Bioarchaeology of the Thoracic Outlet Syndrome through Bioarchaeology of Care model

Cassandra Anderson

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Abstract
Thoracic Outlet Syndrome (TOS) is caused by compression of the nerves of the brachial plexus leading to paresthesia, muscle and bone atrophy, and pain in the affected arm. TOS can be identified on the skeleton through multiple skeletal indicators such as cervical ribs or bone atrophy. The lack of identification of TOS in bioarchaeological remains limits the amount of knowledge that can be gained from archeological populations in relation to social care and respect for physically disabled individuals. This study explores bioarchaeological evidence of TOS, including evidence of prehistoric medical procedures and community support to the disabled. Novel differential diagnoses are made for two case studies from previously analyzed individuals. One case study is from a medieval cemetery in Portugal and the other is from a Woodland era site in Colorado. These two cases both demonstrate skeletal indicators of Thoracic Outlet Syndrome by using the Bioarchaeology of Care theoretical model.

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THROUGH BIOARCHAEOLOGY OF CARE MODEL

By

Cassandra Anderson

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Thoracic Outlet Syndrome (TOS) is caused by compression of the nerves of the brachial plexus leading to paresthesia, muscle and bone atrophy, and pain in the affected arm. TOS can be identified on the skeleton through multiple skeletal indicators such as cervical ribs or bone atrophy. The lack of identification of TOS in bioarchaeological remains limits the amount of knowledge that can be gained from archeological populations in relation to social care and respect for physically disabled individuals. This study explores bioarchaeological evidence of TOS, including evidence of prehistoric medical procedures and community support to the disabled. Novel differential diagnoses are made for two case studies from previously analyzed individuals. One case study is from a medieval cemetery in Portugal and the other is from a Woodland era site in Colorado. These two cases both demonstrate skeletal indicators of Thoracic Outlet Syndrome by using the Bioarchaeology of Care theoretical model.
“...how many times have we [bioarcheologists] seen bone fragments that may well have been cervical ribs, but we put it down as an anomaly that we knew nothing about or dismissed the fragment as simply a part of a normal rib” (Finnegan 1978, 229).

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INTRODUCTION

The Bioarchaeology of Care model is a four-stage analysis of human remains demonstrating serious pathology (Tilley, 2015). Following the four stages allows for interpretation of the probable method of care given to the individual and implications for social relations. The first stage of the Bioarchaeology of Care model is identification of human remains with serious pathology and completing a biological profile on the remains. The second stage is examination of the impact of the disability on daily life. The impact of the serious pathology is examined through the functional impacts on movement and the probability of the individual’s need for care. The third stage is the probable method of care identified through basic medical practices that have not changed. This care can be through direct and indirect depending on which action is most appropriate for the pathology. The final stage of the Bioarchaeology of Care model is the consideration for social relations, social practice, and group identity. The act of care is intentional and examining the medical care given can demonstrate the willingness of the community to care for injured or ill individuals.

Thoracic Outlet Syndrome (TOS) is a degenerative condition caused by the compression of the nerves of the brachial plexus of the shoulder girdle. The compression can cause nerve damage, pain in the affected arm, paresthesia (i.e., a prickling or tingling sensation), and bone or muscle atrophy (i.e., bone or muscle loss). If untreated, the effects of the condition can cause permanent damage and disability (Laulan et al., 2010). Only recently have there been medical breakthroughs which can halt the condition. Medical treatments, such as surgery and physical therapy, were not possible in the past so historic and prehistoric individuals with the condition experienced the progressive pain and increased disability. Over time, individuals with TOS, without medical care, can experience limited mobility of the affected arm, shoulder, and hand. The
limited mobility can severely impact the independence of the individual. Due to these functional adaptations that occur, overuse of the opposite limb can be seen. This overuse is what can be expected to be documented in the osteological evidence, yet in some cases the expected wear is not evident. Through this lack of wear, evidence of care can be interpreted. The use of the Bioarchaeology of Care model can help detail the expected medical care and can give insight into attitudes of social care for physical disabilities. Two case studies, which present with skeletal indicators of Thoracic Outlet Syndrome, are interpretated using the Bioarchaeology of Care model.

During an excavation of Bradford House III in Colorado, a male individual was found with an atrophied left humerus, cervical ribs, and unusual tooth wear (Finnegan, 1978). When the skeletal indications are taken together, a differential diagnosis of Thoracic Outlet Syndrome can be considered. Based on this individual’s age at death and the condition of his left humerus, he had lived a large portion of his life with progressively worse TOS, which limited his independence and required assistance from others.

The remains of an adult female are analyzed from the medieval cemetery of Santiago do Cacém in Portugal and exhibit not only indicators of Thoracic Outlet Syndrome, cervical ribs, and atrophy of the left humerus, but also evidence of vertebral damage and severe anemia (Fernandes & Granja, 2003). The individual lived to approximately 50 years of age and, based on her debilitating pathologies, care would have been necessary.

Other opportunities for future research into the Bioarchaeology of Care, specifically looking at the Thoracic Outlet Syndrome, can be found in New Mexico with individuals uncovered from Gran Quivera (Reed, 1981). These individuals need to be reanalyzed in order to get a positive diagnosis of TOS, including new and detailed photographs. Additionally, further research can be
completed for the remains found at Ohalo II site (Hershkovitz, 1993). The remains found at that site demonstrate significant upper limb bilateral asymmetry. Thoracic Outlet Syndrome was not considered in this case as a differential diagnosis due to the lack of cervical ribs.

Thoracic Outlet Syndrome is a condition that has multiple skeletal indicators and can also be caused by soft tissue, in some cases fibrous bands can imprint on the skeleton. Examining multiple skeletal indicators simultaneously can give insight into probable acts of care given to individuals. Following the Bioarchaeology of Care model and identifying and analyzing human remains that demonstrate serious pathology, medical and social care can be inferred. Care is an intentional act and identifying situations where care was given can increase the understanding and knowledge of a society.

**Bioarchaeology of Care**

Bioarchaeology of Care consists of the identification, examination, and interpretation of individuals who demonstrate pathological issues or physical injuries (Tilley, 2015). The structure of this model can allow for interpretation of the impacts on daily life. There can be an increased understanding of prehistoric attitudes relating to disabled individuals, whose disability can impact the survival of the group. This model can also increase knowledge of the evolution of human health care (Tilley, 2015). In order to fully understand and interpret the Bioarchaeology of Care, four stages should be followed.

The first stage is the identification of human remains that demonstrate evidence of living with serious pathology. During this stage, every aspect of the remains and method of removal should be recorded, including any pathology or trauma. This stage is the basis for the explanation for the following stages (Tilley, 2015).
The second stage of the Bioarchaeology of Care analysis begins to identify the impacts on daily life caused by the serious pathology detailed in the first stage. This must be viewed through modern clinical sources to identify the impacts of the injury or pathology (Tilley, 2015). Functional impacts are evaluated by assessing the likely demands, obstacles and opportunities in that geographic area and time period. The pathology or injuries are examined in relation to the individual’s ability to do the daily tasks related to living and community participation without assistance. The goal of this step is to establish the probability of the individual’s needed care for their disability. Specifically, to identify whether the individual could have lived to their estimated age at death without aid from others (Tilley, 2015). In this stage a differential diagnosis can be given.

Stage three of the Bioarchaeology of Care analysis is the description of the probable model of care. This model of care is based on what was possible and probable during the time period in which the individual lived. In this stage, the estimation of the community level of care is detailed. The community level of care encompasses the amount of people who would have had to be involved in the caregiving, both with social and economic considerations (Tilley, 2015). Direct care are healthcare actions directly following an injury or during an illness. This care can include aid with personal hygiene, managing safety concerns for the injured or ill individual and general health monitoring and maintenance after a medical procedure. Forms of direct care can be considered more intimate, potentially indicating whether the caregiver was family versus non-kin (Tilley & Oxenham, 2011). Indirect care is aid with some daily activities. Some of these activities are provision of food, water, shelter, and transport (Tilley & Oxenham, 2011).

The fourth and final stage of analysis takes into consideration social relations, social practice, and group identity. Care is the product of agency. It is intentionally done and in response
to needed health issues of another individual. The care encompasses a combination of cultural values and beliefs and medical experience (Tilley & Oxenham, 2011). Care is also structured around social and economic organization and the ability to access resources. There is a focus on the choices made to achieving the outcomes of the skeletal remains (Tilley, 2015). The indicators of care can come from both soft tissue and skeletal remains, so some evidence of care would have been lost because soft tissue decomposes. The remains have to suggest survival with a continual disability that impacts functional independent movement, such as a lack of overuse injury in the opposite side of the body. Another example of receipt of care could be a suggestion of healing or healed lesions associated with illness or an injury that required care for recovery (Tilley & Oxenham, 2011). Some questions that can be asked are (1) what options are available for caring, (2) what cost/benefit of care was, (3) what the impact of care on the care giver was, and (4) what could be the personality of the cared or care giver.

