 6.5 years.
Further evidence that the incidence of spondylolysis increases with age is found in the 25 year study by Fredrickson et al (1984). School children were followed from grade one (5-6 years of age) up to adulthood. An increase in incidence of 2% (approximately 4% in grade one to approximately 6% in adulthood) was discovered (Fredrickson et al 1984).

### 3.2 Trauma Induced Theories

In addition to the congenital theories, a group of theories arose isolating trauma as the causative agent. E.A. Nickel in 1949, published a paper on fractures of the thoraco-lumbar spine. In this article he describes a form of spondylolysis called "traumatic spondylolysis". Traumatic spondylolysis occurs in the lumbo-sacral region if, at the time of injury, the knees were extended and the pelvis was fixed by tight hamstring muscles. The usual mechanism in the fracture is hyperflexion associated with a forward shearing stress (Nicoll 1949: 376). However, traumatic spondylolysis is different from "classical" spondylolysis because in approximately half of these injuries, fracture of the transverse process is also associated (Nickel 1949:381).

Roche (1948) presented a case study of a bilateral fracture of the pars interarticularis. The fracture of
the pars interarticularis occurred at the L3 neural arch. After four months of immobilization the bilateral fracture had healed. X-rays revealed new bone formation and healing of the fractures. Roche claimed that this was the first case of documented acute traumatic spondylolysis (Roche 1948:1007).

Many arguments have been formulated against the acute trauma etiology. First, in fractures other than spondylolysis, there is generally an attempt at repair (Willis 1923, Stewart 1953, Wiltse 1956). Stewart (1953) states that anywhere else in the vertebra, the pedicle, for example, attempted repair is seen in the form of callus formation. In an ordinary fracture, if no attempt at repair is made, the rough splintered fragments are generally smoothed and covered by a thin layer of compact bone (Willis 1923:115). Therefore, if spondylolysis is due to an ordinary fracture then either callus formation or a smoothing over of the rough ends of the fragment would be apparent. In most spondylolytic cases neither callus formation nor smoothing over of bone is seen. Second, many authors believe it would be difficult to fracture only one side of the neural arch as seen in the unilateral separations (Willis 1923:115, Congdon 1931:516). Congdon also notes that the unilateral fractures have irregular and serrated edges and therefore could not be mistaken for an old ununited
It is also of interest to note that in all cases of undisputed fracture of the pars (Roche 1948, Wiltse 1962, Lambert and Billings 1960, and Thibodeau personal communications found in Wiltse 1962) all authors report fractures that healed solidly with callus formation. Hence, Wiltse (1963) concludes, if trauma alone is the cause it would seem unusual that fractures of the pars interarticularis would heal when caused by severe trauma but would not heal when caused by a milder trauma (Wiltse 1962:540). Moreover, Willis states, "

a traumatic event is involved in particularly every case of proven spondyloysis, but the
Hitchcock believed that if the fracture occurred in early infancy and childhood, "it would account for the findings of nonunion by fibrous tissue or cartilage, the development of pseudoarthrosis, such as has been reported in different specimens, the absence of healing and unilaterality" (Hitchcock, 1940:13). Therefore, Hitchcock concluded that if the mother had spondylolysis and complicating spondylolisthesis, she may have great difficulty in child birth and in turn great difficulty in childbirth may result in "the child being forcefully..."
pulled, crushed, twisted and turned that the skull ribs and limbs are broken or birth palsies produced" (Hitchcock 1940:13). Hence where spondylolisthesis creates difficulty for the mother in childbirth, the difficulty of childbirth may lead to spondylolysis in the child. Trauma during delivery or shortly afterwards may be the cause of spondylolysis.

In 1953, Rowe and Roche attempted to duplicate the results demonstrated by Hitchcock but all their efforts failed to produce a pars interarticularis fracture. In one experiment, flexion was carried out to the point where the pubic region was brought into contact with the abdomen (Rowe and Roche 1953:104).

Although Hitchcock's observations on 90 fetal specimens could not support the theory of two centres of ossification, he did however make the observation that the isthmic zone is an area of great potential weakness (Hitchcock, 1940:11). Hitchcock further observed, ...

"the isthmus itself consists very largely of cartilage until birth, the body connection between remaining somewhat narrowed. ... There are considerable differences in bone texture. The laminae early show more trabeculation in the longitudinal axis, and the bone of the pedicles is more compact. The isthmic region, however, shows very little bone. Histological sections and injected material ... show this area to be occupied
by a relatively large lake of blood vessels, almost sinusoidal in character. The significance of these nutrient vessels in weakening the arch are pointed out in Willis" (Hitchcock 1940:11).

Subsequent research however has found the opposite to be true. In 1973, Krenz and Troup studied the structure of the pars interarticularis and found that there are anterolateral and posteromedial layers of cortical bone in this area. The few trabeculae between these layers appear to be of greater strength than those found elsewhere in the neural arch. Therefore, Krenz and Troup believe that the pars is capable of withstanding considerable stress. It is important to note that they found that the cortical bone is thickest not only at the narrowest part of the arch but also at the site of spondylolysis (Krenz and Troup 1973:783).

3.3 Genetic / Familial Theories

The idea that spondylolysis may have a genetic or familial nature was first proposed by Friberg in 1939. Friberg studied a family and found that 15/61 members possessed spondylolysis. Further research was needed, however, before conclusive evidence could be obtained.

L.L. Wiltse's interest in a familial theory was sparked in 1950 when the parents of a 15 year old spondylolisthesis patient requested roentgenograms be
taken of the proband’s siblings. Five out of the six children possessed pars defects in L5. Wiltse expanded his research and in 1957 he published a consanguinity study of 24 families. His results showed a definite familial nature. After the exclusion of the probands, the incidence of spondylolysis, was 31.3%. From these results, Wiltse concluded that the trait may be recessive and sex-linked even though the exact mode of inheritance was non-discernible. Wiltse continued this line of research until 1963 when he had a total of 36 families composed of 101 individuals. At the time of study, 26 individuals (16 male, 10 female) or approximately 26%, had neural arch defects. Based on his results, Wiltse proposed a familial etiology for spondylolysis.

Wiltse believed the defect in the pars was due to several factors: (1) an hereditary defect or dysplasia probably in the cartilage model of the arch of the affected vertebrae and usually of several vertebrae in the individual; and (2) a particular strain upon the pars interarticularis in the lower lumbar spine due to the erect stance and to the lumbar curve (Wiltse et al 1962: 556). The reparative process, which bone normally is undergoing all the time, is disrupted by the combination of dysplasia and strain and thus progresses more toward bone resorption than toward bone formation. "The exact
nature of the dysplasia, or hereditary weakness, is believed to be characterized by a lack of normal ability of bone to repair itself" (Wiltse et al 1962: 556).

Unilateral spondylolysis occurs when the factor of dysplasia is so pronounced on one side that the defect occurs where strain is relatively slight. Also, defects may occur in the upper lumbar spine where the element of strain is small. "In those cases which separate in spite of relatively little strain the hereditary weakness in the pars interarticularis must be especially pronounced" (Wiltse 1963:558).

After his 1962 research, Wiltse changed his ideas on the mode of inheritance from a recessive possibly sex-linked trait to a non-sex-linked recessive pattern of inheritance with incomplete penetrance. Since Wiltse’s work, many other authors have become interested in the familial nature and mode of inheritance of spondylolysis. The results of subsequent research, however, tend to favor a dominant rather than recessive mode of inheritance.

Haukipuro et al (1978) presented a pedigree made up of 192 descendants from 2 marriages. X-rays were taken of 105/170 living relatives. Their results were consistent with autosomal dominant inheritance and incomplete (approximately 75%) penetrance. "Incomplete penetrance is understandable if upright posture and other environmental
stresses are essential for the final breakage of a congenitally weak part in the pars interarticularis of a spinal arch" (Haukipuro et al 1978:475). Haukipuro et al believe the inheritance can not be recessive because: 1) a recessive mode of inheritance would presuppose a very high frequency, for 1/3 of the individuals must carry at least one recessive gene for this disorder; and 2) recessive inheritance can not explain the high prevalence among the Eskimos (Haukipuro et al 1978:475).

A generation of one family where 39/65 members were examined was studied by Shahriaree et al (1979). Nineteen defects were found between the ages of 11-80 years. The authors believe that transmission followed an autosomal dominant pattern (Shahriaree et al 1979:1257).

Wynne-Davies et al (1979) studied 35 families and discovered a 15% incidence of spondylolysis. The pattern of inheritance according to the authors was either autosomal dominant with reduced penetrance or multifactoral.

Ravichandran et al (1981) support Wiltse's idea of a genetic predisposition and believe trauma is the trigger responsible for producing the symptoms. Evidence is cited by the authors to support a genetic predisposition theory: (1) the incidence of spondylolysis may be as high as 35% in families where one member has
spondylolysis; (2) spondylolysis has been associated with other spinal anomalies such as spina bifida; and (3) spondylolysis has been known to occur in areas other than the lumbar spine (Ravichandran et al 1981:34).

The longest linear study on spondylolysis is that of Fredrickson et al (1984). The study began in 1954 and ran for three consecutive years, 1954-1957, 500 random first grade schoolchildren were selected for the research. The research consisted of radiographs taken at specific intervals (10-12 years, 15-16 years, and 18+ years) in order to follow the development of spondylolysis and spondylolisthesis. The study was terminated in 1979 after 25 years. The incidence of spondylolysis at six years was found to be 4.4%. In adulthood, however, the incidence had increased to 6.0%. The data supports the hypothesis that there is a hereditary predisposition to the spondylolytic defect and that the defect is the result of a defect in the cartilaginous primordium of a vertebra. Fredrickson et al state that their data alone combined with other literature pedigrees could not distinguish between: (1) genetic heterogeneity with multiple mendelian forms; or (2) multifactoral inheritance with some family members having a higher liability than others (Fredrickson et al 1984: 706).

Most of the above authors believe that if the defect
is of a genetic nature, then the form of transmission is autosomal dominant (Haukipuro et al 1978, Shahriaree et al 1979, Wynne-Davies et al 1979, Ravichandran et al 1981, and Fredrickson et al 1984). There is difficulty, however, in determining whether the autosomal dominance is associated with incomplete penetrance (Wiltse 1962, Haukipuro et al 1978, and Wynne-Davies et al 1979) or whether the trait is multifactoral and/or polygenic (Wynne-Davies et al 1979, Fredrickson et al 1984).

3.4. **Chronic Trauma / Acquired Lesion Theories**

Lane (1887) came up with the idea that the erosion of one bone by two others may cause complete severance of the pars interarticularis. Lane postulated that the excavation of the bone was through the rotation of the pelvis and the last lateral vertebra around the vertical axis in the articulation between the fourth and fifth lumbar segments. This rotation combined with the pressure exerted by the extremities of the upper articular processes of the fifth lumbar and lower articulation process of the third in over extension... "(would) result in complete division of the fourth lumbar arch" (Willis 1923:11). Willis believes that this is not a feasible etiological theory because he believes that when "mechanical interference does occur there is irritation resulting in excessive bone formation"
and ultimate ankylosis rather than excavation of the bone (Willis 1923:111).

Meyer, a German scientist, stated in 1931 that he was able to see in roentgenograms areas of increased and decreased densities in the isthmus followed by gradual fragmentation and dissolution leading to neural arch separation. The process is described as resulting from chronic trauma and therefore, he believed the lesion to be acquired (Meyer in Roche and Rowe 1953:108). The hypothesis that spondylolysis is an acquired lesion has been intensely studied since the time of Meyer, and is still today considered to be one of the most likely etiologies. The exact method in which one acquires spondylolysis is still, however, under debate.

In 1947, Roberts described spondylolysis as an "overstrain deossification" and he fashioned his idea after the "march fracture" which occurs in the metatarsals (Roberts 1947). The most compelling evidence found in the literature to support the idea of a stress fracture comes from four case studies where spondylolysis was acquired after fusion.

