Prevalence of Cervical Spondylolisthesis in the Sagittal Plane Using Radiographic Imaging in a Pediatric Population: A Cross Sectional Analysis of Vertebral Subluxation

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ABSTRACT

Introduction: Cervical Spondylolisthesis (CS) in children is under-studied. This cross-sectional study reports the CS prevalence in children. Materials & Methods: Subjects were selected from a private practice. Inclusion criteria: 0-17 years of age; documented demographics and health complaints; neutral lateral cervical (NLC) radiographs; and CS. Exclusion criteria: pseudosubluxation. Results: 342 NLC radiographs were analyzed. 73 (21.3%) had CS greater than 2.0 mm. 42 (57.5%) had no musculoskeletal complaints. 8 (2.3%) had the presence of a CS greater than 3.5 mm. 5 (62.5%) had no musculoskeletal complaints. Discussion: Pediatric populations endure various traumas. Pediatric cervical spine biomechanics has an increased risk of upper cervical spine injury. Regular spinal radiographic exams may help identify serious spinal conditions in their pre-symptomatic state. Conclusion: CS in pediatric populations is under-studied. CS is present in children and adolescents with and without symptoms.

ORIGINAL RESEARCH

INTRODUCTION

Spondylolisthesis is a vertebral subluxation that refers to a significant transverse structural displacement of one vertebral body on the vertebra below. Spondylolisthesis is detected, analyzed, measured, and monitored by radiograph. It is considered uncommon in the cervical spine when compared to the lumbar spine and is now being recognized as an under-studied condition [1].

Spondylolisthesis is categorized into two main types: congenital and acquired spondylolisthesis. Congenital spondylolisthesis is caused by a failure in development in the vertebrae. Acquired spondylolisthesis refers to a defect in the pars interarticularis caused by degeneration, trauma, pathology, and (or) surgical complications [2].

“Cervical spondylolisthesis prevalence has been reported as low as 5.2% to 12%, whereas that of lumbar spondylolisthesis is 15.8% to 19.7%. Thus, cervical spondylolisthesis has received less attention than lumbar spondylolisthesis" [3]. The male-to-female ratio is 1.5 to 1 in grade 1 and 2.2 to 1 in grade 2 cervical spondylolisthesis (CS) and there is an increased prevalence after 60 years with a 33.3% prevalence in 20 to 59 years and 66.7% in 60 to 99 years of age [4]. CS in symptomatic patients was found to be 16.4% prevalence of grade 1 and 3.4% of grade 2 (Table 1). CS was graded and defined by the following criteria: grade 1 is defined as 2-3.5 mm of displacement and grade 2 is defined as displacement greater than 3.5 mm [1,5]. "Patients with severe spondylolisthesis had unequivocal horizontal displacement of 3.5 mm or more, a criterion established by White et al. as suggestive of instability in the cervical spine, whereas those with moderate spondylolisthesis had horizontal displacement of 2.0–3.4 mm, and those with mild spondylolisthesis had a horizontal displacement of less than 2.0 mm" [6]. White et al. further conclude that "the spine is unstable or on the brink of instability [when] more than 3.5 mm horizontal displacement of one vertebra in relation to an adjacent vertebra, anteriorly or posteriorly, measured on a resting lateral roentgenograms of the spine" [7].

Spondylolisthesis may present with or without pain in children and adolescents. Like scoliosis and other unstable, degenerative structural, spinal conditions, progression of spondylolisthesis occurs during the adolescent growth spurt [8]. "Cervical spondylolisthesis results in not only cervical pain but also radiculopathy or myelopathy as it progresses and thus should never be neglected. In the aging society, the number of patients with degenerative changes of the cervical spine is expected to increase" [9]. CS creates a scissoring effect with the transverse structural displacement of one vertebra on another resulting in a narrowing of the spinal canal at the intervertebral location [10]. CS is an indicator of cervical vertebral instability and associated with disc degeneration and facet joint arthropathy.

Treatment choices for a child with spondylolisthesis include observation, limitation of activities, exercises, bracing, casting, and surgery (repair of a pars defect, fusion, decompression, and reduction of the slippage) [11]. Corrective chiropractic care involving chiropractic adjustments, exercises, and traction have been shown to reduce cervical spondylolisthesis [10]. Regardless, restoration of global sagittal balance of the spine and pelvic alignment is paramount in the treatment of any spinal deformity [12].