An important aspect of any care model is the willingness of the ill or injured individual to participate in treatment. Conditions, such as psychological depression, can occur due to the limits of mobility and forced habitual change. If the illness or injury caused a decrease in functionality, there can be a loss of self-esteem, social isolation, and potential social rejection (Tilley & Oxenham, 2011). Psychological care is not directly seen in the skeleton but is an important consideration in the study of past healthcare.

Constraints of the Bioarchaeology of Care Analysis

Any skeletal remains recovered that demonstrate pathology indicate individuals who were able to live long enough with the condition for the condition to leave an imprint on the bones. This is the osteological paradox (Tilley, 2015; Wood et al., 1992). Those individuals were essentially
healthier because the disease or injury did not kill them immediately. These individuals had chronic conditions or advanced stages of illness thus creating the skeletal indicators. Other individuals could have also had a similar disease but the disease killed the individual before it could be recorded in bone; therefore, it would not be possible to identify the condition for that individual (Tilley, 2015).

Bones have a limited ability to respond to disease; bone can either be added or taken away. Therefore, overlap in the expression of diseases or conditions is common. Differential diagnosis can be given for the same skeletal indicators, but the patterning across the skeleton is important to consider (Ortner 2003).

There can be a large difference in the type of care needed for the affected individual. The Bioarchaeology of Care model is a probable model of care. Care is the action of others to help the individual with a disability. The care is assumed based on the appearance of the skeletal remains and the age to which the individual lived with the serious pathology. The care is what allowed the individual to live to the approximate age of death while having a disabling condition. The true method of care cannot be known because many types of care cannot be recorded in skeletal remains. Thus, the care inferred is probable based on the skeletal remains.

Poor preservation of skeletal remains limits the ability to distinguish conditions (Tilley, 2015). Taphonomy can also distort the bone, which can confound the differential diagnosis. There can also be overreliance on macroscopic examinations with microscopic indicators being overlooked. Additionally, the population available for study may be limited because it can be argued that skeletons of young adult individuals preserve better. The skeletal remains of older
individuals, who are more likely to have chronic conditions, may not preserve well enough to make a clear diagnosis.

**THORACIC OUTLET SYNDROME**

Thoracic Outlet Syndrome (TOS) is a condition in which the nerves of the brachial plexus are compressed due to soft or hard tissue anomalies or injuries. These can be scar tissue, muscle tension, muscle growth, or bone abnormalities. Symptoms of this syndrome include, but are not limited to, paresthesia in the affected hand and/or arm, heaviness of the affected arm, muscle and bone atrophy, loss of function and movement of the affected arm, and nerve damage to the affected hand and/or arm (Laulan et al., 2010). Over time, if untreated, there is increased risk for muscle and bone atrophy, and permanent nerve damage.

There are three types of TOS: neurogenic, arterial, and venous. Neurogenic TOS (NTOS) is the most common type of TOS (Laulan et al., 2010) and is a relatively common pathological syndrome that is frequently not recognized (Kuwayama et al., 2017). General symptoms of NTOS include pain in the neck, face, temple, and mandible. Occipital migraines and stuffiness of the ear can also occur. There can be anterior and posterior shoulder pain, and pain radiating down medial side of arm, forearm, and hand (specifically the 4\textsuperscript{th} and 5\textsuperscript{th} fingers). Numbness, paresthesia, progressive weakness, fatigue, and disfunction of the upper arm, forearm, and hand are common, as well. The hand and/or arm may change color including blanching or turning a blueish or reddish color. Coldness of the hand may occur as well (Christo et al., 2010) (Laulan et al., 2010). NTOS can be separated into two categories that cause different symptoms and results in the patient. “True” NTOS can result in muscular atrophy of the hand and forearm. This occurs after the patient has suffered from NTOS for multiple years. “Pain” TOS does not have a direct connection to a
nerve, but with it occurs pain in multiple locations as listed above and can lead to disuse of the affected limb.

There are multiple areas of compression in the neck/shoulder region which lead to TOS. The first is the costoclavicular triangle (Walker 2022). The anterior border is the middle third of the clavicle, postero-medially is the 1st rib, and postero-laterally is the upper border of the scapula. The second space is the subcoracoid/subpectoralis minor space. The superior border of this space is the coracoid process, the anterior border is the pectoralis minor, and posteriorly bordered by ribs 2-4. The third space is the interscalene triangle in the neck. The anterior border is the anterior scalene muscle, the middle scalene muscle is the posterior border, and the inferior border is the first rib medial surface (Walker, 2022). Some skeletal anomalies that cause TOS are anomalous first ribs, cervical ribs, extended transverse processes of seventh cervical vertebrae, and poorly healed fractures of the clavicle. TOS is not a genetic condition, yet the factors that can predispose someone to TOS can be genetic, such as cervical ribs or an extended transverse process of a cervical vertebra. These skeletal anomalies can run in families giving the implication that TOS is congenital.

Pathology or Injuries

Congenital abnormalities such as cervical ribs, first rib issues, fibrous bands, or muscular abnormalities can lead to TOS (Laulan, 2010). Trauma and consistent overuse can cause TOS, as well. Traumatic causes can include repeated trauma, and ‘whiplash’ injuries from high velocity deceleration events. Functional causes can be an enlarged muscle of the cervico-scapular region (i.e., trapezius) and a dropped scapular morphotype, which leads to issues with function of the
anterior scalene muscle (ASM). Having large breasts and incorrect posture can also play a role in the etiology (Laulan et al., 2010; Walker, 2022).

Repetitive movements can fall under both traumatic and functional causes. Certain occupations with consistent elevation of the arms or an anteriorly flexed head/shoulder can lead to NTOS over time. Specific movements can increase the symptoms of NTOS, including carrying heavy loads on the shoulder and carrying heavy loads with an outstretched hand. Repetitive movement in occupations is a common cause for NTOS. Occupations such as musicians, data entry personnel, assembly line workers, barbers, artists, athletes (especially in sports with repetitive overhand movement like swimming, boxing, volleyball), masons, painters, forestry workers, and construction workers can all be predisposed to NTOS due to the physical demands of these occupations (Christo et al., 2010; Laulan et al., 2010).

**Diagnosis of NTOS**

Modern diagnosis of NTOS must be done with multiple tests in correlation with any physical abnormalities or injuries. “Such an abnormality [cervical rib or prolonged C7 transverse process] on its own [is] not sufficient to confirm the diagnosis of TOS…” (Laulan et al., 2010: 369). For diagnosis, an extensive patient record review is needed, which should be followed by a physical exam (Kuwayama et al., 2017). Modern tests include Roos/EAST test, Tinel’s sign, Morley’s sign, EMG, and intramuscular anterior scalene block. The EAST test is the most reliable test for the diagnosis of NTOS (Kuwayama et al., 2018). During the diagnostic process, special consideration should be taken for the emotional well-being of the patient, due to the lack of knowledge surrounding Thoracic Outlet Syndrome. Patients are often misdiagnosed, informed by physicians that the pain is psychosomatic (Kuwayama et al., 2017).
Conservative treatments for TOS are considered before surgical intervention. These include lifestyle modification, posture correction, and medications. Rehabilitation with physical therapy is encouraged. Physical therapy places emphasis on heat-packs, exercise programs, and cervical traction. In some cases, physical therapy is not successful. Surgery is the last resort if symptoms persist. The types of surgery include first rib resection, scalenectomy, or a combination of the two (Christo et al., 2010; Laulan et al., 2010).

_Cervical Ribs (Supernumerary ribs)_

Cervical ribs (also called supernumerary ribs) appear in approximately 1-3% of the adult human population (Partiot, 2020). There have been studies into the connection between early infant mortality and the presence of cervical ribs. The presence of cervical ribs can indicate other congenital malformations, which are fatal (Giangregorio et al., 2006). In one study, 598 infants who died between 1992 and 1999 with radiographs taken and it was found that at least 78% of infants with a cervical rib died before birth and 83% before one year (Galis et al., 2006). Another study by Schut and colleagues (2019) investigated the link between cervical ribs and esophageal atresia and anorectal malformation. Esophageal atresia occurs when the esophagus does not develop properly. Anorectal malformation is a birth defect in which a link of a child’s anus or rectum is malformed, interfering with the normal passage of stool. In this study, it was found that cervical ribs were common in children who had a chromosomal and genetic abnormalities; 18/20 (90%) (Schut et al., 2019). Based on cervical ribs corresponding with other congenital malformations that can lead to early mortality, the incidence rate of cervical ribs is lower.

Approximately three quarters of cases of cervical ribs remain asymptomatic, but overtime, with the addition of trauma, stress, or increased ossification, these can become pathological (Barnes, 1994). When symptoms occur, it is more likely to occur on the left side rather than the
right. Based on the appearance and length of the cervical ribs, these can fall into four classes. The first class is when the extension of the transverse process from the seventh cervical rib (tubercle) does not extend beyond the normal length of a transverse process (Barnes, 1994). The second class is when the bony protrusion extends to between an inch and a half and two inches from the 7th cervical vertebra. At this length the cervical rib is more likely to compress the brachial plexus, which can cause paresthesia and other TOS symptoms. The third class is when the overall shape of the cervical rib reflects that of the first rib. This class of cervical rib articulates with the first rib or with the sternum via a fibrous band (Barnes, 1994). Evidence of the fibrous band can sometimes be observed on skeletal remains due to the impressions created between the cervical rib and first rib. This class of cervical rib pressure on the subclavian artery is common. The fourth type of cervical rib is a complete separate rib with costal cartilage, yet it may still articulate with the first rib (Barnes, 1994).