One patient who had initially received an L4, L5, S1 fusion for spondylolysis acquired a spondylolytic defect of the L3 neural arch a few months later. Radiographs demonstrated that the arch of the L3 was intact at the time of the initial surgery (Unander-Scharin 1950). Wiltse
(1956) suggests that the "added strain on the pars of having the lamina and inferior facets of L3 solid to the vertebrae below and all the weight of the body above caused the pars to separate" (Wiltse 1956:50). A second case describes an acquired spondylolysis of the fourth lumbar vertebra after an L5-sacrum fusion operation (Anderson 1956). The third case study, published in 1959 by DePalma et al (1957) shows a patient who also developed a bilateral L4 spondylolysis after a fusion operation. Here, the initial lesion was a bilateral defect in the L5 pedicles. A L4-L5-sacrum fusion was performed but 2 years and 10 months later a bilateral spondylolysis had occurred in the L4 neural arch. DePalma et al (1959) believe that the separation occurred at L4 because the stresses that caused the initial separation were still present. Thus, since the stresses were not dissipated by the first fusion operation, these stresses just moved up higher in the vertebral column and caused the separation at L4 (DePalma et al 1959). Finally, the fourth case study is of a bilateral defect that appeared five years after spinal fusion. The location of the defect was immediately above the fused vertebrae. Brunet et al (1984) hypothesized that several contributing factors create the spondylolysis. These factors include: 1) fatigue fracture due to a concentration of stress; 2) a damaged
and altered function of the posterior ligament complex (reduced resistance to shearing stresses); and 3) degenerative disc disease immediately above and below the spondylolytic vertebra (Brunet and Wiley 1984: 721).

3.5 Activity Induced Theories

One of the first major investigations that supported the fatigue fracture hypothesis was conducted by Stewart in 1953. Stewart’s original research into spondylolysis culminated in his 1931 journal publication "Incidence of Separate Neural Arch in the Lumbar Vertebrae of Eskimos". In this work, Stewart found that the Eskimo has the highest recorded incidence of spondylolysis worldwide. In a series of 350, mainly Alaskan, Eskimos, he discovered that 27.4% had one or more separate neural arches. Stewart’s explanation for the high incidence was that "this feature (spondylolysis) has been present in an isolated group and has become fixed through inbreeding over a long period of time" (Stewart 1931:60). The more southern group of Eskimos, however, presented with a lower incidence than the more northern people. Stewart proposed the idea that the difference in incidence may be due to racial mixture although Stewart cites Hrdlicka’s results that "morphological differences are distinguishable between the Pt. Barrow-Seward Peninsula group and those to the south suggesting perhaps varying
origins, or differing lengths of habitation" (Stewart 1931:61).

Subsequent research changed Stewart's outlook on spondylolysis from an inherited condition to that of an activity-induced pathology. Factors that persuaded Stewart to change his views were revealed in his 1953 publication. First, his research revealed that the incidence of spondylolysis increased with age. Spondylolysis progresses from 5% at 6 years of age to 17% at approximately 30 years. However, between 30-40 years, coincident with the appearance of hypertrophic arthritis, the incidence increases to 34% at which point the incidence tends to stabilize (Stewart 1953:945). An increase in incidence with an increase in age is not conducive to a congenital etiology. Second, the physical build or body type of the Alaskan Eskimo does not drastically change from one region to another. Nor is there a great difference between Eskimo and Mongolian body types, yet the Mongols apparently are not as susceptible to arch defects as Eskimos (Stewart 1953). Third, inbreeding is not overly intense in one area in Alaska as compared to another area and thus the regional differences observed can not be explained on inbreeding alone. Fourth, Stewart found a significant sex difference (males > females) between the males and females of the Aleutians and Kodiak Island (22.5%),
however, north of the Yukon River the sex difference was vastly diminished (2.4%). At one time, Stewart thought the higher incidence of spondylolysis in males was evidence to support a genetic theory but the relatively equal incidence between the males and females north of the Yukon changed his opinion.

Stewart hypothesized that some environmentally determined cultural procedures subject the low backs of Eskimos to unusual strains or accidents (Stewart 1953:948). These stresses in the low back are of a chronic nature and are produced by strange body positions required by special occupations which are endured for long periods of time. An example given by Stewart is the occupational posture used by women. "Women are seen standing straight legged and bent over in order to engage in hand operations at ground level. In this position the back and hips are hyperflexed while the lower extremities are nearly or fully extended" (Stewart 1953:949). Men also use this extended posture while sitting for long periods of time in their kayak. This posture decreases the normal lumbar lordosis. Stewart concluded that the high incidence amongst the Eskimo population was due to unusual postural stresses, a high accident rate, and perhaps a more frequent occurrence of anomalous ossification (Stewart 1953:950). Support for Stewart's activity-induced postural theory can be found in Merb's

The sequel to Stewart's 1953 paper was published in 1956. Stewart admitted in his 1953 hypothesis that environmental factors acting through the mechanics of the body to produce a neural arch defect ignored the possibility that certain hereditary characteristics could predispose an individual to spondylolysis. Therefore, in his 1956 work, Stewart examined two comparable skeletal series; one series with spondylolysis and one series without the defect. Specific observations Stewart made between the two groups were: (1) vertebral formula (number of presacral vertebrae); (2) transitional lumbosacral vertebra; (3) type of sacrum (hypobasal or homobasal); (4) dimensions of the sacrum; and (5) dimensions of the last three vertebrae (Stewart 1956:44-45). The results were then analyzed, and Stewart reported on only those observations that affected the sacral inclination, lumbosacral curvature, and lumbosacral articulation. His findings, although not statistically significant, revealed that spondylolysis was associated somewhat more commonly with: (1) a long "prearcuate" spine (the spine above the arcuate lines just below the iliac crests); (2) an acutely inclined top sacral surface; (3) increased lumbar lordosis; and (4) reduced depth and curvature of the superior sacral
articular facets (Stewart 1956:58).

Wiltse (1962) disputed Stewart's findings regarding the relationship between spondylolysis and increased lumbar lordosis. Wiltse claimed that Stewart determined the angle of inclination of the superior surface of the sacrum with respect to the vertical plane when he should have measured the angle between the surface of the sacrum and the horizontal plane. The latter, according to Wiltse, is the function of the lumbar lordosis (Wiltse 1962:541). Wiltse continued his argument further and applied his method of measuring lumbar lordosis to children. Wiltse's results showed a marked similarity in the average angles in the children with and without a pars defect. Hence, Wiltse (1962) believes that lumbar lordosis has no etiological bearing in spondylolysis. Subsequent research has shown that lumbar lordosis may have an effect on lumbar stress. Kraus et al (1975) found, using a mathematical model, that flatter spines tend to fail by flexion whereas spines with an increased lordosis fail by torsion (Kraus et al, in Lamy et al 1975: 58).

3.6 Vertebral Impingement Theories

Another exploration of anatomical peculiarities in specific vertebrae that may predispose to spondylolysis, is the study by Nathan published in 1959.
Spondylolysis is the result of deranged mechanics of the affected portion of the spine permitting the implicated isthmus to be pinched between the inferior articular process of the vertebra above and the superior articular process of the vertebra below (Nathan 1959). The combined pressure of the two articular processes on the pars is described as the "pincher effect". Nathan believes that the two impinging articular processes result in traumatic mechanical injury which creates a zone of osteoporosis and osteolysis possibly as the result of local circulatory deficiency. The injured zone is ultimately replaced by fibrous tissue often found in the spondylolytic cleft (Nathan 1959:312). Once the defect in the isthmus is formed bony repair can not occur because: 1) the presence of shearing stresses displaces the attached vertebral body forward; 2) hypermobility of the neural arches precludes bone formation; and 3) the pincher mechanism may continue (Nathan 1959:312).

The anatomical differences observed between the vertebrae in spondylolytic and normal spines seems fundamental in conditioning the development of lysis. Nathan terms the anatomical differences "conditioning anatomical factors" (Nathan 1959:312). In the non-spondylolytic spine there are certain features that prevent compression. These features are: (1) relatively short inferior articulation processes of L4 and superior
articulation processes of S1; (2) the vertebral bodies may be relatively tall and their discal surfaces impinge on each other; (3) relatively large spinous processes of the L4 and L5 vertebrae may make contact, and similarly, the spinous process of L5 may rest on a relatively large sacral spinal tubercle; (4) relatively large transverse processes of the L5 may rest on the alae of the sacrum; and (5) the roots of the transverse processes of the L4 may rest on well-developed laterally projecting upper parts of the superior articulation processes of the L5 vertebra (Nathan 1959:306).

Therefore, the conditioning factors are the proportions of the vertebral bodies, their spinous, transverse and articular processes, and the relationship between these features that allows compression of the isthmus to occur. "Spondylolysis itself is not inherited but the anatomical conditions are of a familial nature" (Nathan 1959: 316). Hence, external environmental conditions, including cultural habits and postural stresses, exert their effect through these conditioning anatomical features.

In spines predisposed to spondylolysis, Nathan cites various "precipitating factors" that promote the onset of spondylolysis. Precipitating factors include anything that: (1) flattens the intervertebral discs; (2) exaggerates lumbar lordosis; and (3) approximates the
vertebrae, in particular the approximation of the neural arches (Nathan 1959: 315). Such things include trauma, erect posture, lifting-carrying heavy objects, and an increase in age. The increase in age is of particular importance because disc degeneration, and osteoporosis often accompany age. Osteoporosis is significant in the development of spondylolysis according to Nathan because osteoporosis renders the isthmuses more susceptible to pressure (Nathan 1959: 315).

Nathan supports his theory with what he calls "prespondylolysis". Prespondylolysis is the state when "bone depressions of varying size and depth, directly related anatomically to the impinging articular processes of the adjoining vertebrae are found on the isthmuses and laminae but no separation of the neural arch is present" (Nathan 1959: 308). Evidence, according to Nathan, that these depressions represent the "pincher effect" is that in articulation, the inferior articular process of L4 and the superior articular process of S1 fill the superior superior and inferior depressions respectively. In conclusion, Nathan feels a preceding neural arch defect is not necessary for spondylolysis to occur but trauma of some degree, minor or severe, may be needed in some cases to cause the final break-through of a weakened, thinned, mechanically - eroded isthmus.

Newman postulates (1963) that spondylolysis is
caused by an inherent weakness in the soft tissue from laxity, congenital dysplasia, or acquired damage. Breakdown of the soft tissue integrity, in either the posterior ligaments or the intervertebral discs, can cause an alteration in the axis of rotation of the vertebra in flexion or extension which increases the stress on the pars (Newman 1963:56). Newman observed that a common cause of back pain in soldiers carrying heavy backpacks during training was fracture of the pars interarticularis. Newman’s concept of "spondylolysis and hereditary" is very similar to Nathan’s, for Newman also felt the conditioning factors are hereditary and not spondylolysis itself. Newman’s "conditioning factors" are congenital lack of development of the posterior soft tissues or congenital tissue laxity (Newman 1963:53). Tissue laxity, in Newman’s opinion, leads to instability and instability puts extra stress on the pars so it breaks. Initially, there is nothing wrong with the pars.

Three arguments against Newman’s theory have come forward in the literature. First, children who appear to have good posture and well developed "soft tissue" have developed pars defects (Wiltse 1962). Second, women generally have more tissue laxity than men yet men tend to have a higher incidence of spondylolysis that women (Wiltse 1962). Finally, poliomyelitis patients whose back musculature has been paralyzed do not seem to develop
3.7 Fatigue Fracture Theories

The final etiological theory put forward to date is fatigue fracture theory. A fatigue fracture occurs not from one acute episode but results from repeated stress or trauma. According to Wiltse (1975), the development of a fine linear defect at the pars differs from fatigue fractures found elsewhere in the body. The differences are: 1) spondylolysis develops at an earlier age; 2) there appears to be an hereditary predisposition (Wiltse et al 1962, 1975, Fredrickson et al 1984); 3) other fatigue fractures show healing in the form of callus formation whereas spondylolysis does not; 4) the defect tends to persist while fatigue fractures in other bones virtually always heal; and finally 5) patients are generally asymptomatic and the lesion seems to develop following minor trauma (Wiltse 1975:19).

Wiltse et al reported that in nearly all their patients a fatigue fracture was developing and an episode of severe trauma completed the neural arch separation.
producing the spondylolysis. In general these investigators believe that the pars defect is produced by a combination of contributing factors such as trauma and neural arch stresses superimposed on a hereditary diathesis (Wiltse et al, 1975:22).

In their 1978 article, Cyron and Hutton give a definition of a fatigue fracture. The definition is as follows:

When a static force acts on a material, stress is generated within the material. As the applied force increases the material will eventually fail when the stress reaches a certain value, the "ultimate stress". However, the material will also fail when it is subjected to cyclic repetitive stresses which never reach the ultimate stress. This mode of failure is known as fatigue failure. The fatigue life, defined as the number of cycles to failure, is dependent on the amplitude of the cyclic stresses and the method by which they are imposed (Cyron and Hutton 1978:234).