Spondylolisthesis is an understudied condition in pediatric populations. There are studies that report on prevalence of lumbar spondylolisthesis in pediatric populations. However, these studies focus on the lumbosacral spine [11,13]. There does not appear to be any epidemiology study reporting on CS in pediatric populations outside of isolated cases [14]. The objective of this cross-sectional study is to report on the prevalence of CS in the sagittal plane in a pediatric population.

MATERIALS & METHODS

Review of Literature

A review of literature was performed researching cervical spondylolisthesis in children, adolescents, and pediatric populations. Search terms Cervical Spondylolisthesis AND Children OR Adolescents OR Pediatrics OR Pediatric Populations in Google Scholar, PubMed, and ScienceDirect research databases. The results showed many studies and reports. However, there did not seem to be any epidemiology studies reporting on CS in pediatric populations. Epidemiology studies reporting on spondylolisthesis and pediatric populations focus on the lumbosacral spine. There were case studies that reported on isolated incidents of CS in pediatrics. However, this cross-sectional study appears to be the first to report on CS in a larger pediatric population.

Study Design

Subjects in this cross-sectional study were selected from a radiographic records review of a private practice in Cumming, GA, USA. Subjects that met inclusion criteria were selected from a total of 342 pediatric patients (184 females and 158 males). This study is Institutional Review Board approved and all procedures performed in this study involving the 342 human participants were in accordance with the ethical standards of the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

Inclusion/Exclusion Criteria

Inclusion criteria was that subjects needed to: be 17 years of age or younger; have their demographics (age, sex, height, weight, and race) and health complaints documented; have neutral lateral radiographs taken at the time of their documented demographics and health complaints; and have intervertebral, segmental translation in the sagittal plane (Tz) within the cervical spine (C2-C7). Exclusion criteria was any segmental translation in the sagittal plane that qualified as a pseudosubluxation. The CS needed to qualify as a true vertebral subluxation. Suspected CS at C2-C3 were screened using the posterior cervical line (Swischuk line) [15]. "The posterior cervical line [Swischuk line] is a line drawn through the posterior arches of C1 and C3 on a lateral cervical spine radiograph. In physiological displacement of C2 on C3 [C2-C3 pseudosubluxation] the anterior cortex of the posterior arch of C2 is allowed to pass through, touch or lie up to 1 mm behind the posterior cervical line" [15].

Measurements

This study involves the analysis of upright, weight bearing, neutral lateral cervical (NLC) radiographs of 342 pediatric patients. Radiographs were analyzed using PostureRay® X-Ray Electronic Medical Records Software (PostureCo, Inc., Trinity, FL, USA) according to the Harrison Posterior Tangent method for spine views in the sagittal place [16,17]. Spondylolisthesis was measured in millimeters as the perpendicular translational distance between the posterior tangent line of the inferior vertebra to the posterior inferior aspect of the adjacent superior vertebra (Figure 1) and was defined as greater than or equal to 2.0 mm of translational distance [9]. Normal cervical sagittal spinal alignment maintains a circular lordotic curvature and a perpendicular translational distance of 0.0 mm between the posterior tangential line of the inferior vertebra to the posterior inferior aspect of the adjacent superior vertebra (Figure 2) [18].

Analysis

Subject demographic and radiographic analysis data were exported to a Microsoft Excel (Microsoft Corporation, Redmond, WA, USA) spreadsheet and analyzed using Microsoft Power BI (Microsoft Corporation, Redmond, WA, USA). Microsoft Power BI is an analytics software that provides data warehouse capabilities including data preparation, data discovery, and interactive visualizations that can generate reports.

Microsoft Power BI allowed for the discovery and reporting of the following aspects of this study:

- |CS| > 2.0 mm;
- |CS| > 3.5 mm;
- CS < -2.0 mm;
- CS < -3.5 mm;
- CS > 2.0 mm;
- CS > 3.5 mm;
- > 2 |CS| > 2.0 mm;
- > 2 |CS| > 3.5 mm;
- |CS| > 2.0 mm with and without health complaint(s);
- |CS| > 3.5 mm with and without health complaints(s).

RESULTS

A total of 342 patients' NLC radiographs were analyzed. There were 184 females and 158 males from 4 through 17 years of age with a mean age of 12.3 $\pm$ 6.8 years (95% CI), a mean height of 157.4 $\pm$ 35.2 cm (95% CI) and weight of 62.2 $\pm$ 42.0 kg (95% CI).