**Bone Atrophy**

Bone atrophy (i.e., bone loss) can be caused by many factors. It can be caused by decreased blood supply to bone, muscle atrophy, age related osteoporosis, rheumatoid arthritis, and Sudeck atrophy\(^1\). Another cause of bone atrophy results from immobility of the bone (Carter, 1984). In many cases when a bone is immobilized in a splint or cast, the muscles and bones in the area atrophy slightly but are typically able to regain mass after use recommences. Extended immobilization can lead to more severe bone atrophy.

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\(^1\) Atrophy develops rapidly in the area of injury relative to bone (Carter, 1984)
**First Thoracic Ribs**

Malformations of the first thoracic ribs can also be a skeletal cause of TOS, because the malformation of the first ribs may narrow the scalene triangle. Anomalous first ribs occur more superiorly than the average first rib, and the placement can cause misidentification in imaging as cervical ribs due to the appearance of articulations with the C7 vertebrae (Sanders & Hammond, 2002). Usually, these ribs are thinner than normal first ribs and can be inserted into the costal cartilage of the 2nd rib, whereas first ribs are usually inserted in the costal cartilage near the sternum. In a case study of a patient who was presenting with TOS symptoms, it was found that she had a “hypoplastic first rib that was causing pseudoarthrosis\(^3\) with the second rib” (Hidlay et al., 2014). The patient decided on physical therapy as the first course of action, yet there was significant muscle atrophy of her deltoid muscle even with physical therapy. Surgery was necessary because the compression of the brachial plexus caused neurogenic TOS. The compression had to be relieved via a first rib resection surgery.

**Clavicle Fractures**

Evidence of healed or partially healed clavicle fractures could point to Thoracic Outlet Syndrome with identification of other markers. TOS due to a clavicle fracture “is caused by misalignment of the fracture, formation of a callus or nonunion of the fracture” (Van de Pas et al., 2018: 89). TOS symptoms usually occur after the healing of the clavicle begins, so there is a space of time between original injury and TOS symptoms. In a study by Ishimaru and colleagues (2012), an individual was received in the emergency department with multiple traumatic injuries, including a clavicle fracture. Due to the other injuries, the normal treatment of a clavicle fracture could not

\(^3\) Failure of fracture to stabilize and refuse can heal with the bone sections separated to form a fibrous joint called false joint or pseudoarthrosis (Hidlay, 2014).
be followed. The lack of this treatment caused a shortening of the individual’s clavicle and the formation of a bony callus. The shortening of the clavicle also caused the shortening of nearby tendons and compression the brachial plexus causing Thoracic Outlet Syndrome.

_Fibrous Bands_

Though fibrous bands do not commonly survive in the archaeological record, it is one of the most common causes of TOS (Magill et al., 2015); however, fibrous band and muscle and tendon attachment points can be seen sometimes on skeletal remains. This is due to the tendon or fibrous band pulling on the bone as the muscle is used. Some large muscle attachment points near the brachial plexus are the biceps brachialis, pectoralis major, and trapezius. Overuse of these muscles can cause issues with the connective tissue bands that could lead to TOS.

_Treatments_

Treatments for thoracic outlet syndrome vary by type of TOS and severity. When soft tissue is the cause of the compression, physical therapy is encouraged before surgical interventions. Different methods of physical therapy can occur, but all have a focus on stretching the trapezius muscle and scalene muscles to loosen the tendons and ligaments contributing to the compression of the brachial plexus.

There is also emphasis on strengthening the muscles in the lower back. TOS can cause scapular dyskinesis (Larsen, 2018), which is when the muscles of and around the shoulder girdle (teres major and minor, rhomboid major and minor, and latissimus dorsi) weaken causing the shoulder blade to drop lower due to lack of muscle support or causing the scapula to wing out. This causes issues with shoulder mobility and strength. If this condition occurs, the muscles of the back and the anterior serratus muscle are strengthened with physical therapy (Larsen, 2018).
In many cases where a bony abnormality is involved such as cervical ribs, surgery is performed to remove the abnormality and relieve the pressure on the brachial plexus. Types of surgical intervention include the removal of cervical ribs and the first rib resection. In Thoracic Outlet decompression surgery, the entire first rib must be removed leaving only the head and neck. Partial removal can cause recurrence of the symptoms and necessitate a second surgery. The first rib resection can be done anteriorly and superiorly to the clavicle leaving at 4-to-5-inch scar or through the lateral ribcage of the affected side. For full decompression of the area, the anterior scalene muscle is removed opening the interscalene triangle area further (Roos, 1971). Scar tissue connected to the first rib can also contribute to the compression of the brachial plexus. Healing post-operatively consists of a short stay in the hospital with a drain in the newly opened interscalene triangle. While the drain is in place, there may be discomfort in the back. Once fluid is no longer draining, the patient is released from the hospital and cannot raise the arm on the affected side more than 90 degrees until the beginning of physical therapy.

For recovery after surgery, physical therapy should begin two to three weeks post operation. While healing, the patient may experience extreme tension in the neck on the affected side, changes in the ability to feel heat or touch around incision, and paresthesia. All postoperative effects listed should decrease overtime until the patient no longer has symptoms, but the loss of sensation can be permanent. Thoracic Outlet decompression surgery has a high success rate, although there are cases where the surgery was not successful and the patient begins to have symptoms once more.

**Differential Diagnoses**

Paresthesia, shoulder and back pain, and weakness in extremities can be symptoms of different conditions. Cervical spine disorders (including cervical dystonia), rotator cuff pathology,
impingement syndrome, Pectoralis Minor Syndrome, Suprascapular Nerve Entrapment (SNE), Brachial Neuritis, Carpal Tunnel Syndrome, Ulnar Entrapment Syndrome, and Peripheral Nerve Tumors all have traumatic and occupational causes similar to TOS, specifically Neurogenic Thoracic Outlet Syndrome (NTOS), which includes swimming and baseball (Jordan, 2013). Some of these conditions can occur in conjunction with NTOS, potentially causing issues with NTOS rehabilitation.

**Cervical Spine Disorders**

Cervical myeloradiculopathy is the dysfunction of the cervical spinal cord and nerve root. Disc disease and cervical spine strain can mimic NTOS symptoms. The patterns of paresthesia differ between TOS and cervical myeloradiculopathy (Jordan, 2013: 99). The paresthesia of the fourth and fifth digits is less likely to occur when there is cervical root compression caused by disc disease or cervical spine strain. Cervical root compression causes limited mobility of the neck and there is increased sensitivity to the axial compression and extension. These symptoms can also be present in patients with Thoracic Outlet Syndrome.

**Cervical Dystonia**

Cervical Dystonia is a cervical spine disorder characterized by the involuntary contraction of the muscles of the neck leading to spontaneous twisting of the neck and head. This condition can cause pain the neck, upper back, and shoulders. In some cases, this condition can cause paresthesia as well. Traumatic or occupational injuries, similar to injuries that cause TOS, can cause cervical dystonia. Patients with this condition can respond well to injections of botulinum toxin (i.e., botox) of the affected muscles of the neck (Jordan, 2013).
Rotator Cuff Pathology

Rotator cuff pathology is the most common shoulder injury that requires medical treatment. Many rotator cuff injuries can be caused by a partial tear in the undersurface or articular portion of the supraspinatus tendon (Jordan, 2013:100). Injuries that affect the rotator cuff are similar to Thoracic Outlet Syndrome. Patients with rotator cuff tears have complaints with the lateral deltoid and usually display weakness in external rotation. It is unusual for isolated rotator cuff injuries to cause paresthesia and there is usually no pain with palpation of the scalene triangle. Patients with rotator cuff injuries or labral tears may develop NTOS even after shoulder surgeries.

Impingement Syndrome

Impingement syndrome causes shoulder pain because of impingement in the vulnerable avascular region of the supraspinatus muscle and the biceps brachialis tendon (Jordan, 2013: 100). The tendons of the rotator cuff are compressed as they pass between the humerus and the acromion of the scapula. The impingement of the tendons can degenerate into rotator cuff injuries. A rotator cuff injury may cause weakness of the shoulder and arm causing difficulty for a person to elevate the arm. There can also be grating or catching of the muscles of the arm and shoulder as the arm is rotated or raised (Kuwayama et al., 2017).