Fatigue fracture, according to Cyron and Hutton, is due to mechanical fatigue and will only develop in bone (in vivo) when the cellular mechanism of repair fails to keep pace with the microscopic damage caused by the repetitive force (Cyron and Hutton 1978:234). Therefore, fractures may occur after strenuous activity such as walking with a heavy backpack or working for extended periods of time in a flexed position. For example, when walking with a back pack, the upper part of the body rotates loading each inferior facet alternately (Cyron and Hutton 1978:238). Fatigue fracture will occur if enough stress reaches the neural
arch and persists over time.

Cyron and Hutton's research has shown that the intervertebral disc is more elastic under the age of thirty and this elasticity may enable "a large proportion of the intervertebral shear force to reach the inferior articular facets. If the partes interarticularaes of L5 are also vulnerable under fatigue, then this may explain the higher incidence of spondylolysis under the age of about thirty" (Cyron and Hutton 1978:237). Young people may also be at higher risk of developing neural arch defects because young people tend to partake more frequently in strenuous activities and may be exposed to critical fatigue. Moreover, strenuous activities may affect the young person more because the intervertebral discs are more elastic and the arch may not be completely ossified (Cyron and Hutton 1978:238).

Advancing age is coincident with degenerative disc disease and the formation of osteophytes around the borders of the vertebral bodies. This, according to Cyron and Hutton, together with any increase in strength of the neural arch, may lessen the chance of spondylolytic fracture in middle age. "By the age of sixty to eighty the disc will become more stiff and fibrous and the chance of a critical force reaching the inferior facets must be rather low" (Cyron and Hutton 1978:237-238).

Farfan, Osteria, and Lamy (1975) found there were
Thus from their research, Farfan et al conclude that the pars interarticularis defects are due to a single episode of overloading inducing the first microfracture with repeated overloads ensuring the progression to
complete the fracture and promote non-union (Farfan et al 1976: 44).

Suezawa et al (1980) developed a experimental procedure to test the loading conducive to produce a fracture in the pars. Their results demonstrated that a single traumatic episode when it occurs under "favorable" conditions, hyperlordosis of the spine whilst weight bearing, can fracture the pars interarticularis (Suezawa et al 1980: 209).

A model was set up by Dietrich et al (1985) to perform an analysis of the loads and stresses in the human lumbar spine. The purpose of the experiment was to determine if purely mechanical factors could create spondylolytic fractures in a normal spine. First, they studied the muscle forces and reactions in the joints of the lumbar spine. Second, they carried out photoelastic experiments designed to find effective stresses and stress concentrations in the lower lumbar vertebrae. Their research revealed that the highest stresses appear in the pars interarticularis and that damage resulting from highly repetitive or constant loads will occur in the pars (Dietrich et al 1985:540). Dietrich et al (1985:541) also believe that loads and stresses in the lumbar spine depend on external load, position and weight, as well as the dimensions of the vertebrae. Hence, purely mechanical factors are of fundamental importance in the etiology of spondylolysis.
Monticelli and Ascani (1975) postulated that the origin of spondylolysis was "chronic overweight" that leads to "duration fractures". The authors advanced their ideas by studying athletes who practice sports activities with continuous and heavy loads applied on the lumbar spine postured in hyperlordosis such as diving, weight lifting, and wrestling.

Other studies involving athletes support the theory that spondylolysis is an activity-induced fatigue fracture. A higher incidence of spondylolysis has been found in individuals who engage in "jarring" sports such as football, gymnastics, hurdling, high jump, and karate (Alexander 1985, Ferguson et al 1974, Semon et al 1981, Jackson et al 1976). Gymnasts, who regularly hyperextend and hyperflex in floor, vault, and beam exercises, and football players, in particular interior linemen who hyperextend in their "three point stance" have been studied vigorously.

The incidence of spondylolysis in the literature for gymnasts is 11% or approximately four times higher than for non-gymnasts (2.3% incidence) (Jackson et al 1976: 68). College football players have a wide range of recorded incidences in the literature. Semon et al (1981), reported 21%; and McCarroll et al (1986) cite 15.2%. The most extreme incidence was reported by Ferguson (1974) where a 50% incidence of spondylolysis
was found in college interior linemen.

In 1855, Robert of Coblenz discovered the defect in the pars interarticularis today termed spondylolysis (Wiltse, 1957). After 133 years, the true etiology of spondylolysis remains a mystery. There tends, however, to be a general agreement that the primary etiological cause of spondylolysis is repeated load bearing, particularly in extreme body positions such as hyperflexion and hyperextension and rapid rotational movements that cause "high stress concentrations" on the pars interarticularis (Lamy et al 1975, Cyron et al 1976, 1978, Suezawa et al 1980, Alexander, 1985). A familial or genetic nature is also well documented for spondylolysis and the mode of inheritance is believed to be either multifactorial or autosomal dominant with incomplete penetrance (Wiltse 1956, 1962, 1975, Haukipuro et al 1978, Shahriaree et al 1979, Wynne-Davies et al 1979, Ravichandran et al 1981, Fredrickson et al 1984).
4.0 HISTOLOGY AND COINCIDENT BONY VARIATIONS

4.1 Spondylolytic Lesion: Bone Ends

One of the most intriguing aspects of spondylolysis is the observation that the histological appearance of the defect is not identical in every case. The bone ends of the defect appear to take one of two forms. First, if the bone ends are close together they tend to be smooth, blunt, and eburnated, or even to have some hyaline cartilage on the bone at each side of the defect. Second, the bone ends taper out at the defect so that the pars interarticularis becomes longer than normal. Often these bone ends come to a point "resembling taffy candy which had been pulled apart" (Wiltse 1962:547). Wiltse further noted that there was no periosteum over the two ends at the defect, but periosteum was present on the remaining surfaces of the pars interarticularis (Wiltse 1962:547). My research supports the observations of Wiltse. As described in chapter 3, the bone ends are referred to as either rounded or spiky in appearance.

4.2 Spondylolytic Lesion: Soft Tissue Histology

The histological appearance of the lesion appears to have five basic "types" and combinations of these five types is also noted in the literature (Boswell 1955, Wiltse 1963). The five basic soft tissue types bridging
the bony gap are: (1) thin and tenuous fibrous bands; (2) thick and heavy fibrous columns; (3) a bony bridge; (4) cartilage and (5) a pseudoarthrosis (Boswell 1955:781).

4.2.1 Thin and Tenuous Fibrous Bands

A microscopic and gross examination of 6 cases of spondylolysis was carried out by Wiltse (1956). The posterior element was removed at surgery, and the histological sections were oriented to follow the transition from bone into the defect. The findings showed: (1) no endochondral or intramembranous ossification; (2) no osteoid or cartilaginous callus; (3) no cystic change; (4) no periosteum over the ends of the bone at the defect; and (5) no attempted healing (Wiltse 1956:54). However, Wiltse did find completely acellular finely fibrillar fibrous connective tissue extending up to the bony cortex at the defect (Wiltse 1956:55).

4.2.2 Thick and Heavy Fibrous Columns

The presence of thick and heavy fibrous columns as opposed to thin and tenuous fibrous bands appears to depend on the width of the spondylolytic gap. Wiltse (1962) discovered from 15 specimens removed from surgery that when wide gaps were encountered the soft tissue was more fibrous in nature and often normal ligaments filled
the gap. Wiltse found, in most cases, dense relatively acellular fibrous tissue attached intimately to the bone which seemed to penetrate quite deeply in some areas (Wiltse 1962:547). Generally, an abrupt transition from fibrous tissue to bone was observed.

In one specimen, Roche (1949) observed that the defect in the isthmus was united by unusually strong fibrous ligaments ensheathed in a fibrous capsule and not by fibrocartilage (Roche 1949:537). He stated:

The defect itself was not filled with fibrocartilage, but the junction of the two segments was well stabilized by fibrous ligaments. Three ligaments were present - a cephalad, a middle, and a caudal. ...The ligaments were intimately attached to both bone fragments (Roche 1949:533).

4.2.3 Bony Bridge

A bony bridge within the defect has been found by several authors (Boswell et al 1955, Krenz and Troup 1973, Soren et al 1985). Boswell (1955) observed plaques of bone within fibrous bands and suggested these plaques may represent early or abortive attempts at reossification of the defects (Boswell 1955:781). Krenz and Troup (1973) also noted new bone formation and further suggested a healing attempt.

In 1985, Soren et al performed a microscopic examination of the defect that revealed poorly vascularized dense connective tissue that underwent
cartilaginous metaplasia in some areas and contained a few interspersed islands of cancellous bone. The cortical borders were more dense and broad (Soren et al 1985). According to Soren et al, histopathology did not provide any interpretation of the etiology except that no signs of recent or old fracture or the dissolution of bone by trophic or destructive processes were present (Soren et al 1985). Soren et al's histopathological investigation found no evidence of attempted healing.

A study by Taillard in 1976 revealed that the histology of spondyloysis shows striking differences between children and adults. His results demonstrated:

In adults the bony defect is usually filled by a dense fibrous tissue well organized and separated from the bone trabeculae by a calcified layer similar to those observed in tendinous insertions. It looks like a scar, like a well stabilized lesion without any sign of activity. In children and specially in young ones, we find in the defect a bridge of cartilage with active zones of endochondral ossification producing trabecular bone and contributing to the elongation of the pars articularis. In the trabeculae of the isthmic bone we can find small islets of calcified cartilage indicating the enchondral origin of this bone tissue. The spondyloysis shows probably a constant remodeling which ceases at the end of the growth of the vertebral arch (Taillard 1976: 33-34).

4.2.4 Cartilage

By definition a pseudoarthrosis is a false joint, therefore I further subdivided the four categories of
spondylolysis given by Boswell et al (1955) to include those cases where the lesion contains cartilage but is not a true pseudoarthrosis. Two specific examples in the literature are Raney (1945) and Wiltse (1962).

Raney's (1945) microscopic sections consisted of both bony fragments and soft tissue. Hyaline cartilage, fibrocartilage and dense bands of "atypical cartilage" (which resembled both hyaline and fibrocartilage) were identified. Mixed with this cartilage was connective tissue (Raney 1945).

Wiltse (1962) found fibrocartilage in some of his 15 surgical specimens. In these cases, the fibrocartilage had built up to the point where it appeared to press on the nerve roots (Wiltse 1962:547).

4.2.5 Pseudoarthrosis

Although pseudoarthroses have been mentioned by several authors (Hitchcock 1940, Gill, Manning and White 1955, Boswell 1955) the best description of spondylolytic pseudoarthroses is given by Gill et al (1955). Their surgical exploration consistently revealed the presence of a fibrocarilaginous mass at the defect in the pars interarticularis of the fifth lumbar vertebra (Gill et al 1955: 495). In every case they found a pseudoarthrosis between the fourth and fifth lumbar and between the fifth lumbar and the sacrum (Gill et al 1955:509). Almost
always the defect was filled with a mass of fibrocartilaginous tissue comprising the fifth lumbar root. Histologically, Gill et al (1955) reported that the mass is a "typical pseudoarthrosis composed of fibrocartilaginous tissue and some bone formation" (Gill et al 1955:497).

4.3 COINCIDENT BONE VARIATIONS

Over the years the search for the etiology of spondylolysis has led many investigators to question whether spondylolysis is associated or etiologically tied to other bony variations. The coincident bony variations most often investigated in conjunction with spondylolysis are: (1) spina bifida occulta; (2) transitional vertebra; (3) lumbarization of S1 or sacralization of L5; and (4) enlarged transverse processes.

4.3.1 Spina Bifida Occulta

Spondylolysis coincident with spina bifida occulta has been reported extensively. The percent incidence of spina bifida occulta in patients with spondylolysis include: 33% (Meyerding 1933), 28% (Friberg 1939), 41% (Nathan 1959), 22% (Laurent and Einola 1961), 27% (Kettlekamp and Wright 1971), 42% (Taillard 1976), 58%
Roche and Rowe (1952) found spina bifida occulta associated with spondylolysis of L5 in 9/153 or 5.9% of the spines examined. Their results were 10 times the normal established by Lanier (1939) and 4.5 times the frequency established by Willis (1923) (Roche and Rowe 1952:492-493). Roche and Rowe (1952) also found that an "open" sacrum (spina bifida occulta of the complete sacrum) was twice as frequent in patients with spondylolysis. In a study by Wiltse (1962) spina bifida occulta was found to be 13 times more frequent in patients with spondylolysis than in patients without the defect (Wiltse 1962:554).