CS Measuring Greater Than 2.0 mm

Seventy-three of 342 radiographs revealed the presence of a CS greater than 2.0 mm (21.3%) (Figure3) comprised of 4 anterolistheses and 101 retrolistheses (105 CS in total). There were 41 females and 32 males from 4 through 17 years of age with a mean age of 12.1 $\pm$ 6.4 years (95% CI), a mean height of 157.8 $\pm$ 29.4 cm (95% CI) and weight of 60.9 $\pm$ 38.6 kg (95% CI). Within the 73 radiographs, 41 CS were located at C2-C3, 21 at C3-C4, 19 at C4-C5, 11 at C5-C6, and 8 at C6-C7. The greatest number of pediatric patients with CS measuring greater than 2.0 mm were between 9 and 16 years of age with the greatest number of CS at 10, 14, and 16 years of age (Figure 4).

Fifty of 342 radiographs (30 female and 20 male patients) revealed the presence of 1 CS greater than 2.0 mm (14.6%) per pediatric patient comprised of 1 anterolistheses and 49 retrolistheses (50 CS in total). Within the 50 radiographs, 26 CS were located at C2-C3, 9 at C3-C4, 8 at C4-C5, 3 at C5-C6, and 4 at C6-C7. The greatest number of pediatric patients with 1 CS measuring greater than 2.0 mm were between 9 and 16 years of age with the greatest number of CS at 9, 12, and 16 years of age (Figure 5).

Fifteen of 342 radiographs (8 female and 7 male patients) revealed the presence of 2 CS greater than 2.0 mm (4.4%) per pediatric patient comprised of 3 anterolistheses and 27 retrolistheses (30 CS in total). Within the 15 radiographs, 8 CS were located at C2-C3, 11 at C3-C4, 6 at C4-C5, 4 at C5-C6, and 1 at C6-C7. The greatest number of pediatric patients with 2 CS measuring greater than 2.0 mm were between 10 and 14 years of age with the greatest number of CS at 10 and 14 years of age (Figure 6).

Seven of 342 radiographs (3 female and 4 male patients) revealed the presence of 3 CS greater than 2.0 mm (2.0%) per pediatric patient comprised of 0 anterolistheses and 21 retrolistheses (21 CS in total). Within the 15 radiographs, 6 CS were located at C2-C3, 5 at C3-C4, 4 at C4-C5, 4 at C5-C6, and 2 at C6-C7. The greatest number of pediatric patients with 3 CS measuring greater than 2.0 mm were between 10 and 14 years of age with the greatest number of CS at 10 years of age (Figure 7).

One of 342 radiographs (0 female and 1 male patients) revealed the presence of 4 CS greater than 2.0 mm (0.3%) per pediatric patient comprised of 0 anterolistheses and 4 retrolistheses (4 CS in total). Within the 15 radiographs, 6 CS were located at C2-C3, 5 at C3-C4, 4 at C4-C5, 4 at C5-C6, and 2 at C6-C7. The pediatric patient with 3 CS measuring greater than 2.0 mm was 10 years of age (Figure 8).

Within the 73 radiographs of pediatric patients with 105 CS greater than 2.0 mm, 22 patients (30.1%) reported head and(or) neck musculoskeletal complaints. Of those 22 patients, 9 reported only head and(or) neck musculoskeletal complaints. Nine patients reported mid-back, low back, and(or) pelvic musculoskeletal complaints without head and(or) neck musculoskeletal complaints. Forty-two patients (57.5%) reported no musculoskeletal complaints (Table 2).

CS Measuring Greater Than 3.5 mm

Eight of 342 radiographs revealed the presence of a CS greater than 3.5 mm (2.3%) (Figure 9) comprised of 1 anterolistheses and 9 retrolistheses (10 CS in total). There were 5 females and 3 males from 4 through 17 years of age with a mean age of 11.5 $\pm$ 6.2 years (95% CI), a mean height of 160.0 $\pm$ 28.2 cm (95% CI) and weight of 60.6 $\pm$ 39.4 kg (95% CI). Within the 8 radiographs, 3 CS were located at C2-C3, 2 at C3-C4, 1 at C4-C5, 3 at C5-C6, and 1 at C6-C7. The greatest number of pediatric patients with CS measuring greater than 3.5 mm were between 12 and 14 years of age with the greatest number of CS at 12 years of age (Figure 10).

Seven of 342 radiographs (4 female and 3 male patients) revealed the presence of 1 CS greater than 3.5 mm (14.6%) per pediatric patient comprised of 1 anterolistheses and 6 retrolistheses (7 CS in total). Within the 7 radiographs, 3 CS were located at C2-C3, 1 at C3-C4, 1 at C4-C5, 2 at C5-C6, and 0 at C6-C7. The greatest number of pediatric patients with 1 CS measuring greater than 3.5 mm were between 12 and 14 years of age with the greatest number of CS at 12 years of age (Figure 11).