Suprascapular Nerve Entrapment (SNE)

Suprascapular nerve entrapment can be caused by repetitive trauma due to by sports or occupation. The entrapment is at the suprascapular notch of the scapula. Pain in the posterior and superior areas of the shoulder is characteristic of this condition. There can also be wasting of the supraspinatus and infraspinatus muscles (Bruce & Dorizas, 2013). The location of pain and the
location of muscle atrophy are different between SNE and TOS. In TOS the pain is generally located around the scalene triangle and muscle wasting occurs in the arm and forearm. In both TOS and Suprascapular Nerve Entrapment there is weakness with forward flexion and external rotation (Bruce & Dorizas, 2013).

**Pectoralis Minor Syndrome (PMS)**

Pectoralis Minor Syndrome (PMS) occurs when the brachial plexus is compressed under the clavicle (Sanders & Annest, 2018). This condition can also occur in tandem with TOS. The pain associated with Pectoralis Minor Syndrome is different than NTOS pain. There is pain with palpation directly over the coracoid process of the scapula instead of the scalene muscles. Both conditions can cause paresthesia, limited movement of the shoulder, occipital migraines, and scapular dyskinesia (Sanders & Annest, 2018). TOS and PMS can be diagnosed using similar techniques: electrodiagnostic studies, and scalene muscle and pectoralis minor muscle blocks (Sanders & Annest, 2017).

**Brachial Neuritis (Parsonage Turner Syndrome)**

Brachial Neuritis is a rare inflammatory, autoimmune disorder of the brachial plexus. The pain is characterized by sudden, severe shoulder pain that occurs mostly in one shoulder and the pain occurs most often in the evening or while sleeping. There is also the development of weakness and paresthesia in the upper extremity. This condition is also associated with winged scapula. Winged scapula occurs when the serratus anterior muscle, teres major and minor muscles and/or latissimus dorsi muscles weaken and atrophy causing the scapula to move posteriorly with anterior movement of the arms (Kuwayama et al., 2017). Winged scapula condition is also associated with TOS, but the paresthesia of the upper extremities (deltoid muscle, trapezius) is more associated
with Brachial Neuritis than with Thoracic Outlet Syndrome. The paresthesia associated with TOS is throughout the arm and hand.

**Carpal Tunnel Syndrome**

Carpal Tunnel Syndrome occurs when there is entrapment of the median nerve as the nerve travels through the carpal tunnel. The tunnel is an opening that is created between the carpal bones of the wrist and the transverse carpal ligament. When this occurs, there is numbness on the palmar aspect of the first three and a half digits (Jordan, 2013). The paresthesia can also occur in the forearm. There is some occupational etiology overlap between Thoracic Outlet Syndrome and Carpal Tunnel Syndrome, especially in musicians and typists, but the functional cause is different.

**Ulnar Entrapment Syndrome**

Ulnar Entrapment Syndrome is caused by the compression of the ulnar nerve between the ulna and the humerus at the level of the elbow (Jordan, 2013). This syndrome can cause paresthesia of the forearm and of the fourth and fifth fingers. In rare cases, muscle atrophy and weakness of the hand can also occur. The cause of the syndrome can be traumatic or exercise related. Some of the causes include repetitive compression of the area, fractures, and bony abnormalities.

**Peripheral Nerve Tumors**

Peripheral Nerve Tumors are rare tumors that grow in or near nerves anywhere in the body including the brachial plexus. These growths can cause nerve compression and cause similar symptoms as NTOS. This condition can be distinguished from NTOS by a CT scan or an MRI (Jordan, 2013).
Pain around the chest, shoulder and arm, paresthesia, weakness in extremities, and lack of dexterity of the hand are symptoms of multiple conditions. Differences in pain and paresthesia location can help in differentiating between conditions. Cervical spine disorders have similar symptoms to TOS but can be differentiated by location of paresthesia. Rotator cuff injuries can be caused by similar injuries, but the main complaints are with the lateral deltoid and weakness in external rotation. Impingement syndrome is the impingement of the supraspinatus muscle and the biceps brachialis tendon. Suprascapular Nerve Entrapment (SNE) has pain that occurs in the posterior and superior areas of the shoulder and the potential muscle atrophy occurs in those locations rather than in the arm. Pectoralis Minor Syndrome (PMS) is compression of brachial plexus under clavicle with pain occurring over the acromion process rather than on the scalene muscles of the neck. Brachial Neuritis is an autoimmune disorder of the brachial plexus with differences in paresthesia locations than TOS. Carpal Tunnel Syndrome and Ulnar Entrapment Syndrome pain and atrophy occurs below the elbow. Peripheral Nerve Tumors can cause compression on brachial plexus and has to be distinguished by a CT or MRI scan. These other conditions and TOS can also occur with multiple different comorbidities affecting the patient at the same time.

**COMORBIDITIES**

Comorbidities are coexisting or complicating factors/conditions indicating that an individual has more than one illness at one time. The comorbidities associated with Thoracic Outlet Syndrome can include mental health conditions, myofascial pain, nerve damage, and chronic headache/migraines (Jordan, 2013)
Myofascial Pain

Myofascial pain is localized, and regional pain associated with tender and palpably tight muscles. Pain can occur with pressure placed on the muscle. One treatment for TOS is to relax many of myofascial trigger points in muscles. These muscle trigger points are found in the trapezius, levator scapulae, sternocleidomastoid, teres minor, teres major, rhomboid major and rhomboid minor muscles (Jordan, 2013). The muscle tension can be created by the body protecting the injured area to limit the pain. For TOS pain in the shoulder joint, the body may compensate of flex the muscles to protect the area, causing constant muscle tension.

Chronic Headaches/Migraines

Disabling headaches/migraines can occur after technically successful Thoracic Outlet decompression surgery (Jordan, 2013). These headaches are based around the occipital bone near the base of the skull and can be associated with myofascial pain in the trapezius. Relaxation of the muscles in the neck and base of skull can relieve or decrease the headaches/migraines. Vision issues or vision loss can occur with these migraines and can occur due to the potential blood flow decrease from the compression of the arteries in the brachial plexus.

Psychological Considerations of TOS

In many cases, physical injury or illness that causes functional damage and limits movement can cause post-traumatic stress disorder, depression, and anxiety. Some individuals who have advanced cases of TOS can have anxiety when attempting to use the affected arm due to the fear of continued pain. Pain-related anxiety has been shown to lead to avoidance behaviors, which can lead to physiological changes related to an inactive lifestyle and increased emotional distress (Hands, 2016). Continuation of symptoms of anxiety following an injury or illness reduce
the patient’s quality of life and long-term limitations (Wiseman et al., 2013). Individuals with physical disabilities have a higher risk of experiencing depression and anxiety due to the conditions (Hands, 2016). Depression has also been reported because of the inability to do physical activities. Additionally, depression can lead to decreased care of injury or illness, poorer coping mechanisms, and an increased risk of substance abuse. Depressive symptoms can increase the disability and can interfere with rehabilitation efforts, with symptoms that can last decades after the injury (Wiseman et al., 2013). Ideally, treatment for depression or anxiety should accompany efforts at rehabilitation.

Somatization (the experience of psychological distress in the form of somatic symptoms) (Lipowski, 1987) can also occur when stress and emotional upset can cause or worsen pain (Jordan, 2013). Individuals with cumulative trauma disorders (such as Thoracic Outlet Syndrome) can have an inability to cope with life stressors, which subsequently increases recovery time. Thoracic Outlet Syndrome can also correspond with other nerve pain conditions, such as complex regional pain syndrome and fibromyalgia (Jordan, 2013).

Multiple conditions can present with paresthesia, shoulder and back pain, weakness, and loss of function of the hand or arm. Similar conditions to Thoracic Outlet Syndrome, such as Pectoralis Minor Syndrome, have similar occupational causes, as well. Detailed physical examinations aid the diagnosis along with different medical imaging techniques.

In summary, Thoracic Outlet Syndrome is a condition that can affect the individual’s physical and mental health. Long-term pain can occur with improper or lack of treatment, which can drastically impact an individual’s mental health and cause functional changes in movement that can be restrictive. Due to this condition an individual’s ability to live independently can be
affected, necessitating care from others. The following sections apply the Bioarchaeology of Care model to analyze historic and prehistoric cases using a biocultural analysis of the skeletal pathology with a short background of each culture. In the two examples, TOS is diagnosed by other authors. In the two cases studies, the current author provides a novel diagnosis of TOS based on pathological descriptions published by other authors.

**Evidence of Thoracic Outlet Syndrome in a Roman Era Woman**

A Roman period (4th - 5th century CE) woman was discovered with a key identifying marker of TOS was found, a cervical rib, according to Rubini and colleagues (2019). This cervical rib was connected to the 1st thoracic rib through a fibrous bundle which could have caused compression of the brachial plexus. The individual found was a female between the ages of 30-40 years at death. The differences found in this individual’s skeletal anatomy include the sixth cervical

![Figure 1](image)

**Figure 1.**

“A) Cervical rib (CR) and first ribs with the ster-num. DE=Distal end of the CR with roughness of the concavity for the insertion of the fibrous bundle and osteophytosis of the edge; B) Reconstruction of the articulation between the cervical rib and first rib; C) 3D pattern of the fibrous bundle that articulates the two ribs. IA=insertion area.”

vertebra presenting with osteophytosis along the left edge of the vertebral body. The seventh cervical vertebra (C7) has an absence of transverse foramen and morphologically follows the structure of a first thoracic (T1) (Rubini et al., 2019). C7 also has asymmetrical bilateral costal facets, with the right demonstrating a more regular appearance. There is an absence of the tubercle of the anterior scalene muscle and the presence of a large depression on the superior surface of the first thoracic rib. The left costal facet of C7 articulates with the head of the cervical rib. The cervical rib inferior surface shows vascular and muscular prints that are normally present on the 1st thoracic rib. The distal end of the cervical rib is not fused to the 1st thoracic rib.