Bosworth et al (1955) had 39/115 patients with spondylolysis/ spondylolisthesis who also had spina bifida. In nine of these patients it involved the lumbar arch and was occult, 2/9 also had incomplete sacral spina bifida, 21 had spina bifida affecting the sacrum to some degree, while 5/21 had complete sacral spina bifida.

Of Eisenstein’s (1978) 17 spondylolytic skeletons, two or 11.8% had coincident spina bifida. The incidence of spina bifida on the whole of 485 skeletons was 1.9%. Therefore, spina bifida was more common in the presence of spondylolysis than in his general (cadaver) population by a factor of six. S1 was not affected in any of the
seventeen spondlyolytic skeletons (Eisenstein 1978: 490). Eisenstein (1978) postulated that spina bifida, because of its associated local ligamentous inadequacy and the reduced spacer effect of the spinous processes, allows excessive pivotal strains in extension, across the pars interarticularis of the affected vertebra (Eisenstein 1978:492).

A group of children was followed into adulthood by Fredrickson et al (1984). They found the overall incidence of spina bifida in patients with a pars defect to be 92% in childhood, with 55% of the spina bifida involving L5. Spina bifida persisted into adulthood in 70% of pars patients with 35% involving L5 (Fredrickson et al 1984: 702). Fredrickson et al (1984) interpreted the high incidence of spina bifida associated with spondylolysis as support for the view that spondylolysis has an inheritance factor (Fredrickson et al 1984:706).

A second paediatric study (Oakley and Carty 1984) revealed 67% of the 30 spondylolytic children studied also had spina bifida occulta (Oakley and Carty 1984: 887). The bifid defect occurred at either L5 or S1, however, the majority of cases were spina bifida occulta of S1.

Athletic children have also been found to have a higher incidence of spina bifida occulta associated with spondylolysis. Jackson et al (1976) found coincident
spina bifida occulta in 9/11 spondylolytic gymnasts.

Wynne-Davies and Scott (1979) investigated whether spondylolysis was associated with neural tube defects such as anencephaly, spina bifida with or without meningocele, spinal dysraphism or other generalized vertebral anomalies. From their results they concluded that the developmental defects of the vertebrae associated with spondylolysis are not etiologically related to neural tube defects (Wynne-Davies and Scott 1979: 304).

4.3.2 Spondylolysis and Transitional Vertebrae

The debate surrounding a relationship between spondylolysis and transitional vertebrae began in the early years of research and still continues to some extent today. In 1939 Friberg noted transitional vertebrae at the lumbosacral junction were more frequent in spondylolytic patients than in the general population. However, Stewart (1953) and Roche and Rowe (1952) found no relationship between variations in presacral count and the incidence of spondylolysis.

Eisenstein (1978) supports Stewart (1953) and Roche and Rowe (1952) for he believes there is no relationship between variations in presacral count and the incidence of defects in the neural arch. In his study of 17 spondylolytic skeletons, no spondylolytic defects in
transitional lumbosacral vertebra were found in spite of a high (5.6%) transitional incidence in this collection (Eisenstein 1978: 493).

Support for the relationship surfaced once more in 1975 when Grantham and Imbrigelia (1975) reported on 3 patients with spondylolysis in transitional vertebrae, two of whom were father and daughter.

Although the evidence against a relationship out-weighs the evidence for a relationship, there are enough odd cases where spondylolysis is associated with transitional vertebrae to keep the debate alive.

4.3.3 Lumbarization and Sacralization

Both lumbarization and sacralization associated with spondylolysis have been found by several authors (Laurent and Einola 1961, Fredrickson 1984, and Simper 1986). However, the question of whether or not some of these results are statistically significant has been raised (Fredrickson et al 1984).

Laurent and Einola (1961) found either lumbarization or sacralization in 9% of their patients with spondylolysis. Lars Bo Simper (1986) noted sacralization of L5 in 2/25 patients with spondylolysis at L5. Finally, Fredrickson et al (1984) had a group of 27 patients with pars defects of L5. One patient had lumbarization and a second patient had sacralization for
an overall incidence of 7%. Their results were not statistically significant (Fredrickson et al 1984: 703).

4.3.4 Transverse Processes

Enlarged transverse processes have also been found to occur less frequently with spondylolytic patients than in the general population (Roche and Rowe 1952, Farfan, Osteria, and Lamy 1975). Roche and Rowe (1952) noted enlarged transverse processes of the L5 that articulated with the sacrum and/or the ilium in only 3/171 or 1.8% of their spondylolytic patients (Roche and Rowe 1952: 493). The average incidences recorded for the general public have been 6% in unselected skeletons (Moore 1923, 1925) or 6% in white males, and 8% in black males (or approximately 3-4 times more frequent in the general public) using skeletons selected for sex and race (Lanier 1939).

Roche and Rowe also noted in their 1952 study that accessory sacro-iliac articulations occurred approximately 1/2 as frequently in spondylolytic patients (Roche and Rowe 1952: 493).
5.0 DESCRIPTION OF SPONDYLOLYTIC DEFECTS IN SASKATCHEWAN MATERIALS

Spondylolysis is a vertebral defect occurring in the pars interarticularis. The defect separates the vertebra into a posterior segment (neural arch, lamina, inferior articulation processes), and an anterior segment (centrum, superior articulation processes, transverse processes). In the University of Saskatchewan Physical Anthropology collection there are twelve cases of spondylolysis, ranging from bilateral separations of a single vertebra, to unilateral, and multiple vertebral incidences.

5.1 GRAY SITE

The Gray site is dated between 5100 +/- 390 years B.P. (S-647) and 2915 +/- 85 years B.P. (S-1449) (Millar 1981). This individual had a bilateral separation of the L5 pars interarticularis. The right superior articular facet and the right transverse process were damaged postmortem (Figure 2). The left superior articular facet was enlarged and ovoid, whereas the left transverse process also suffered postmortem damage (Figure 2). The bone ends of the spondylolytic separation were rounded, and show nodular bone growth. Bone remodelling around the area of separation is taken as evidence to support
the view that the separation occurred during the individual's life and was not the result of post mortem damage. The arch was not recovered. Some hypertrophic bone growth was observed along the anterior border of the vertebral body (Figure 2). The hypertrophic bone appears to indicate resulting spondylololithesis.

5.2 BRADWELL SITE

Perhaps, the oldest human remains found in Saskatchewan are those of the Bradwell Burial. Dated at 2800 +/- 75 years B.P., (S-441)(Wilmeth 1978), this burial is assigned to the Pelican Lake complex. From the pelvic remains and the overall robusticity of the skeleton this individual appears to be male. Post mortem damage to the innominate bones resulted in the loss of the pubic symphysis and thus aging was restricted to the auricular area of the innominates and to the teeth. Assessment of the auricular area (Lovejoy et al 1985) placed the age at death between 30-34 years. Unfortunately, many of the teeth have been lost. The left mandibular canine and first premolar were lost during life due to abscess, yet the greatest amount of tooth loss occurred post-mortem. Using the remaining teeth to age the individual, the Lovejoy et al method gave 35-40 years (maxilla) and 30-40 years (mandible).
Figure 2: GRAY SITE: (inferior oblique angle) (A) Area of separation exhibiting bone remodelling. (B) Right transverse process and right superior articular process broken post-mortem. (C) Left superior articular facet is enlarged and ovoid in shape. (D) Hypertrophic bone can be seen along the anterior border of the vertebral body.
The Brothwell (1965) method aged these teeth between 25-35 years. Thus, from the above age estimates, the Bradwell individual appears to have died in his early to mid thirties.

The skeletal inventory revealed a moderately complete skeleton. Unfortunately, for the scope of this study, many of the vertebrae were not recovered. In fact, the only lumbar vertebra found was a spondylolytic L5. Post mortem damage of the vertebra includes part of the superior surface of the centrum, and both transverse processes. Both L5 superior articular processes are very large and demonstrate periarticular lipping. The right side is particularly lipped and hypertrophic bone development is present on the superior aspect of the right arch remnant (Figure 3). Ossification of the ligamentum flavum is probably the source of this hypertrophic bone. The bilateral separation of the L5 vertebra occurs directly under the superior articular facets. Bone growth and remodelling in the area of the separation is manifest (Figure 3). Contact facets are found under the arch remnants on both sides of the separation. The left appears to have one small facet whereas the right has one large oval-shaped facet. The dark brown patches in the photograph and the areas of increased density on the X-rays are plaster used during reconstruction and should be ignored. There is no
Figure 3: BRADWELL BURIAL: (inferior oblique angle) Male, mid-thirties. (A) Area of separation exhibiting bone growth and remodelling. (B) Large superior articular processes with periarticular lipping. (C) Laminar Spur. (D) Transverse process broken post mortem. An attempt at reconstruction has been made. Note the brown plaster on the tips of these processes. (E) There is no anterior border lipping, thus spondylolisthesis was not manifest.
Figure 4: BRADWELL BURIAL: Male, mid-thirties. (A) Area of spondylolytic defect. (B) Periarticular lipping of the superior articular processes. (C) Laminar Spur. (D) Plaster reconstruction attempt of the transverse processes. (E) No anterior border lipping, therefore spondylolisthesis can be ruled out as a complication of the spondylolytic break. (F) Incomplete separation of the S1 vertebra.
anterior border lipping on either the L5 vertebra or the sacrum suggesting that spondylolisthesis was not present (Figure 4). Evidence of incomplete fusion of S1 is seen on the ventral surface of the sacrum. Otherwise, the sacrum is essentially normal.

5.3 BRACKEN CAIRN SITE

The Bracken Cairn remains date to 2465 +/- 85 years B.P. (S912, Pendree 1980). A single Pelican Lake projectile point from the burial pit corresponds with the radiocarbon assay. This date is representative of the Late Middle Archaic Period of the Northern Plains. The spondylolytic L5 vertebra recovered in this burial belonged to one of two adult individuals. Based on the pelvic remains, one male and one female were identified. Using the method of studying pelvic metamorphosis by McKern and Stewart (1957), and Gilbert and McKern (1973) respectively, the male had an approximate age of 41 years with an age range of 36-46 years, whereas the female was approximately 47 years old with an age range of 44-54 years.

There was a classic bilateral separation at L5. The left superior articular facet and the left transverse process were lost due to postmortem trauma (Figure 5). The right superior articular facet was enlarged and
Figure 5: BRACKEN CAIRN SITE: (inferior view) (A) Bone ends of the lesion are rounded in appearance. (B) Left transverse process and left superior articular facet were broken post-mortem. (C) The right superior articular facet is enlarged and ovoid in shape. (D) Post-mortem damage is also evident on the superior aspect of the right transverse process, and the right superior margin of the vertebral body.
oviod. Some post mortem damage was also evident on the superior surface of the right transverse process and the right superior margin of the vertebral body (Figure 5). Hypertrophic bone was found on the anterior margins suggesting spondylolisthesis. The bone ends of the lesion were rounded and the complete intact arch was recovered. Enlarged inferior articular facets were observed on the arch.

5.4 CABRI SITE

The Cabri burial dates to 2335 +/- 105 B.P. (S-2943). The remains are only partially complete. An examination of the gracile skeleton, the partially complete innominates, and the cranium suggests that the remains are female. The age at death was assessed using the Gilbert and McKern (1973) method of pubic symphyseal aging, as well as both the Lovejoy et al (1985) and Brothwell (1965) methods of aging via the teeth. The respective age results were: 32-52 years (39.00 +/- 8.54); 35-39 years, and 30-40 years. Thus from the above results it appears that the individual involved was in her mid to late thirties at the time of her demise.

All lumbar vertebrae were recovered. The first three vertebrae (L1, L2, and L3) are essentially normal. Post
mortem damage has occurred on the transverse processes of L2, L3, and L4. The L4 vertebra is intact and small periarticular hypertrophic bone projections are found on the inferior articular processes. The facets of these processes appear large and diffuse. There is a post-mortem break on the posterior aspect of the right inferior articulation. Anterior border lipping is not evident.

Bilateral spondylolysis occurs in the L5 vertebra. Periarticular lipping is evident on otherwise well-defined, superior articular facets (Figure 6). It is interesting to note that there is bilateral foramen formation on the L4 and L5 vertebrae just under the mammary process of the superior articulation process. The foramina are more complete on the left side of both vertebrae (Figure 6). The right transverse process is larger than the left. Anterior border bone hypertrophy occurs on the inferior surface of the centrum. The hypertrophy is more advanced to the left of the midline. There is no evidence of contact facets. The defect in the pars interarticularis is bilateral with nodular bone growth and remodelling in the area of the separation. The separated arch was not recovered.