One of 342 radiographs (1 female and 0 male patients) revealed the presence of 4 CS greater than 3.5 mm (0.3%) per pediatric patient comprised of 0 anterolistheses and 4 retrolistheses (4 CS in total). Within the 1 radiograph, 0 CS were located at C2-C3, 1 at C3-C4, 0 at C4-C5, 1 at C5-C6, and 1 at C6-C7. The pediatric patient with 4 CS measuring greater than 3.5 mm was 8 years of age (Figure 12).

Within the 8 radiographs of pediatric patients with 10 CS greater than 3.5 mm, 2 patients (25.0%) reported head and(or) neck musculoskeletal complaints. Of those 2 patients, 1 reported only head and(or) neck musculoskeletal complaints. One patient reported mid-back, low back, and(or) pelvic musculoskeletal complaints without head and(or) neck musculoskeletal complaints. Five patients (62.5%) reported no musculoskeletal complaints (Table 2).

C2-C3 Pseudosubluxation

Pseudosubluxation is defined as a non-pathological anterolisthesis of C2 on C3 and described as a normal variant with no significant association with injury severity or outcome [15]. "Lack of awareness of the normal variation in the alignment of the upper cervical spine in children may lead to over diagnosis of significant injury" [15]. In a pseudosubluxation, the C2 body translates anteriorly on C3 but the C2 spinolaminar line does not cross the posterior cervical line (Swischuk line) from the posterior arch of C1 to that of C3 (Figure 13). Suspected CS at C2-C3 were screened using the posterior cervical line (Swischuk line). C2-C3 anterolistheses greater than 2.0 mm where the C1-C3 posterior cervical line passed through, touched, or lied 1 mm in front of the C2 spinolaminar line did not qualify as CS in this study. Within the 73 radiographs of pediatric patients with 105 CS greater than 2.0 mm, 9 patients (12.3%) had C2-C3 pseudosubluxation which were not included in the data for CS prevalence.

DISCUSSION

This study shows that CS, even to the point of spinal instability and including multiple levels of CS, is present in children and adolescents with and without the presence of symptoms. Seventy-three of 342 radiographs revealed the presence of a CS greater than 2.0 mm (21.3%), 8 radiographs revealed the presence of a CS greater than 3.5 mm (2.3%), and 9 radiographs revealed the presence of C2-C3 pseudosubluxation (12.3%).

Spinal Alignment and Posture

Prevalence of CS may be more common than previously thought [1]. CS has been showed to be caused by abnormal sagittal cervical alignment, facet joint angles and arthrosis which alter cervical biomechanics. This leads to increased stress with cervical flexion and extension, damage to cervical discs and ligaments, and allows for instability and slippage to occur [19]. Woiciechowsky states that instability causes damage to the ligaments and the disc causing the vertebral body to horizontally displace [19]. Most of the time, neck pain is the first symptom [19]. If patients with neck pain are evaluated for instability before there is damage to the facet joints, ligaments, and discs, degenerative cervical spondylolisthesis may be slowed or prevented.

Jun et al. shows that anatomy has influence cervical spine sagittal alignment [20]. Jun et al. states that T1 slope is an important factor in the cervical sagittal alignment, which causes anterior translation of the vertebral body's center of gravity [20]. Increased mobility, sliding force, and loss of cervical lordosis cause stress at the disc and facet joints [20].

Degenerative changes in the cervical spine has been shown been shown to increase as the cervical sagittal alignment is altered. It is well documented in the literature that cervical lordosis is associated with nerve entrapment, pain, and degeneration of the cervical spine [20].

Restoration of global sagittal balance of the spine and pelvic alignment is paramount in the treatment of any spinal deformity [12].

Epidemiology and Spinal Deformity

The developing anatomy of the cervical spine in children increases the risk of injury of the upper cervical spine. The biomechanics of the pediatric cervical spine has the fulcrum of motion at the C2-C3 level as opposed to C5-C6 in the adult cervical spine. "The immature spine is hypermobile because of ligamentous laxity, shallow and angled facet joints, underdeveloped spinous processes, and physiologic anterior wedging of vertebral bodies, all of which contribute to high torque and shear forces acting on the C1-C2 region. Incomplete ossification of the odontoid process, a relatively large head, and weak neck muscles are other factors that predispose to instability of the pediatric cervical spine" [22]. Younger children are more likely to sustain an upper cervical spine injury located from the occiput to C3. These injuries are also associated with a high risk of neurologic damage [22].