It is hypothesized that the insertion of the fibrous bundle would change the functional morphology and change the mechanical strain (Rubini et al., 2019) (Figure 1). The superior body of the 1st thoracic rib insertion area was probably in articulation with the cervical rib through the fibrous band. The clavicles show enthesal changes at the attachment site for the costo-clavicular ligament (Figure 1). The identification of the cervical rib, and the vascular and muscular prints aided in the diagnosis of TOS for this individual (Rubini et al., 2019).

This case study demonstrates how multiple pathologies can be taken in tandem to give a diagnosis of Thoracic Outlet Syndrome. Both of the cervical rib and the evidence of fibrous band attachment between the cervical rib and first rib demonstrate how the brachial plexus could have been compressed. In the analysis the aspect of care for TOS was not investigated in the original analysis. Unlike the novel case studies, the female individual did not have atrophy of the humerus or lower arm bones. This could be due to the age of death being between 30-40 years. The individual may have also had less severe symptoms of TOS, which did not necessitate care or changes in movement. Each case of TOS is different with varying degrees of pain and limited
mobility. The elderly female individual from Pachacamac Peru had such significant pain that attempts at treatment included trepanation and repeated shoulder dislocations.

**Bioarchaeology of Care Provided to a Physically Disabled Individual from Pachacamac, Peru**

The skeletonized remains of an elderly female (ID# H3-CF3) were discovered in Pachacamac, Peru along with the remains of two other burials. The remains of the elderly female show bilateral cervical ribs which likely caused neurogenic TOS according to Palma Málaga and Makowski (2018). Her age was approximately 50 years at death. The remains also show osteoarthritic destruction of the right shoulder joint and a healed skull trepanation (Palma Málaga & Makowski 2018).

Based on the pottery located with the burial, the individuals were dated to the Initial Ychsma period (AD 900-1100). The individuals were located in a general cemetery location. H3-CF3 was discovered in the northern face of the Old Temple in the archaeological site of Pachacamac. Pachacamac is one of the most famous ceremonial centers in the Andes and is 40 km southeast of Lima, Peru in the Lurin river valley (Palma Málaga & Makowski 2018). The close proximity of the three burials could indicate some degree of close kin relationship. Individuals were found buried in a sitting/squatting position and wrapped in textiles. Liquid clay was used to seal the burial pits (Palma Málaga & Makowski, 2018).

During the identification of the social position of H3-CF3 there were obstacles, both of a theoretical nature and as a result of a lack of material evidence. The theoretical issues stem from the absence of systematic studies on rank and status during this time period in Andean prehistory.
The lack of material evidence is based on the organic material of textiles because a method of status indication is the quality, complexity, and bundle structure of textiles.

The probable social structure of the period follows the concept of *ayllu* (Palma Málaga & Makowski, 2018), a form of social and community structure and organization. It is based on kinship and territorial communities united by a common ancestry (real or mythological). This information comes from historical sources from the 15th century from the Lurin Valley. The evidence from the Initial Ychsma in Pachacamac does not correspond with the common model of a highly stratified society (Palma Málaga & Makowski, 2018), but that the ruling class of the *ayllu* lived with their communities and operated with the cooperation of their community. Due to this integration, there were few status differences based on resource access, so Ychsma funerary contexts differentiated status by the type and/or quantity of material goods (Palma Málaga & Makowski 2018).

H3-CF3 was buried with a single plain ceramic pot with evidence of possible floral remains based on the common funerary traditions of this period. The lack of preserved burial offerings is more likely due to the taphonomic destruction of the burial’s organic elements. The pathology of the skeleton includes an incomplete posterior arch and no mid-line fusion of the anterior arch of C1 and bilateral cervical ribs at C7 (Palma Málaga & Makowski, 2018). The bilateral ribs are asymmetric with the right cervical rib. The right cervical rib was assigned Class III and the left cervical rib were assigned Class II as per Palma Málaga and Makowski (2018). Trauma of the skeleton includes one partially healed cranial trephination (surgical procedure involving the removal of parts of the skull) and severe arthritic lesions in the right shoulder joint (Palma Málaga & Makowski, 2018). The rationale for trephination can be an attempt to alleviate headaches (which neurogenic TOS can cause) or an attempt to alleviate pressure on the nerves of the right shoulder.
Severe “…osteoarthritic lesions in the right arm potentially associated with repeated dislocation of the right shoulder” (Palma Málaga & Makowski, 2018: 140) may also be evidence of medical treatment. The right shoulder joint had extensive lipping and spicule formation around the joint. The right humeral head showed equally extensive lipping and spicule formation around the entire circumference (Palma Málaga & Makowski, 2018: 145). The right humeral head was greatly deformed, becoming oblong in shape. There was minor porosity of the humeral head in the posterior spicule formation. Two-thirds of the glenoid fossa circumference had sharp ridges and some spicule formation. The ridges were on the posterior border and the inferior acromion had minor surface porosity (Palma Málaga & Makowski, 2018).

The dislocation of the right shoulder was likely an attempt at treatment for the woman’s TOS symptoms (Palma Málaga & Makowski, 2018). Neurogenic TOS symptoms can include pain in upper and lower arm, pain in the hand, numbness and tingling of arm and hand, and loss of function of the hand specifically the pinky finger (Bassett & Gupta, 2021). The injuries caused by the repeated dislocations may demonstrate the need for assistance for individual H3-CF3. She would have also needed assistance while healing after the surgical trephination. The direct assistance could have likely been help with her daily activities, such as eating, drinking, and bathing. Indirect assistance could have been help with food and necessary household supplies, because while healing, she could not have collected or prepared her own food. The osteoarthritis in her right shoulder would have affected her ability to perform hard labor, reach overhead, or carry heavy loads. Her range of motion would have been severely affected (Palma Málaga & Makowski, 2018).

The diagnosis of TOS was based on the evidence of the treatment in the skeletal remains. The cervical ribs alone would not have been enough for a diagnosis for TOS. The combination of
cervical ribs with damage to the humeral head and trephination, provide more convincing evidence for TOS. More harm was done while dislocating the shoulder to alleviate TOS symptoms than to have lived with the TOS alone (Palma Málaga & Makowski, 2018). Yet, due to only having skeletal remains, diagnostic evidence of minor muscle atrophy, Paget-Schroetter Disease, or Gilliatt-Sumner hand, are not available. These soft tissue effects could have represented further daily struggle requiring daily care. The lack of any other joint damage to the same extent as the right shoulder, though normal age-related damage was identified, eliminated degenerative joint disease as the cause. A single severe traumatic dislocation event was also eliminated by the lack of fissures or fractures to the humerus or scapula (Palma Málaga & Makowski, 2018).

The severity of the trauma experienced by H3-CF3 was limited to her right shoulder, no degenerative changes occurred to the left shoulder or spine. The degenerative changes to those locations would have occurred if HS-CF3 continued the normal actions required for daily living, such as lifting heavy items and reaching overhead (Palma Málaga & Makowski, 2018). If these actions occurred, more strain would have been placed on the left side of her upper body compensating for the lack of ability of her right side. The lack of these degenerative changes demonstrated that H3-CF3 had assistance when performing the tasks that she could not do. The level of care she received helped improve her quality of life.

Diagnosing TOS for individual H3-CF3 by Palma Málaga and Makowski (2018) involved multiple features on the skeleton. A single skeletal anomaly, such as bilateral cervical ribs or clavicle fracture, would not be enough to diagnose TOS. The combination of factors (e.g., cervical ribs, osteoarthritis of the right shoulder, and trephination) provides enough evidence to permit a diagnosis for TOS. TOS can be identified through skeletal remains, but there is no one single
indicator; multiple traits must be present simultaneously as demonstrated in this published analysis by Palma Málaga and Makowski (2018).

In the analysis of the Roman era woman and H3-CF3 in Peru, cervical ribs along with other skeletal anomalies were taken in tandem to give a diagnosis of Thoracic Outlet Syndrome. The articulation of the cervical rib and the first rib through a fibrous bundle was hypothesized to be the cause of Neurogenic Thoracic Outlet Syndrome in the archaeological excavation in Graffignano, Viterbo in central Italy. In Pachacamac, Peru H3-CF3 had several skeletal markers of TOS. First is the presence of cervical rib and the atrophy of the humerus. The osteoarthritis of the humeral head and the glenoid fossa can indicate a method of care for the pain caused by TOS along with the skull trephination. These skeletal indicators can be seen in other sets of human remains and can be used for a novel diagnosis of Thoracic Outlet Syndrome such as the human remains excavated from Bradford House III and the human remains recovered from Santiago do Cacém in Portugal.