Incomplete fusion of S1, the least amount of S1 fusion in the study, is also found in this individual (Figure 7, 8 & 9). Lack of fusion can be seen on the
Figure 6: CABRI BURIAL: (posterior view) Female, mid-late thirties. (A) Nodular bone growth and remodelling at the site of the spondyloytic separation. (B) Periarticular lipping of the superior articular facets. (C) Ossification has occurred around a blood vessel or a nerve to create a foramen. (D) The right transverse process is slightly larger than the left. (E) The inferior surface of the centrum is concave.
Figure 7: CABRI BURIAL: (anterior view) Female, mid-late thirties. (A) Evidence of incomplete S1 fusion on the ventral surface of the sacrum. (B) Osteophytic development of the superior anterior border of the sacrum.
Figure 8: CABRI BURIAL: Female, mid-late thirties. (A) Nodular bone growth and remodelling at the site of the separation. (B) Periarticular lipping of the superior articulations. (C) Incomplete fusion of S1 to the rest of the sacrum.
Figure 9: X ray, CABRI BURIAL: Female, mid-late thirties. (A) Remnants of the spondylolytic separation. (B) Incomplete fusion of S1.
ventral surface on the sacrum (Figure 8 & 9) and on the dorsal surface, in the area of the inferior articular process (Figure 7). The sacrum also has osteophytic development to the left of the midline, on the anterior border (Figure 7). The relatively small amount of hypertrophy suggests spondylolisthesis was not present.

5.5 BETHUNE SITE

The skeletal remains from the Bethune Burial have a radiocarbon date of 1389 +/- 40 years B.P. (S-1575) (Dawson and Walker 1989). From the overall gracility of the skeleton and the morphology of the pelvis, this individual was assessed as female. The age at death was derived from the pubic symphysis and the auricular area of the innominates. The teeth of this woman were not used because most of the teeth were absent and those present were extremely worn.

The pubic symphysis revealed an age range of 23-39 years (32.00 +/- 5.54) (Gilbert and McKern 1973) and an age range of 35-39 years was established via the auricular method (Lovejoy et al 1985). It is important to note that these remains illustrate a fairly advanced state of degenerative joint disease throughout the skeleton. Thus, if one takes the extent of osteoarthritis and the worn teeth into account, the upper end of the age range favored.
The entire spinal column exhibits osteoarthritis. Osteophytes are particularly numerous on the superior surfaces of the neural arches in the thoracic and lumbar vertebrae. Anterior border lipping is evident in L2, L3, and L4. L2 has lipping on the inferior centrum with a left of the midline concentration of osteophytes. Both superior and inferior lipping are found in L3. The superior anterior border is most affected and again there is a higher proportion of osteophytes left of the midline. L4 has osteophytic development along the entire superior anterior border of the centrum.

Other pathologies found in the Bethune spinal column include; Schmorl's nodes, calcification of the intervertebral discs, and osteochondritis dissecans. Schmorl's nodes are the result of the protrusion of intervertebral disc tissue into the surrounding vertebral bodies. Such disc displacement can only occur when gaps are present in the cartilaginous plate. Gaps have many pathological origins, such as disease, developmental abnormality, and trauma. Schmorl's nodes occur most often in the area of the nucleus pulposus. According to Schmorl and Junghanns (1971:159):

This prolapse of disc tissue (intervertebral disc hernia according to Geipel) is a result of the expansive pressure of the nucleus pulposus and especially of the pressure produced by the constant elastic tension of the weight-bearing spine. At first, through the resorption of small fine trabeculae, a small cavity is created into which
more and more of the disc tissue is pressed. Gradually, the continued and repeated pressure stimuli produce reactive changes in the surrounding trabeculae which at first produce a cartilaginous and later an osseous casing in the surrounding of the prolapsed disc tissue.

Schmorl's nodes are evident on the inferior centra of L1, and L2. Disc calcification remnants can be found on the inferior centrum of L2, and the superior centrum of L3. Thirdly, the left superior articular surfaces of L2, L3, L4, and L5, demonstrate osteochondritis dissecans. According to Wells (1974 :365) osteochondritis dissecans is:

avascular necrosis occurring in the subchondral bone of a joint followed by degenerative changes in the overlying cartilage. As the disease progresses, a zone of demarcation forms around the avascular area and the necrotic fragment separates from the rest of the bone, forming a loose body within the cavity of the joint.

The articulation surfaces of L2, L3, and L4, show the typical indentation or depression diagnostic of this condition, (Figure 10), whereas L5 shows a raised "bump" (Figure 10). The "bump" occurs when the osteochondritic pit fills with regenerated tissue, which calcifies and rises above the level of the normal articular surface (Wells 1974 :365).

The Bethune Burial is the only example of a unilateral spondylolysis in this series. The separation occurs on the left pars interarticularis directly beneath
Figure 10: BETHUNE BURIAL: (posterior view) Female, mid-late thirties. (A) The unilateral break of the left pars interarticularis. (B) Osteochondritis dissecans of the superior articular facet of L4. (C) The osteochondritis "bump" of the L5 superior articular facet. (D) A contact facet of the inferior surface of the L4 spinous process. (E) The articulating contact facet on the superior surface of the L5 spinous process. (F) A "pit" in the opposite pars interarticularis.
Figure 11: BETHUNE BURIAL: (inferior and superior views of L4)
Female, mid - late thirties. (A) The unilateral break in the left pars interarticularis. Note the assymetry of the arch, and the distorted neural canal. (B) A contact facet on the superior aspect of the spinous process which articulates with a facet on the L4 spinous process. (C) The spinous process of L4 has a "twisted" appearance. (D) Anterior border osteophytes.
Figure 12: X-ray, BETHUNE BURIAL, Female, mid-late thirties. (A) Unilateral separation of the left pars interarticularis. (B) Note asymmetry of the arch and the resultant deformity of the neural canal.
the superior articular facet (Figure 10& 11). There is a slight gap between the two separated surfaces. Bone remodelling stretches into this gap from each side, yet the two sides are not united by these bony excrescences. There is a marked asymmetry to the arch, which has produced a definite skewing to the left (Figure 11). Articulating contact facets are noted on the inferior aspect of the L4 and the superior aspect of the L5 spinous processes (Figure 10&11). The inferior centrum of the L5 vertebra has an almost imperceptible amount of arthritic lipping. Thus, there must have been some vertebral slip (spondylolisthesis) in order to produce the L4-L5 contact facetting. In the middle of the right pars interarticularis is a "pit" (Figure 10). Such "pits" occur on other specimens in this series and will be discussed in greater detail later. Without a control group it is impossible to ascertain whether or not such "pits" have any spondylolytic significance. Yet, their occurrence in the location of the pars interarticularis, where the separation generally occurs, and the fact that these "pits" are found in the pars interarticularis (Bethune Burial) of adjacent vertebrae, may indicate their involvement in the expression of the spondylolytic defect.

5.6 BUFFALO POUND LAKE SITE

The remains found at Buffalo Pound Lake are those of
a subadult. A radiocarbon assay, dates the remains to 920 +/- 90 B.P. (S-2944) (Walker, personal communication). Using a pictorial sequence of the formation and eruption of teeth among American Indians (Ubelaker 1978 :47) and a radiograph of the child’s teeth, an age of 12 +/- 2.5 years was obtained. Age based on skeletal remains, namely the maximum diaphyseal length correlated with chronological age, revealed an average age of 9.5-10.5 years. Thus, when the dental development is compared to the postcranial measurements, the author concludes that the child was between the ages of 10-12 years at the time of death.

Sex determination of the prepubescent subadult can be attempted via a combination of the development of the teeth, and the maturation of the post-cranial skeleton (Hunt and Gleser 1955). This method relies on the belief that boys mature more slowly than girls post cranially, whereas, the rate of tooth calcification is approximately the same in both sexes (Hunt and Gleser 1955). Hence, since the post cranial remains of the Buffalo Pound Lake subadult seem to be less mature than the teeth, the child may have been male. It should be noted that the sexing of a subadult is extremely subjective, since all subadults fail to show non-metric sexually dimorphic features.

Only one lumbar vertebra was recovered; a bilaterally
Figure 13: BUFFALO POUND LAKE BURIAL: (inferior view) subadult, 10-12 years. (A) Spiky "pinched off" separation remnants. (B) Post mortem damage to the anterior border of the centrum.
spondylolytic L5. The superior articulation facets appear normal or at least within the range of normal variation. The centrum is somewhat poorly preserved particularly the anterior border right of the midline (Figure 13). There is no evidence of contact facets. The arch was not recovered. Separation of the arch occurs directly under these facets and the remnants of the arch have formed spike-like "pinched off" excrescences which project medially. These excrescences are bilaterally symmetrical (Figure 13).

5.7 WHITE CITY SITE

The preserved skeletal remains are nearly complete although the innominates were not recovered. Based on the overall gracility of the skeleton and the very feminine skull, this individual appears to be female. Since the innominates were missing, the age at death was assessed via the teeth and via the degree of degenerative disease. Lovejoy et al’s (1985) method for teeth gave an age range of 35-40 years for both the maxilla and the mandible whereas Brothwell’s (1965) method aged the teeth at between 25-35 years. The amount of degenerative disease corresponds to the upper age range given by the Lovejoy et al method (Walker, personal communication), therefore, an age of 40 years is estimated for this woman.
The entire vertebral column was recovered, and apart from some osteophytic development the column shows no abnormalities. Postmortem breakage of the majority of transverse and spinous processes has occurred. The upper lumbar vertebrae are generally unremarkable.

The L4 vertebra has some minute lipping of the articulation surfaces. The neural arch is asymmetrical with the short side on the left. Directly under the superior articular processes are "pits". These pits occur bilaterally in the area where separation of the pars interarticularis is most frequent. The spinous and transverse processes have suffered extensive postmortem trauma. The centrum is unremarkable with no evidence of anterior border lipping.

The transverse processes of the L5 vertebra have been broken postmortem. The superior surface of the centrum looks relatively normal, whereas, the inferior surface displays osteoarthritis (Figure 14). Osteophytic lipping of the anterior border is present. In addition, the entire inferior surface is marked by depressions (Figure 14). These depressions mirror depressions found on the superior aspect of the sacrum in both appearance and distribution pattern. Therefore, degenerative disc disease was manifest during life, however, there is not enough osteophytic development to
Figure 14: WHITE CITY BURIAL: (inferior view) Female, approximately 40 years.  (A) "Pinched off" arch remnants.  (B) Inferior centrum demonstrating anterior border osteoarthritic lipping.  (C) Degenerative disc disease depressions.  (D) Post mortem break in the inferior surface of the right lamina of the arch.  (E) Note the asymmetry of the arch.
Figure 15: X ray, WHITE CITY BURIAL: Female, approximately 40 years.  (A) Site of Spondylolytic separation.  (B) Note the asymmetry of the recovered arch.  (C) Osteophytic development of the superior surface of the sacrum.  (D) Incomplete fusion of the S1 Vertebra.
Figure 16: WHITE CITY BURIAL: Female, approximately 40 years
(A) "Pinched off" arch remnants. (B) Osteophytic
development of the inferior surface of the L5 and superior
surface of the sacrum.
suspect spondylolisthesis. The spondylolytic L5 vertebra displays a separation directly under the superior articulation facet. The remnants of the separation are rounded projections with a "pinched off" appearance. These "pinched" excrescences are bilaterally symmetrical (Figure 14 & 16).

The arch of L5 has been recovered. There is a post mortem break of the posterior inferior portion of the right side (Figure 14, 15 & 16). The arch is clearly asymmetrical with the left side being the short side. The right inferior articular process is broken in half while the left articular process is intact. Directly above the two inferior articular facets there is evidence of bone remodelling. Incomplete fusion of S1 to the rest of the sacrum can also be observed in this specimen (Figure 15).