Parents, guardians, and caregivers often seek healthcare treatment options for their children due to the presence of symptoms such as pain, discomfort, or abnormal posture. However, the reality is that children and adolescents are likely to endure any number of various forms of trauma. Birth trauma [23], unintentional falls [24], sports-related trauma [25], motor vehicle crash trauma [26], play-related trauma [27], childhood violence [28], and other trauma risks are ever present. A major problem is that many forms of childhood trauma are not reported and underestimated [29]. In some cases, only children are witness to the trauma. In other cases, the appearance of a lack of physical damage or an absence of symptoms following a trauma results in a lack of physical examination for many children following a trauma. Also, children are very resilient which may mask underlying risks and physical injuries that become evident later. "To remedy spine-related problems, assessments of X-ray images are essential to determine the spine and postural parameters" [30]. Further investigation into the sagittal spinal alignment of children and adolescents with or without symptoms may help to identify the precursors or presence of CS. Studying the prevalence of spinal deformity and vertebral subluxation, such as CS, in pediatric populations educates and informs parents, guardians, caregivers, healthcare providers, and healthcare policymakers to help treat and prevent degenerative spinal conditions for children and adolescents.

Differential Diagnosis

The differential diagnosis for CS includes cervical fracture, cervical canal stenosis, cervical disc degeneration, and cervical facet dislocation or arthropathy [31]. These conditions often present with the similar clinical symptoms, such as neck pain and radiculopathy. However, CS is often made worse with extension and can be asymptomatic (Table 1) [31].

Limitations

While this study contains several patients (n=342), the subjects may not represent the general population because they were recruited from one area in the United States and were patients presenting to a private practice. It is important to note, however, that not all the patients presented with pain in the cervical or thoracic region which allows for greater application. Second, in pediatric populations, physiological changes take place over shorter time intervals than in adulthood. Further studies should focus on more subjects with increased attention to the sub-groups of ages within the pediatric population. Third, this is a cross-sectional study. We cannot confirm a causal relationship involving CS. Fourth, more and less critical subjects might not have participated in our study. Fifth, we failed to evaluate dynamic instability of the cervical spine, which should be taken into consideration in CS evaluation.

CONCLUSION

At present, pediatric CS epidemiology does not seem to be represented in research. This cross-sectional study shows that CS in pediatric populations seems under-studied and needs greater attention. This study shows that CS, even to the point of spinal instability and including multiple levels of CS, is present in children and adolescents with and without the presence of symptoms. The data presented support further investigation into the sagittal spinal alignment of children and adolescents with or without symptoms to identify the precursors or presence of CS.

Future prospective studies involving larger populations, multiple locations, long-term follow-ups, and more anthropometric and clinical data will shed more light on the epidemiology of CS and the associated functional and symptomatic effects and pathologies.

TEACHING POINT

Cervical spondylolistheses greater than 2.0 mm (21.3%) and 3.5 mm (2.3%), even to the point of spinal instability and including multiple levels of cervical spondylolisthesis, are present in children and adolescents with and without the presence of symptoms. The data presented support further investigation into the sagittal spinal alignment of children and adolescents with or without symptoms to identify the precursors or presence of cervical spondylolisthesis.