EXCAVATION OF HUMAN REMAINS FROM BRADFORD HOUSE III

From the 1978 archaeological excavation of Bradford House III in Jefferson County, Colorado an individual was excavated who had skeletal indicators of Thoracic Outlet Syndrome, although TOS was not included in the differential diagnosis conducted by Finnegan (1978). The site at Bradford House III in Jefferson County, Colorado is a Late Woodland Era rock shelter (Finnegan, 1978). Through the description of the skeletal remains and photographs of the report, the diagnosis of Thoracic Outlet Syndrome is proposed here in the current research due to the presence of cervical ribs, an atrophied left humerus, and the unusual wear on the dentition.
Woodland Era in North America

The Woodland Era in North America is the Native American time period between 500 BC and AD 1100, which is pre-contact and before the reintroduction of the horse. During this time period, regional patterns of cultural activity began to develop. This period is subdivided into three smaller ones: the Early, Middle, and Late Woodland periods (Fort Smith, 2015). During the early period the emergence of sedentary village life began along with the cultivation of crops. The Late Woodland Era is characterized by the lack of non-local artifacts and materials, yet it was also a time of great cultural changes and technological advancements, such as the invention of the bow and arrow (Fort Smith, 2015). During the Late period, the population size greatly increased, creating larger villages and communities. In this period, the beasts of burden in the Great Plains were dogs, consequently humans had to do more heavy lifting. Humans followed bison herds on foot, slaughtered the animals at the site, and carried the meat back.

There were gendered responsibilities in most Late Woodland era communities. The general gendered responsibilities of men were hunting bison, deer, elk, fish, and fowl, and the carrying and movement of housing materials as the communities followed the bison herds. Female gendered responsibilities were preparation and creation of material goods (clothes and basketry) and planting and plowing of crops (Fort Smith, 2015).

Wear Patterns on Teeth

Certain wear patterns on teeth are due to use of the mouth as a tool or third hand. Studies have been able to help identify the differences in gendered wear patterns between females and males. In general females demonstrate greater wear on the teeth than males (Estalrrich & Rosas, 2015; Reinhard et al., 1994). The wear common on female teeth is on the anterior, labial
mandibular teeth. Males tend to have more wear and chipping on the maxillary teeth, especially on the upper incisors and canines (Estalrrich & Rosas, 2015; Reinhard et al., 1994). Labial wear (i.e., near the lips) relates to diet as well as cultural factors. The texture and composition of the food can cause different wear on teeth such as the difference between stringy meat and soft meat (Estalrrich & Rosas, 2015). Cultural striation, also known as “stuff and cut” (Estalrrich & Rosas 2015), occurs when material is held in one hand and between anterior teeth while the remaining hand is used for cutting. Female cultural activities, which involved third hand use, are preparation of skins, spinning, and manufacture of leather products.

Bioarchaeology of Care - Case Study Analysis # 1

Following the steps detailed in the ‘Bioarchaeology of Care’, a methodology proposed by Lorna Tilley (2015), determination of the extent of this individual’s disability and the perception of disability of the society can be explored. During the first stage of the Bioarchaeology of Care, model disability pathology is detailed, and a probable diagnosis is given (Tilley, 2015). Following this model, the human remains analyzed are of an approximately 50-year-old, Native American male (Finnegan, 1978). This individual has unusual wear on the mandibular (lower jaw) teeth. The wear is high on the buccal surface (cheek side) of the teeth and moves inferiorly towards the lingual surface where there is a significant amount of wear (Finnegan, 1978; Smith, 1984). The individual displays shortening of the left humerus due to bone atrophy, and cervical ribs. This individual has bilateral cervical ribs, with the right cervical rib measuring 21.4 mm (~.85 inches) and the left cervical rib is 17.8 mm (~.7 inches). The left humerus also exhibits a decrease in the cortical bone compared to the right humerus. There are age related osteoarthritis and osteophytic lipping on some of the cervical vertebrae (Finnegan, 1978).
The left humerus atrophy indicates that when the individual abducted his left arm (raising it up and to the side), pain possibly occurred. The individual kept his left elbow against his rib cage and the continued disuse of the arm caused bone atrophy. The cervical ribs can compress the brachial plexus of the arm causing shoulder pain, numbness, and loss of function with abduction. Thus, the cervical ribs and the atrophy of the left humerus support a differential diagnosis including Thoracic Outlet Syndrome.

Stage two of the Bioarchaeology of Care is the description of the impacts on daily life (Tilley, 2015). These impacts include both the clinical and functional impact on daily life. These impacts are assessed using the modern day clinical and functional impacts detailed in modern populations. The clinical presentation of Thoracic Outlet Syndrome includes, but is not limited to, pain in the neck, face, upper chest and back, shoulder, upper and lower arm, and occipital migraines (Walker, 2022). Compression of the brachial plexus can also lead to paresthesia of the limb, and decreased coordination and fine motor function of the affected hand. In many cases, the pain increases with abduction of the arm and movement of the arm overhead. For comparison, modern activities that are difficult and can increase pain include: carrying heavy loads, brushing teeth, writing, tying shoes, holding bottles/cups, zipping, or buckling, and opening containers.

The symptoms experienced by modern patients with Thoracic Outlet Syndrome can be assumed to be similar to those who had the condition in the past. The individual held his left arm immobile by keeping the arm pressed against the ribcage. This limited the lateral movement of the arm and limited the amount of weight that could be carried. This immobility is demonstrated through the atrophy of the left humerus. For many patients with TOS lateral movement of the arm causes pain or paresthesia. The use of only one arm would have limited the personal freedom of
the individual causing difficulties with personal hygiene, obtaining food or water, and carrying heavy loads.

The radiocarbon date of this individual places his time of death around 490 B.C to 589 B.C. which falls into the Late Woodland Period (Finnegan, 1978). The individual was excavated in Colorado, which is included in the geographic identification of the Great Plains (Pauls, 2020). The social structure of the Native American groups who occupied the area during that time period present with evidence of gendered activities for men and women. Some of the economic activities that men were expected to perform included hunting, both small and large game. Horses had yet to be reintroduced to North America, so hunting consisted of following large bison herds, killing bison, slaughtering the bison at site, and carrying the meat back (Pauls, 2020). The individual would have had issues with use of the bow and arrow, slaughtering animals, and carrying heavy loads over long distances. Many activities related to hunting require consistent use of both arms and hands. So this individual’s economic abilities would have been limited based on his diagnosis and, likely, his economic activities shifted.

Stage 3 of the Bioarchaeology of Care elaborates on the question of what the care could have been (Tilley, 2015). The care provided could have taken the form of direct or indirect care. Direct care is aid given after an injury or treatment such as after a medical procedure. Indirect care is low level consistent care such as with acquiring food or water. Both indirect and direct care involve social and economic support from the caregivers. The care given is an intentional act. The analysis of the care provided is based on basic medical practices, such as binding and cleaning of wounds.
To elaborate on evidence of Stage 2 for the individual, aid was given more in long term care or indirect care (Palma Málaga & Makowski, 2018). This individual would have required longer term indirect economic and social care. The individual still had the ability to care for himself to a certain extent. The needed care would have been with, but is not limited to, food/water acquisition, aid with personal hygiene, and aid with cooking. Yet as the individual aged, the condition would have decreased his ability to make substantive material contribution to the community (Tilley et al., 2011). The probable care given extends from the societal structure of prehistoric Native American Great Plains societies, so the structure was created via familial bonds, and the groups were generally smaller (Pauls, 2020). During the late Woodland Era the population was expanding and there were more sedentary villages. This individual was most likely aided by his family, which could have positively impacted the quality of his care and assistance. The number of individuals who would have helped the individual likely varied. He would not have needed a fulltime caretaker and was still likely able to do many day-to-day activities, requiring help with specific tasks. An assumption can be made that the people who were physically close to the man while he was performing tasks aided him when required. This assumption is directly linked to modern individuals with Thoracic Outlet Syndrome and the care that current patients receive (Walker, 2020).

Stage four of the Bioarchaeology of Care is the consideration of the implications for social relations. This stage focuses on the choices made through the care that led to the conditions of the remains when they were uncovered (Tilley, 2015). The lack of damage to the right shoulder joint, right hip, knee, and ankle demonstrate that the individual was not overusing the non-injured right side. For the remains to present as they are, the individual must have received aid in day-to-day activities in order to not overuse the non-affected side.
The individual would have had issues with traditional male economic subsistence activities and likely had to switch to different economic endeavors. This switch is demonstrated through the differences of wear on the mandibular teeth. The wear on the labial surface mirrors tooth wear common on many females in hunter-gatherer societies (Estalrrich & Rosas 2015; Reinhard et al., 1994). This wear signifies the increased use of teeth as tools. Some of the tasks including preparation of leather/hide for use for clothes can cause similar wear. The wear pattern of the left lower arm bones of the remains are very similar with those of the right lower arm bones. The individual used his lower arm to a similar extent as the right. The individual was able to do economic activities consisting of some food preparation and tool creation once his condition progressed. According to Michael Finnegan in his 1978 report on the human remains uncovered at Bradford House III, the unusual wear of the lingual side of the teeth is consistent with the use of teeth as tools. It can be assumed that once the individual’s pain became too great to participate in specific gendered activities, there was a switch to other economic activities that did not increase the pain.