5.8 SILVER BURIAL SITE

The Silver Burial site is a historic burial. The spondylolytic L5 vertebra found in the Silver Burial is that of a child. This young individual was interred in a multiple burial site. Due to poor excavation techniques, it was impossible to precisely determine which child possessed this spondylolytic L5 vertebrae during life. Therefore, this spondylolytic vertebrae was examined
Figure 17: SILVER BURIAL: (inferior view) subadult, 5-6 years.  
(A) Spiky "pinched off" arch remnants.  (B) Relatively symmetrical arch.  (C) The fusion of the two halves of the arch is not yet complete.  (D) Ossification of the Ligamentum Flavium.
independently. Aging of the child was attempted based on the fusion of the centrum epiphyses to the body of the vertebra and the fusion of the neural arch, both still incomplete. Fusion of the neural arch generally occurs when a child is approximately six years old (Krogman 1986:87). Since the fusion of the arch is not yet complete, I assume that this child was slightly younger than six years at the time of death.

The vertebra is relatively well preserved although the transverse processes were broken postmortem and some postmortem breakdown of the anterior aspect of the centrum has occurred. The separation of the pars interarticularis is bilateral and occurred directly beneath the superior articular facets. The remnants of the defect are spiky "pinched off" excrescences that project medially (Figure 17).

The arch of this specimen was recovered intact (Figure 17). The inferior articular facets appear normal but there is evidence of bone remodelling directly above. There is no obvious asymmetry to the arch (Figure 17). Ossification of the ligamentum flavum has occurred on the right superior aspect of the arch (Figure 17).

5.9 P.A. #1 SITE

The Prince Albert mass burial is a historic
burial site. Two individual spondylolytic vertebrae were recovered, one adult L5 (P.A. #1) and one prepubescent L5 (P.A. #2). Poor excavation techniques were employed, thus the spondylolytic vertebrae had to be studied independently. Due to the relative size of the P.A. #1 vertebra, the complete epiphyseal fusion, and some degree of osteophytic development, the individual was assessed to be a middle-aged adult at the time of death. Periosteum is still present on the specimen, thus indicating a relatively recent burial. There is evidence of osteoarthritis on the surfaces of the centrum, particularly on the inferior surface. No anterior border osteophytic lipping is evident (Figure 18 & 19). The superior articulation facets have a slight degree of periarticular lipping. Bilateral spondylolysis occurred directly under these facets. The remnants of the separation are porous and display remodelling as well as nodular bone growth (Figure 18 & 19). The neural arch was not recovered.

5.10 P.A. #2 SITE

The remains of P.A. #2 consist of a very poorly preserved L5 vertebra of a subadult recovered from a mass burial. Again, poor excavation techniques were used in the excavation of this mass burial, therefore the exact
Figure 18: X-ray, P.A.#1: Adult (L5) vertebra. (A) Spondylolytic separation of the L5 pars interarticularis. (B) No anterior border lipping, hence this individual did not have spondylolisthesis.
Figure 19: P.A. #1: (posterior view) Adult vertebra. (A) Porous separation remnants displaying bone remodelling and growth. (B) Periarticular lipping. (C) There is no anterior border lipping, hence, this individual did not have spondylolisthesis.
individual who possessed this vertebra during life could not be ascertained. The vertebra is quite small and formation of the centrum epiphyses had not occurred at the time of death (Figure 20). Centrum epiphyses appear during puberty and fuse between the ages of 17-25 years (Bass 1987:96), therefore the child was prepubescent at the time of death. The bilateral separation of the pars interarticularis occurred directly under the superior articular process and the remnants of the arch are spiky "pinched off" medially projecting excrescences (Figure 20). The arch was not recovered.

5.11 PRINCE ALBERT SITE

The preserved skeletal remains of the Prince Albert Burial date to the historic period and are probably from the late 1800's, or early 1900's. Remnants of the periosteum are still present on the bones. Postcranially the remains are nearly complete, whereas cranially, only the mandible was recovered. Based on the pelvis and overall skeletal robusticity the individual was assessed to be male. The age at death was investigated using the pubic symphysis, the auricular area of the innominate, and the teeth.

The pubic symphysis revealed age ranges of 22-28 years (24.4 ± 1.93), (McKern and Stewart 1957), and 20-27 years (Suchey 1986). The auricular area (Lovejoy
Figure 20: P.A.# 2: (inferior view) subadult vertebra. (A) Arch remnants with a "pinched off" appearance. (B) The right transverse process has been broken post mortem. (C) The fusion of the centra epiphyses has not yet occurred.
et al 1985) gave a result of 25-29 years. Since the skull was not recovered, age estimates based on teeth were restricted to the mandible. The ages obtained were between 20-30 years (Lovejoy et al 1985), and 17-25 years (Brothwell 1965). In order to rule out the younger age range for this individual the epiphysial fusion of the ilial crest and the ischial tuberosity were examined. Both epiphyses are fused indicating the individual was probably older than 24 years at the time of death. The age range of 25-29 years, with a mean age of 27 years, appears to be the approximate age at death of this young male.

The Prince Albert Burial is unique compared to the other cases thus far presented because here the level of the pars interarticularis defect is L4. The L1, L2, and L3, vertebrae have periarticular lipping of the articular facets and slight osteophytic development on the superior aspect of the neural arch. There is no evidence of anterior border lipping on any of these vertebrae.

The bilateral break of the L4 occurs directly under the superior articular facets. These facets appear enlarged, well defined, and show periarticular lipping. The transverse processes of the L4 vertebra are substantially smaller than those of the L2, L3, and L5 vertebrae (Figure 21 & 22). The superior surface of the
Figure 21: PRINCE ALBERT BURIAL: (posterior view) Male, approximately 27 years. (A) The site of spondylolysis on the L4 vertebra. Note the porosity of the remnant surfaces. Bone growth and bone remodelling in the area of separation is also evident. (B) The superior articulation processes of L4 display periarticular lipping. (C) The L4 transverse processes are substantially smaller than those of L2, L3, and L5. Here, compare the relative size of the L4 transverse processes to those of the L5. (D) Bilateral "pits" occurring in the pars interarticularis of the L5 vertebra.
Figure 22: PRINCE ALBERT BURIAL: (posterior view) Male, approximately 27 years. (A) Remodeled and porous L4 separation remnants. (B) Periarticular lipping of the L4 superior articulation processes. (C) L5 bilateral pars interarticularis "pits". (D) Spina Bifida Occulta of the sacrum.
Figure 23: X-ray PRINCE ALBERT BURIAL, Male, approximately 27 years. (A) Spondylolytic defect. (B) Spina Bifida Occulta along the entire length of the sacrum.
centrum is relatively normal although there is slight osteophytic lipping on the inferior surface. The lipping occurs around the midline and thus is not concentrated on any particular side. Nodular bone growth and remodelling are evident at the site of the spondylolytic separation. The entire remnant surfaces are porous with protruding hypertrophic bony spicules (Figure 21 & 22).

The L5 of this individual merits special notice because it too possesses the bilateral "pits", previously mentioned, that occur directly under the superior articular processes. Again, these "pits" are situated where spondylolysis generally occurs (Figure 21 & 22).

Spina bifida occulta is manifest along the entire length of the sacrum (Figure 21, 22 & 23). The sacrum also demonstrates some anterior border lipping suggestive of spondylolisthesis.

5.12 SASKATCHEWAN LANDING SITE

The Saskatchewan Landing remains are nearly complete, and date from the historic period (post 1760) and probably in the mid 1800's (E.G. Walker personal communication). Cranial and pelvic observations as well as the overall robusticity of the skeleton suggest a male individual. The determination of age at death was based on the analysis of the pubic symphysis, the auricular area of the innominates, and the teeth.
To age the pubic symphysis, both the McKern and Stewart (1957) and the Suchey (1986) methods were used. The ages observed were 36+ (41.00 +/- 6.22), and 45-59 years respectively. The Lovejoy et al (1985) auricular aging method gave a range of 50-59 years. Unfortunately, the mandible for this individual was not recovered, therefore, the age results based on the teeth are from the maxilla only. The results were, 40-60 years (Lovejoy et al 1985) and 35-45 years (Brothwell 1965). Based on the above findings this individual was probably in his early fifties at the time of death.

The recovered spinal column of the Saskatchewan Landing Burial illustrates a rather rare and extensive case of spondylolysis with separation of the pars interarticularis at multiple levels. In this individual, bilateral separation has occurred in the L2, L4, and L5 vertebrae (Figure 24 & 25). All five lumbar vertebrae were recovered and due to the unique features found, the entire lumbar segment will be discussed.

The L1 vertebra is intact with only a small amount of postmortem trauma to the inferior surface of the centrum (Figure 26). There are well-defined superior articulations yet the inferior articulations are enlarged, diffuse, and show signs of lipping. Osteophytes are noted on the top portion of the neural arch but these are probably unremarkable considering probable lifestyle and age.
The L2 vertebra is bilaterally spondylolytic with the separation occurring more medially on the arch than is generally seen (Figure 26, 27 & 28). Small contact facets are noted on the inferior border of the separation (Figure 26 & 28). The superior articular processes are enlarged and show signs of bone remodelling and increased bone porosity. Spicules of bone passing upwards superiorly on the prezygapophyses are also present (Figure 28). The superior surface of the centrum has only slight hypertrophic bone lipping at the anterior border (Figure 26 & 27) and a small "nob" close to the posterior border. The "nob" is the calcified remnant of the intervertebral disc. The inferior surface of the centrum has a great degree of osteophytic, hypertrophic bone to the point where the anterior border is no longer sharply demarcated (Figure 26 & 27). Although the whole border is affected, the lipping is greater left of the midline. A postmortem break of the left transverse process makes the determination of any size discrepancy between the two processes impossible. The arch of L2 was not recovered.

L3 is an intact vertebra. The superior articular processes are relatively small (normal variation) with well-defined articulations. The inferior articulations are also basically unremarkable with a small degree of lipping. Postmortem trauma is noted on the spinous
process. The right transverse process appears slightly larger than the left (Figure 26 & 28). Pathological variation is seen at the superior and inferior anterior borders of the centrum. Both borders have osteophytic development which is more pronounced left of the midline (Figure 26 & 27). The superior surface is affected to a much greater extent than is the inferior surface.

The L4 vertebra is bilaterally spondylolytic. A small amount of lipping is found on the superior articular processes but the articulations are essentially normal. There are contact facets immediately beneath the superior articular processes (Figure 28). The left facet is a small, round, well demarcated facet whereas the right is more diffuse and rectangular in shape. Both contact facets are porous. The anterior border of the superior and inferior surfaces of the L4 centrum show hypertrophic bone development, particularly left of the midline (Figure 26, 27& 28). The osteophytes of the inferior border are the most prominent. Also, there is a considerable amount of bone remodelling and hypertrophic growth present along the whole anterior aspect of the centrum. Moreover, there is evidence to suggest vertebral compression. The bilateral separation of the pars interarticularis of the L4 occurs directly under the superior articulation process. The bony remnants of the separation are "spiky" hook-like
Figure 24: X-ray, SASKATCHEWAN LANDING BURIAL: Male, mid-fifties. This film shows the lumbar spine and the sacrum. Note the spondylolytic separations occurring in the L2, L4, and L5 vertebrae.
Figure 25: SASKATCHEWAN LANDING BURIAL: (posterior view) Male, mid-fifties. (A) Articulated lumbar vertebrae showing the multiple incidence of spondylolysis occurring at L2, L4, and L5.
Figure 26: SASKATCHEWAN LANDING BURIAL (inferior view) Male, mid-fifties. (A) Post mortem trauma on the inferior centrum of the L1. (B) The L2 spondylytic break occurring more medially on the lamina than is generally seen. (C) Anterior border lipping of the L2 centrum. (D) Osteophytic lipping of the anterior border of the intact L3 vertebra. (E) The right transverse process of the L3 vertebra is larger than the left. (F) The L4 spondylytic separation. (G) The inferior surface of the L4 vertebra shows a great deal of osteophytic development. (H) The recovered L4 arch. (I) There are two sets of facets on the L4 arch. The inferior articulation facets and two contact facets on the superior aspect of the arch. (J) The L5 spondylytic break. (K) Contact facet. (L) Osteophytic development of the L5 centrum. (M) The recovered arch of L5. (N) Ossification of the Ligamentum Flavum on the L5 arch.
Figure 27: X-ray, SASKATCHEWAN LANDING BURIAL: Male, mid-fifties. This film is the companion film to fig. 19. See fig. 19 for the details.
Figure 28: SASKATCHEWAN LANDING BURIAL: (inferior oblique angle)
Male, mid-fifties. (A) The L2 spondylolytic break is more medial than is generally seen. (B) Spicules of bone project upwards from the superior articulation processes of L2. (C) Contact facets. (D) The L4 spondylolytic separation. (E) The arch remnants are bony hook-like excrescences. (F) Contact facet. (G) Anterior border osteophytic development of the L4 vertebra. (H) The "pinched off" arch remnants of the L5 vertebra. (I) Osteophytic hypertrophy of the right inferior border of L5.
excrescences that project medially towards the area of the neural canal (Figure 26, 27 & 28).