Palma Málága and Makowski’s analysis of the evidence of care in Pachacamac, Peru (2018) noted on the lack of “equivalent degenerative disease markers” (147) and the absence of degenerative changes in the individual’s spine can be evidence of “indirect receipt of care” (147). The indirect receipt of care indicates the use of accommodation for the individual, where the expectations and daily requirements of an individual are adjusted. This method of care creates a new method in which an individual can continue to participate in their community.

The right humeral head did not have unusual osteoarthritis, which would have been highly probable in this situation if care was not provided. The individual would have had to overuse his right arm because of the limited function of the left. The lack of unusual osteoarthritis of the right
humeral head shows that he received aid in performing daily activities or received accommodation in the expected daily activities, similar to the analysis from Pachacamac, Peru. This individual lived with his condition for at least 5 years due to the extent of the atrophy. Thoracic Outlet Syndrome is a degenerative condition. Over time his physical condition would have worsened and his ability to function independently decreased. For him to live to such an old age at death, other individuals must have helped him with daily activities.

EXCAVATION OF HUMAN REMAINS PORTUGUESE MEDIEVAL CEMETERY; SANTIAGO DO CACÉM

In the cemetery Santiago do Cacém in Portugal, 14 individuals were uncovered from the ancient necropolis. The site was dated using 15th century coins found with the remains. The individuals were uncovered from the sepultures, including adults, juveniles, preterm infants, and elderly individuals. One of the sets of human remains uncovered was of an older female around 50 years of age at death. This individual exhibits pathology similar to the individual from Bradford House III, including cervical ribs and an atrophied humerus. The woman also presents with different healed traumas and age-related osteoarthritis.

Medieval European Social and Kinship Structure

Medieval Europe lasted between 500 and 1500 C.E. Kinship in this time period was characterized within canon and secular law. Secular law framed kinship by validating marriage and outlining family groups (Laumonier, 2021). Spiritual kinship was the relationship between the godchild and the godparents and was said to be the purest form by the church. This method of kinship was a convenient way to secure and reinforce other types of kinship. Kinship and family structure can influence the methods of care which an individual can receive. With a larger support
network, framed by both secular and spiritual kinship, differences in care could occur. For example, more members of the family could care for an individual at different times of day, so that individual would have care on a more regular basis.

This time period also developed strong relations with extended family members, as demonstrated through surviving documents, such as wills (Laumonier, 2021). The household consisted of many people. The core was the nuclear family: parents and children. The *familia* were all the members of the household, anyone who lived in the home. *Parentes* or *consanguinei* were the people related by blood or by marriage (Laumonier, 2021). In urban settings it was common for elderly couples to live with their married children, creating multigenerational households.

In many cases, the elderly turned to family for support, yet when that was not possible society could have helped the elderly individual. Some of the social structures available for the elderly in the Middle Ages, including alms houses, monasteries or nunnery care, and hospital admittance (Laumonier, 2022). Old age is not requisite for receiving church alms, but the elderly could receive alms due to physical weakness and inability to work. There were specific almshouses and hospitals for widows. At some hospitals, an individual could work for as long as they could until they were physically unable to continue, and then the hospital would care for the elderly (Laumonier, 2022). The work done for the hospital would cover the maintenance of the individual. The aid given could be long term and would continue after death because many institutions funded funeral costs as well. There are also instances in which the rich covered living expenses for the elderly, by setting up homes or personally seeing to care of an elderly individual (Laumonier, 2022). Additionally, there were widow societies created for both emotional and financial support of widows.
Bioarchaeology of Care - Case Study Analysis #2

In this case study, the human remains presented with different skeletal indicators of Thoracic Outlet Syndrome. These include a cervical rib and an atrophied humerus. Description of the skeletal remains is critical in the examination of care because this individual has skeletal markers which could have contributed to different types of impacts to her movement including unhealed fracture, laminar spurs, and porotic hyperostosis. The detailed description of the pathology and trauma is the first stage of the Bioarchaeology of Care.

The remains are of this older female are approximately 50 years of age at death. The trauma identified on these remains are consistent with an unhealed complete fracture of a right rib and a healed fracture of a left rib (Fernandes & Granja, 2003). In terms of other pathologies identified, the left humerus is 1cm shorter than the right. There was additional asymmetry between the left and right clavicle. The left being smaller than the right. there is an absence of transverse foramina

Left (Fig. 2): Asymmetry between the right and left humerii (Fernandes, T., & Granja, R. (2003). Reprinted with permission.

Right (Fig.3): Porosity of the cranial vault (Fernandes, T., & Granja, R. (2003). Reprinted with permission.

on the seventh cervical vertebrae. There are bilateral cervical ribs, with the left cervical rib smaller than the right. Almost all the thoracic vertebrae have laminar spurs and there is agenesis of the left inferior articular process of thoracic vertebrae 12 and on the superior facet of first lumbar vertebrae. (Fernandes & Granja, 2003: 242). The individual also presents with incomplete spina bifida and there is sacrum degeneration on the right anterior side of the sacrum with a severe osteophyte. There is evidence of *cribra orbitalia* in the superior eye sockets. *Porotic hyperostosis* is in the palatine vault, squamous portion of temporal bone, and basilar portion of the occipital bone. Taken in tandem, pathology and trauma on these remains permits a differential diagnosis of Thoracic Outlet Syndrome. The cervical ribs and the atrophied left humerus are potential skeletal indicators of TOS. The same indicators were identified in the remains from Bradford House III described above. There is also evidence of *cribra orbitalia* and the *porotic hyperostosis*, which likely indicates chronic anemia (Walker et al., 2009).

In the analysis of the second stage of the Bioarchaeology of Care, the daily impacts of the serious pathology demonstrated by this older individual from the cemetery at Santiago do Cacém are elaborated on. In many cases individuals with TOS have decreased dexterity in their hands and limitations to the rotation of the shoulder due to pain. The asymmetry between the left and right humeri and the asymmetry of the clavicle can indicate a decreased use of the left arm likely due to the pain caused by TOS. It can be expected that in order to compensate, the individual relied on the right arm and there would be degenerative changes in the right shoulder, hip, knee, and ankle. Age related degenerative changes are found in the joints, but not to the expected extent (Fernandes & Granja, 2003).
The cause of the asymmetry of the humerii and clavicle could be due to functional changes as the disease progressed. The individual would have had issues with overhead movement, lateral movement of her arms and carrying heavier loads. The lack of degenerative changes on the non-affected side shows a method of accommodation occurred, similar to the case study from Bradford House III and from Pachacamac, Peru. The individual would have received aid from others to carry out daily tasks that required overhead movement.

The thoracic vertebral laminar spurs would have also restricted her movement over time. The spurs would have caused pain with movement and become progressively worse, causing (Zukowski et al., 2012) stiffness, radiating pain, weakness, tingling in the limbs. The laminar spurs also suggest that the adjacent vertebrae were grinding together, creating friction, and leading to inflammation in the vertebral canal and increasing the compression on the spinal cord. The compression of the nerve root would have caused numbness and pain of the limbs (Saadat, 2019).

The *cribra orbitalia* and the *porotic hyperostosis* in the skull indicates chronic anemia (Walker et al., 2009). When a person is anemic (has a decreased red blood cell count), they can experience a lack of oxygen diffusion leading to fatigue. Anemia is often a presentation of an underlying disease/condition and there can be multiple causes of anemia including erythropoiesis, sickle cell anemia, and decreased red blood cell production, among others (Badireddy et al., 2022). The pit like appearance of *cribra orbitalia* and *porotic hyperostosis* is due to the increased red blood cell production in the flat bones of the skull.

Due to the different pathologies that the female from Santiago do Cacém including Thoracic Outlet Syndrome, chronic anemia, and thoracic vertebral laminar spurs, a probable outline of care can be created. The third stage of the Bioarchaeology of Care involves social care and economic
care (Tilley, 2015). The lack of degenerative condition on the non-affected side demonstrates accommodation that the woman received. The female from the Santiago do Cacém cemetery would have needed daily assistance especially over time. Pain from Thoracic Outlet Syndrome restricted the use of her left arm as seen through the bone atrophy to the left humerus. Thoracic Outlet Syndrome restricts motion progressively over time, so as the woman grew older, her need for care would have increased. The evidence of chronic anemia, as seen in the skull, would have also resulted in fatigue and breathlessness. Doing work, both social and economic, would have been increasingly taxing. Thoracic vertebral laminar spurs put pressure on nearby tissues such as the spinal cord causing a variety of symptoms including stiffness in the low back area, inability to maintain normal posture, muscle spasms during activity or at rest, continual days with chronic pain, and a potential for reduced motor function (AANS 2021).

Even with the conditions with which this female was living, the skeleton demonstrates continued daily stress on the bones (Walker et al., 2009). Thus, this individual must have continued to move and do day-to-day activities. It is probable that the individual needed aid as she aged and the number of people who helped her might have increased over time. As seen in the Bradford House III case study, accommodation was given depending on the circumstances. She would have potentially needed help with carrying heavy loads and walking distances. She may have needed help with hygiene, as well. It can be presumed that she would have needed general supportive care when symptoms became too painful to continue daily activities.

The indication of accommodation based on skeletal evidence such as the lack of degenerative changes on the non-affected side of the female from Santiago do Cacém gives insights into social relations. The implication for social relations is the fourth stage of the Bioarchaeology of Care model (Tilley, 2015). The female from Santiago do Cacém lacked
evidence of overuse damage (unrelated to normal aging processes) to her right shoulder joint, right hip, and right knee. Injuries to the opposite side would be common if the individual was overcompensating in order to perform day-to-day activities. The individual also presented with other conditions that would have limited her movement over time. For the individual to live to around 50 years of age with her conditions, care and community aid would have been necessary.

The aid given could have come in multiple forms, which can be hypothesized from the social structure documented for medieval Portugal. The most probable assistance would be through family care. There were many multigenerational households involving parents, children, spouses, and grandchildren. The individual in this case would have received help, but would have also contributed to her family household, as well. The individual might have received different types of social aid available, such as alms, care at hospitals, monasteries, or nunneries.

One possible explanation for providing support to an older female is proposed in the Grandmother Hypothesis (Blell, 2017), which explores the evolutionary rationale for menopause being unique to human senescence compared to other primate species and other mammals. It is argued that the long senescence of women evolved because women were able to increase their fitness by investing energy and time into their adult children, specifically supporting daughters and grandchildren (Blell, 2017). By stopping reproduction sooner, women can live longer lives without the complications of childbirth and decreasing the risk of childbirth for the woman and her daughter. This time then spent caring for adult offspring and grandchildren increase’s the woman’s fitness because she is increasing her offspring’s ability to survive. This hypothesis also supports the older woman’s adult offspring to have more children in quicker succession. The individual in this case study would have had the opportunity to aid any adult offspring and any grandchildren, with the added benefit of mutual assistance for her own medical issues.
SECTION 11: POSSIBILITIES FOR CONTINUED RESEARCH

This current research has recognized two other potential cases of TOS for continued research, but the documentation available for these cases does not yet permit a diagnosis, requiring further analysis. During an excavation at Gran Quivira (Reed, 1981), four individuals were uncovered, from Mound 7, each demonstrated different possible skeletal indications of Thoracic Outlet Syndrome. To fully investigate the possibility of TOS and analyze through the Bioarchaeology of Care stages, there needs to be additional analysis of the remains. Better photographic documentation of the remains is required, specifically of the upper limbs. Of the individuals recovered, female #418 would likely yield the most probable diagnosis of TOS due to the facets on C7 corresponding to cervical ribs, a partially destroyed humeral head, and premature glenoid lipping (Reed, 1981). To make the diagnosis for these remains, examination of the humeral head needs to be conducted and comparison of this case to the humeral head found in the excavation in Pachacamac, Peru will give more evidence to the diagnosis. It is possible that the damage described to the humeral head and glenoid fossa was due to intentional dislocation of the shoulder to relive TOS symptoms as was the case in the individual recovered in the excavation from Pachacamac, Peru (Palma Málaga & Makowski, 2018).

Additionally, a 1993 excavation at the early Paleolithic Ohalo II site in northern Israel uncovered an individual with significant asymmetry in the upper torso. The male individual from this site died in his mid-30s (Hershkovitz 1993). The right humerus was thicker and longer than the left, with damage to the glenohumeral, acromioclavicular, and claviculostral joints. This damage could have been caused by overuse, which is common to see in individuals who have TOS and thus favor one side. The injuries described also occurred after the closure of epiphyseal plates, thus after puberty (Hershkovitz 1993). The differences in size could possibly be attributed to disuse...
due to chronic pain. Unfortunately, the pictures published on this case are not satisfactory to complete an analysis retrospectively. Descriptions also lack information that is also scanty in the images. Unlike other cases described herein, there is no evidence of cervical ribs or issues with the first ribs, so the clearer skeletal indicators of TOS are not present. Yet there are different skeletal indicators that could be present but were not described because the significance possibly overlooked at the time of initial analysis, such as attachment points for fibrous bands that could have been present or evidence of blood vessels on the bone. Even though TOS can have soft tissue causes cannot be fully excluded as a differential diagnosis.

**SECTION 12: CONCLUSION**

Thoracic Outlet Syndrome is a degenerative condition which, if not treated, can lead to serious complications with the arms and shoulder. These complications include muscle and bone atrophy, pain with movement of the affected arm, and decreased functionality of the hand. An individual who is suffering from this condition would have decreased economic abilities and possibly rely on the care of others. With the identification of multiple skeletal indicators of TOS and the use of the Bioarchaeology of Care model, a better analysis of accommodations created by a community for physical disabilities can be interpreted.

The Bioarchaeology of Care model includes four stages to determine the possible care provided to ancient human remains. The first stage is to identify individuals who lived with serious pathology for a longer period of time. The second stage is to identify the impacts on daily life. This is used to establish probability of the individuals needed care for an impairment. The third stage is the probable model of care based on what was possible and probable during the time period and is analyzed by examining basic medical practices that could have been used such as wound cleaning, among others.
Other aspects that need to be considered when applying the Bioarchaeology of Care Model (Tilley, 2015) are the limited responses of bone. Bone can be added or taken away as a response to stress or illness. Care has to be inferred from skeletal remains; any receipts of care that are recorded on soft tissue are not preserved. Poor preservation of remains can impact the ability to distinguish disease or injury on skeletal remains and taphonomy can further distort the appearance. The osteological paradox must also be considered, which sheds light on the fact that remains found with evidence of living with chronic pathology represent hardier and thus “healthier” individuals than those who would have died immediately (Wood et al., 1992). Finally, there is also the complication of morphological overlap in expression of skeletal pathology.

The current research reanalyzed the case study from Bradford House III for TOS, a male individual approximately 50 years of age, was seen to have bone atrophy of the left humerus, bilateral cervical ribs, and unusual tooth wear. Taken together, these skeletal indicators point to a diagnosis of TOS. The pain from the condition stopped the man from using the full rotation of his arm. Evidenced by the amount of bone atrophy present, this individual had lived with Thoracic Outlet Syndrome for at least five years. During this time, the pain from this condition would have worsened, reducing the work the individual could do for himself. The lack of osteoarthritis in the right humeral head indicates that the affected individual must have received help during his day-to-day tasks. If he did not, then it is probable that the right humeral head, right femoral head, and right tibia would have exhibited overuse injuries such as osteoarthritis, which is not present. The wear on his teeth also shows that he changed his economic activities once he could not perform the normal gendered activities of his community.

In the second case study analysis from the cemetery Santiago do Cacém, there is evidence of care for the older female individual, as well. The individual uncovered had skeletal indicators
of Thoracic Outlet Syndrome, evidence of porotic hyperostosis, and thoracic laminar spurs (Walker et al., 2009). Each of these conditions would require care as the conditions worsened over time. The time period in which the individual was found coincides with the Renaissance in Portugal and during this time there were medical, cultural, and religious changes that could have helped with her care and further increased her ability to help her community, as well. In also considering the grandmother hypothesis, which proposes that when grandmothers are able to help with childcare activities, their daughters are able to have more children in a quicker succession. This not only increases the evolutionary fitness of the mother, but also the grandmother who shares genes with the grandchildren (Blell, 2017). The grandmother also can serve as a cultural encyclopedia, whose information helps her community, as well. This case study analysis presents a community with high care and respect for individuals who are physically disabled, especially within their own families.

The interactions with the society due to an identified impairment increases the knowledge of the society. Identifying methods of patient care employed in the past can increase the understanding of prehistoric and historic medicine. There are possibilities for further research into identification of Thoracic Outlet Syndrome and analysis through the Bioarchaeology of Care model at Gran Quivira, female #418, with demonstrated pathology consistent with TOS and glenoid lipping was described that was similar to the case in Pachacamac, Peru. In order for a diagnosis to be made, however, an analysis of care requires further documentation and/or access to those remains

The following quote touches on an important concern in bioarchaeology: “...How many times have we [bioarcheologists] seen bone fragments that may well have been cervical ribs, but we put it down as an anomaly that we knew nothing about or dismissed the fragment as simply a
part of a normal rib” (Finnegan 1978, 229). What have we missed because we were not aware of a pathology to know what to look for? Increasing the knowledge of pathological conditions that can impact the bone can increase the knowledge an individual’s personal history. Understanding the possible impairments caused by a condition through the lens of the Bioarchaeology of Care can give a better context of understanding how impairments and disabilities were viewed in a past culture and giving the opportunity to evaluate how disabilities and care are seen today.
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