Spondylolysis also occurs in the L5 vertebra. The superior surface of the L5 centrum mirrors the inferior surface of L4, such that the inferior surface of L5 is slightly concave with the greatest concentration of bony hypertrophy to the right of the midline (Figure 28). The transverse processes are approximately the same size. Again, the separation occurs directly under the superior articular facets. These facets are somewhat porous. The bony remnants of the arch have a "spiky" appearance (Figure 26, 27 & 28). There is evidence of remodelling and increased bone porosity in the area of the separation. Small contact facets are found on the under surface of the defect (Figure 26). The left facet is small, well-defined, and matches a facet found on the superior aspect of the left sacral prezygapophyses. The right facet is larger and more diffuse.

The arches of the L4 and L5 vertebrae were recovered (Figure 26 & 27). The L4 arch is well preserved. There are four facets on the anterior aspect of this (L4) arch. Two bilateral, round symmetrical facets are found at the superior surface of the arch and two similar facets are found on the inferior surface. The superior facets are well defined while the inferior facets are somewhat diffuse. The spinous process appears
normal. There is a very slight asymmetry to the arch. The left side is the shortest side.

The arch of the L5 vertebra has only the two inferior articular facets (Figure 26 & 27). Above these facets, there is evidence of bone remodelling. On the left superior aspect of the arch is an ossified remnant of the ligamentum flavum (Figure 26 & 27). Again, the arch is only minutely asymmetrical with the short side on the left. The spinous process is essentially normal.

In summary, the skeletal series examined in this study consist of three subadults, and nine adults (three females, three males and three of unknown sex). All the subadult cases have a bilateral break of the L5 pars interarticularis. In the adult males, 2 of the 3 cases are bilateral and occur in the L5, while 1 of the 3 is a bilateral L4 break, and 1 of the 3 has multiple separations occurring in the pars at L2, L4, and L5. The spondylolytic breaks in the adult females, however, consist of a (1 of 3 unilateral separation of the left pars, and two cases (2 of 3) of bilateral breaks of the L5 pars. The three cases of unknown sex all have bilateral separations of L5.

Similarities are also found between these cases. First, the separation remnants take one of two forms: 1) an increase in porosity with bone remodelling and growth,
or 2) a "pinched off" appearance. Second, 11/12 cases have the separation directly under the superior articular processes. The L2 vertebrae of the Saskatchewan Landing individual has a separation that is slightly more medial than the rest. Finally, most of the specimens exhibit some form of osteophytic development of the anterior border of the centrum. Although osteophytes are present in many of the specimens, spondylolisthesis, the clinical manifestation of spondylolysis, is suspected but not proven. The Saskatchewan Landing spinal column is the only column in this collection where spondylolisthesis can be verified.
Table 2: Level of Spondylolysis

<table>
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<tr>
<th>Site</th>
<th>Sex</th>
<th>L1</th>
<th>L2</th>
<th>L3</th>
<th>L4</th>
<th>L5</th>
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<tr>
<td>Bethune</td>
<td>F</td>
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<tr>
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<td>?</td>
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<td>?</td>
<td>B</td>
<td>B</td>
<td>B</td>
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</tbody>
</table>

Key:

B = bilateral separation
U = unilateral separation
L = left
6.0 DISCUSSION

6.1 Incidence

The incidence of spondylolysis in the general public is believed to be approximately 5-6% (Willis 1923, Batts 1939, Friberg 1939, Hitchcock 1940, Nathan 1959, Wiltse et al 1975, Merbs 1981, Eisenstein 1984). However, when the general public is separated into racial/ethnic groups, it becomes apparent that some groups report much higher spondylolytic incidences than other groups. Roche and Rowe (1953) studied 4,200 adult skeletons from the United States and found the incidence of spondylolysis to be 6.4% in white males, 2.8% in Black males, 2.3% in white females, and 1.1% in Black females (Roche and Rowe 1953).

Other racial and ethnic group incidences reported in the literature include, the Bantu of South Africa, Orientals, American Indians, and Eskimos. The Bantu of South Africa were found to have an incidence of 6.09% (Shore 1930). A range from 3.5% to 10% has been reported for Orientals (Wiltse 1962, Nathan 1959, Merbs 1981). The Japanese seem to be the most often studied oriental population with reported incidences of 5.5% (Hasebe 1913 in Wiltse 1962: 554), and 7-10% (Nathan 1959, Merbs 1981). Unfortunately, little work has been done on the incidence of spondylolysis in the American Indian. In fact, the most widely cited reference is Congdon’s
(1931) study. In this work, Congdon reported an incidence of 5% (10/200) for American Indians based on his study of 200 skeletons (Congdon 1931). However, there are some more recent studies that show a much higher incidence for the American Indian. Snow (1948:466) reported 17.5% for the males and 21.6% for the females in a total of 310 individuals, from Indian Knoll, Kentucky and Stewart (1979:261) found an incidence of 30.8% in the males and 28.1% in the females from a total of 163 Arikara skeletons.

Some of the most interesting data on spondylolytic incidence has been found among Eskimo populations. Stewart (1931) studied 350 Eskimo skeletons and arbitrarily divided the material into northern and southern groups. The overall incidence was 27.4%; however, when the two groups were separated, the northern group had a higher incidence than the southern group. Other authors have also found high incidences among Eskimo populations. Lester and Shapiro (1968) reported an overall incidence of 41% while Kettlekamp and Wright (1971) reported a spondylolytic incidence of 28.1% in 153 northern Eskimos admitted to hospital for non-orthopaedic problems.

The incidence between the sexes has also been studied. At first, spondylolysis was believed to be a predominately female disorder, since it was most often diagnosed in conjunction with an obstruction of the birth
canal during delivery (Stewart 1931). During the late 1800’s spondylolysis became associated more frequently with men, particularly among men with labour-intensive occupations (Lane 1893). The issue of whether spondylolysis affects the sexes differently has still not been resolved. As already discussed, Roche and Rowe’s 1953 results found the white male to be most often affected (6.4%) whereas the black male, and white female (2.8%, 2.3%) have very similar incidences while the black female has the lowest incidence of all (1.1%) (Roche and Rowe 1953). Other authors have found spondylolysis to be approximately the same in both sexes (Hitchcock 1940, Jackson et al 1976).

Wiltse, Widell and Jackson (1975) believe that the defects are much more common in boys than in girls because boys play games that are related to more violent physical activity (Wiltse Widell and Jackson 1976: 22). The next year, however, two of the above authors altered their views. Jackson, Wiltse, and Cirincione (1976) studied a group of young female gymnasts and found 9/11 to be affected with spondylolysis. This study led the authors to believe that the female athlete may have the same incidence of pars interarticularis defects as the male performing the similar activities (Jackson, Wiltse and Cirincione 1976: 73).
Fredrickson et al (1984) reported the male to female ratio to be nearly 2:1. The authors believe that arguments such as: (1) environmental factors may be an important ancillary factor in the development of a pars interarticularis defect, and (2) studies often occur at the time when girls were not as active in sports as boys (Fredrickson et al 1984: 706) do not hold much merit, for they feel that up to the age of five the activity level of girls and boys is similar. The authors support their view by stating that the 2:1 boy/girl ratio was the same sex ratio noted in their adult series.

A possible 2:1 sex ratio favoring males was also reported by Lester and Shapiro (1968). The results of one group, the Ipiutak, showed an almost 2:1 male: female ratio, however, when they combined the two groups, the sex ratio was approximately even. Their sample size was insufficient to prove the results.

Stewart (1931, 1953) found in two studies that the sex difference always favors the male, and that this difference seems to hold at all age periods. In the 1931 study he reported male / female ratios of 40.6% / 37.4% in the northern population and 16.3% / 10.7% in the southern group of Eskimos. The combined totals showed a sex ratio of 29.5% to 25.1%. These results are far from a 2:1 ratio, although the males were favored in each case. Kettlekamp and Wright (1971) also found the males
An interesting feature of spondylolysis is its age of onset. Spondylolysis has never been seen at birth (Batts 1939, Wiltse 1956, Wiltse 1962) and there is little evidence to suggest that the defect occurs in individuals under the age of five years (Wiltse 1962). The youngest cases of spondylolysis reported with radiographic evidence were an 11 month infant (Friberg 1939) and a 17 month toddler (Kleinberg 1934).

Many authors believe spondylolysis first appears between the ages of 5.5 and 6.5 (Wiltse, Newman, McNab 1975, Wiltse et al 1976, Fredrickson et al 1984, Baker and McHollick 1956). At this age children begin to push each other around, tumble and first sit for long periods of time with a lordotic posture (Wiltse et al 1975, Fredrickson et al 1984). Apart from radiographic evidence of spondylolysis at a young age, Wiltse et al (1976) postulate that the rounding and resorption of the bone at the site of the defect is further evidence to support a genesis at a young age.

Both Baker and McHollick (1956) and Fredrickson et al (1984) studied the increase in the incidence of spondylolysis from childhood into adulthood. Baker and
McHollick found an incidence of 5% in first grade students. The incidence increased 0.8% by the time 18 years was reached and most of the 0.8% increase occurred between the ages 11 and 15. The authors postulated that from 11 to 15 years is the time of life when boys and girls are engaging in the very strenuous athletics which produce fatigue fractures. The adult incidence stayed at 5.8%. Fredrickson et al’s (1984) findings were very similar to those of Baker and McHollick (1956) for the incidence of spondylolysis was 4.4% at the age of six compared to approximately 6% in adulthood.

Roche and Rowe’s (1953) study of American Blacks and Whites showed the incidence of spondylolysis varied between the two races and the two sexes, however, the incidence of the defect did not increase during the age period from 20–80 years. Therefore, the authors believe the genesis of spondylolysis in American Whites and Blacks probably occurs before 20 years of age. Stewart (1953:940) reported a rapid increase in the frequency of spondylolysis up to the age of puberty, at which time a gradual increase occurred until approximately 30 years of age. The general rate of increase progressed fairly regularly from around 5% at six years of age to 17% at approximately thirty years of age (Stewart 1953:945). The incidence doubled with the onset of arthritis, but from 40 years onward the defects
did not become more common. Stewart also noted a progressive involvement of the lumbar segments with increasing age (Stewart 1953:944). Both Kettlekamp and Wright (1971) and Lester and Shapiro (1968) reported similar incidence increases to that of Stewart's (1953) study. Lester and Shapiro (1968: 45) also noted that as age increases so does the number of multiple spondylolytic vertebra.


The finding that family members of spondylolytic patients tend to have a higher incidence than the general public is one of the strongest pieces of evidence in favour of the genetic theory. As mentioned in chapter 3, Wiltse (1957:58) studied 24 families where one member of the family presented with spondylolysis. His research found that in the relatives, the incidence of defective pars was approximately 31.3% as compared to 5%-6% in the general population. He also found other stigma of the defect in relatives of patients with spondylolysis such as elongation, thinning or twisting of the pars (Wiltse
1962: 553). A similar study by Wynne-Davies and Scott (1979) revealed an incidence of 15% among family members (Wynne-Davies and Scott 1979:301). Several other authors also found a definite incidence increase among family members (Haukipuro et al 1978, Shariaree 1979).

In their 1971 study Kettlekamp and Wright compare the isolated interrelated Eskimo population to the extended families examined by Wiltse (1957, 1962). Kettlekamp and Wright (1971:566) believe the two groups represent families or extended families with a high percentage of pars interarticularis defects. Other authors argue that the association between spondyloysis and spina bifida is further evidence in favor of a genetic predisposition (Ravichandran et al 1981, Fredrickson et al 1984).


Human upright posture and lumbar lordosis have also been shown to play a role in the etiology of
spondylolysis (Wiltse 1962, Lamy et al 1975, Stewart 1956, Taillard 1975). Wiltse (1962) corresponded with all veterinary schools in the US and many other veterinary institutions abroad. Of the schools that responded, none found any evidence of spondylolysis in any other animals besides humans. Spondylolytic defects have been found in prehistoric man, but not in any apes or other primates. Schultz reviewed 4,000 primate skeletons and found no evidence of spondylolysis (Schultz 1962 in Wiltse 1962). "Only man has a true upright stance, a true lumbar lordosis and a bipedal gait" (Wiltse 1962:551).

Taillard (1976) discusses two European studies (French and German) where human’s lumbar lordosis figured prominently. Piwnica et al (1958) and Schluter (1965) used plastic models submitted to different types of loading in order to stress the vertebral arch. Their research showed that the stress reaches its maximum in the isthmus particularly in standing (Piwnica et al 1958 and Schluter 1965 in Taillard 1976:32). Pfeil (1971) studied 500 children between the ages of birth and 6 years. Seventeen children had spondylolysis with the youngest case being 1.5 years old. He believes the defect is associated with man’s upright posture and lumbar lordosis (Pfeil (1971) in Taillard 1976: 32-33).

As previously mentioned in chapter 3, Kraus et al
(1957) developed a mathematical model used to explore the influence of lordosis on the stress in the human spine. It was shown that flatter spines would tend to fail by flexion while spines with more lordosis would tend to fail by torsion (Kraus et al. (1975) in Lamy 1975:58). These conclusions are supported by the clinical observations made by Farfan (1973). Farfan noted that spines with greater curvature generally resulted in torsional failures whereas flexural failures occurred more often in spines with less curvature (Farfan 1973:152).

Stewart (1956), another advocate of the view that lumbar lordosis plays a large role in the etiology of spondylolysis, stated:

"We alone have true upright posture and spondylolysis. There can be little doubt that the two are related. We have inherited the basic predisposition to arch defects along with the mechanism for upright posture. In other words, arch defects are a consequence of man’s still imperfect skeletal adjustment to upright posture" (Stewart 1956: 59).

Due to the nature of this investigation based on skeletal materials, it is impossible to assess any genetic element in the etiology of spondylolysis. Therefore, only evidence of mechanical stress can be examined. Following the research of Stewart (1931, 1953, 1956) and Merbs (1981) the possibility of odd habitual postures leading to mechanical strain and subsequent
spondylolysis was assessed by this author. The difficult lifestyle of the Northern Plains hunters and gatherers cannot be denied. The task then was to find evidence of postural strains that could lead to fatigue fracture among the Northern Plains people.

There are basically three documented activities that lead to mechanical failure of the pars interarticularis, (1) athletics, (2) odd habitual postures, and (3) the lifting and carrying of weight. Although the Plains Indians were "athletic", this discussion will concentrate on the last two activities.

Stewart (1953) was the first to postulate odd habitual postures as a possible mechanical causative factor of spondylolysis in Eskimos. His aim was to investigate extra stresses within the lower back, which, in contrast to injuries and beyond the fundamental adaptations to upright posture, are of a chronic nature and perhaps lead to de-ossification and spondylolysis (Stewart 1953:948). He believed that strange body positions (environmentally or culturally - determined) required by special occupations and endured for long periods of time might supply some of these extra stresses (Stewart 1953:948). Thus the idea of occupational activities leading to chronic strain and eventual de-ossification was formed. To explain the high incidence of spondylolysis among the Eskimos he studied, he stated:
women are seen standing straight legged and bent over inorder to engage in hand operations at ground level. In this position the back and hip joints are hyperflexed while the lower extremities are nearly or fully extended. Most other people find... the extension of the hamstring muscles too painful and hence kneel or sit down to do such work. When Eskimos sit they often assume a similar position with the lower extremities fully extended in front of them. The men also sit in this fashion ... when they are in their slender, skin covered boats (kayaks). ... The effect of such posture on the low back is to reduce the normal lumbar lordosis (Stewart 1953:949)

Stewart concluded that the unusual incidence of spondylolysis in Eskimos is due to the combination of unusual postural stresses, a high accident rate ( falls on the ice), and perhaps a somewhat more frequent occurrence of anomalous ossification (Stewart 1953:950).

Lamy et al (1975) agreed with Stewart’s (1953) work for they found it was impossible to produce a fracture in the pars interarticularis except in the presence of high degrees of tension in the posterior ligaments and muscles (Lamy et al 1975: 230). The shear forces on the facet joints were also found to increase with forward flexion, thus, the lumbar spine must be flexed for the defect to occur.

Hyperflexion is one of the extreme body positions postulated to cause spondylolysis (Lamy et al 1975). According to Hitchcock (1940:13):

....of the movements of the lumbar column, flexion is far more restricted than extension. Virchow pointed out many years ago that in flexion the lumbar column simply straightens out, while extention increases the lumbar curve. By actual
Thus one can conclude that the same straight-legged, hyperflexed posture, found in the Eskimo may also cause spondylolysis in other racial groups if that posture persists over time.

Little or no previous investigations of similar postures among Plains Indians has been carried out in order to verify this possibility. Photographs from the Glenbow Museum, in Calgary Alberta, show that this straight-legged hyperflexed posture was also popular among the Plains Indians. Apparently, women habitually used this posture when working animal hides (Figure 29, 30, & 31). A second set of photographs shows a woman demonstrating the use of an instrument called a "beamer". The instrument keeps the hide elevated off the ground, yet the woman must keep the same "straight-legged" posture as she runs a stick up and down the hide (Figure 32&33). Merbs (1981) also studied the effect of odd habitual postures in the Eskimo. He believes that the straight-legged posture is beneficial in working animal hides for it enables direct short powerful strokes toward the carcass of the animal lying on the ground, however,

measurement, the movement of the lumbar column in flexion is scarcely 12 degrees from the perpendicular, whereas in extension it amounts to 25 degrees. It is apparent, therefore, that, if flexion is slightly forced, great leverage is exerted upon the neural arches with the vertebral bodies as fulcra, which is resisted by ligaments and soft structures only. Such a force naturally has its maximum effect upon the lower lumbar neural arches, which fracture at their weakest part - namely, the isthmus or pars interarticularis.
Figure 29: Blood Indian woman scraping a hide, ca. 1904. Note the straight legs and hyperflexed lower back. Glenbow Museum.
Figure 30: Blackfoot woman scraping a hide, ca. 1875. Note the straight legs and hyperflexed lower back. Sketch by Dr. R.B. Nevitt. **Canadian Illustrated News**, July 2, 1881. Glenbow Museum.
Figure 31: Sarcee Indian woman working on a hide, ca. 1920's. Note the fully extended lower extremities and the hyperflexed lower back and hips. Glenbow Museum.
the strong torsional stresses generated are absorbed effectively by the thoracic vertebrae but poorly by the lumbar vertebrae (Merbs 1981: 175).

Plains men also assume the straight-legged hyperflexed posture when sitting much like the Eskimo men (Figure 34 & 36). Women may also sit with their lower extremities fully extended in front of them (Figure 35) but it appears they generally assume a more "twisted" sitting posture. The back is rounded, the legs are bent and the feet are off to one side, perhaps causing torsion in the lower back (Figure 35 & 36). Many of the photographs depicting the women in this odd sitting posture show the women working, thus one may conclude that this posture is also endured over long periods of time (Figure 37, 38, 39, 40, & 41).

The view that spondylolysis may first appear in childhood also applies to the Plains Indians. The habitual straight-legged hyperflexed posture is found in children riding in the travois (Figure 42 & 43). Children are strapped into this position and may travel for long distances without changing their posture. Such a constriction is very similar to the Eskimo men in their Kayaks. The ride in the travois may also be very bumpy thus adding some trauma to the already confined odd posture.

Being nomadic hunters and gatherers almost
Figure 32: Cree Indian woman demonstrating the use of the "beamer", ca. 1963. Note the straight legs and hyperflexed posture needed to operate the instrument. Glenbow Museum.
Figure 33: A second angle of the Cree woman demonstrating the use of the "beamer", ca. 1963. Glenbow Museum.
Figure 34: Blackfoot Indians gather near agency for a visit from Lord Minto, ca. 1900. Note the straight legged sitting posture. Glenbow Museum.
Figure 35: South Peigan women inside a medicine lodge, Browning Montana, ca. 1900-05. Note the two sitting postures assumed by the women. One is a straight legged posture and the other is a curled back with the legs bent off to one side. Glenbow Museum.
Figure 36: Sarcee Indian man (Head Above Water) with his two wives, ca. 1880's. Note the two sitting postures. The man is sitting with his lower extremities fully extended in front, while the women have a curled back with the lower extremities off to one side. Glenbow Museum.
Figure 37: Sarcee Indian woman drying meat, ca. 1920's. Note the "curled" sitting posture. Glenbow museum.
Figure 38: Sarcee Indian woman drying berries, ca. 1920's. Note the sitting posture. Glenbow Museum.
Figure 39: Sarcee Indian woman drying berries, ca. 1920's. Note the sitting posture. Glenbow Museum.
Figure 40: Sacree Indian woman drying meat, ca. 1920’s. Note the unusual sitting posture. Glenbow Museum.
Figure 41: Sarcee Indian woman drying meat, ca.1920's. Note the sitting posture. Glenbow Museum.
Figure 42: Close-up of a little Stoney Indian girl on a travois, ca. 1923. Note the sitting posture (fully extended lower extremities). Glenbow Museum.
Figure 43: Stoney Indians with travois, ca. 1925. Note the sitting posture (fully extended lower extremities). Glenbow Museum.
guarantees that the Plains people lifted and carried objects over extended periods of time. As already mentioned in chapter 3, both Newman (1963) and Cyran and Hutton (1976) found that walking with a 500 newton pack on the back (or the equivalent force) can lead to mechanical fatigue and that mechanical fatigue can cause the neural arch to fracture as long as enough stress reaches the arch and persists over time. Two photographs from the Glenbow Museum show women carrying firewood strapped on their backs (Figures 44 &45).

In summary, athletic activities, odd habitual postures, and weight bearing over extended periods of time have been shown to cause spondylolysis (Newman 1963, Cryan and Hutton 1976, 1978, McCarroll 1986). The Plains Indians were a nomadic hunter and gatherer people leading a strenuous lifestyle. Similar postures shown to account for the high incidence of spondylolysis among the Eskimos have also been found among the Plains people.
Figure 44: Sioux Indian women gathering and carrying firewood, ca. 1882. Glenbow Museum.
Figure 45: Women hauling wood to a Blackfoot Indian camp, ca. 1875. Sketch by Dr. R.B. Nevitt. Canadian Illustrated News, July 2, 1881. Glenbow Museum.
7.0 CONCLUSIONS

Spondylolysis is a defect which occurs in the pars interarticularis region of vertebrae. Lumbar vertebrae are usually affected, however, there are cases of spondylolysis found in the cervical spine (Rowe et al 1978). The incidence of this defect in the general public is approximately 5-6%, however some racial/ethnic groups and certain families have reported incidences far beyond 6% (Snow 1948, Stewart 1931, 1956, 1979, Nathan 1959, Wiltse 1962, Lester and Shapiro 1968, Kettlekamp and Wright 1971, Merbs 1983). Debate still continues as to whether males are more often affected than females (Hitchock 1940, Stewart 1953, Lester and Shapiro 1968, Kettlekamp and Wright 1971, Wiltse et al 1975, Jackson et al 1976, Fredrickson 1984).

Histologically, the defect does not always appear the same in each case. Bone ends may be rounded or "spiky" (Wiltse 1962), whereas the soft tissue can have one of five different appearances or combinations of these five (Hitchock 1940, Roche 1949, Raney 1949, Roche and Rowe 1952, Boswell 1955, Gill et al 1955, Wiltse 1956, 1963, Krenz and Troup 1973, Taillard 1976, Soren et al 1985). Bone variations coincident with spondylolysis are spina bifida occulta (Meyerding 1933, Friberg 1939, Taillard 1976, Nathan 1959, Laurent and Einola 1961,
sacralization of the vertebrae (Laurent and Einola 1961, 1979, stress and rapid intense Wynne-Davies et al 1986) and enlarged transverse processes which tend to occur less frequently in spondylolysis patients than in the general public (Roche and Rowe 1952, Farfan et al 1975).


Stewart (1953) was the first to postulate that
habitual postures (environmentally or culturally-determined) required by special occupations and endured for long periods of time may lead to spondylolysis in Eskimos. The above premise was used in this thesis to investigate spondylolysis among Plains Indians. Since the same straight-legged, hyperflexed back and hip joint posture was found in the Plains Indians when performing specific occupations and activities, I conclude that environmentally and/or culturally-determined postures, that result in hyperflexion or weight bearing over an extended period of time, may have lead to spondylolysis in the Plains Indian.
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