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FIGURES

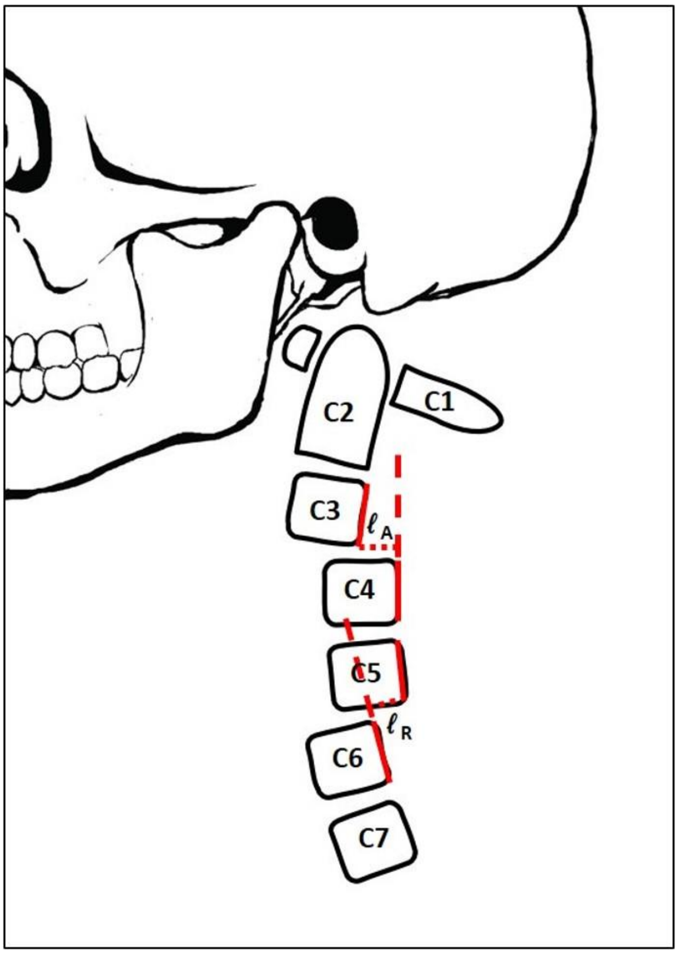

Figure 1: NLC Rendering Illustrating Anterior and Posterior CS and Method of Measuring the Sagittal Translation of One Cervical Vertebra on Another in CS

Image Features: The first through seventh cervical vertebrae are labelled C1-C7. The solid red line represents the actual posterior tangent lines of the C3, C4, C5, and C6 vertebrae. The dashed red line represents an extension of the posterior tangent lines of C4 and C6 vertebrae. The dotted red line represents the perpendicular distance from the posterior tangent of the inferior vertebra in a CS to the posterior, inferior aspect of the adjacent superior vertebra in a CS. ℓA represents the length of the segmental anterior translation in an anterolisthesis at C3 (a CS where the superior vertebra moves anterior to the inferior vertebra). ℓR represents the length of the segmental posterior translation in a retrolisthesis at C5 (a CS where the superior vertebra moves posterior to the inferior vertebra).

Findings: CS is measured in millimeters as the perpendicular translational distance between the posterior tangential line of the inferior vertebra to the posterior inferior aspect of the adjacent superior vertebra.

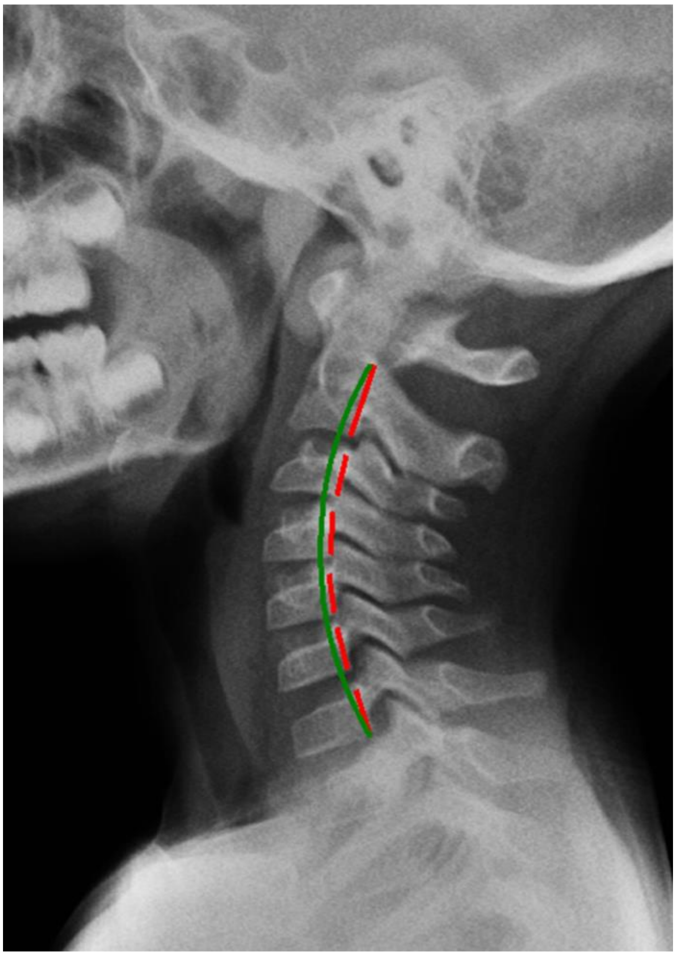

Figure 2: NLC Radiograph of a Pediatric Patient with a Normal Cervical Alignment

Description: 8-year-old male with no reported symptoms or history of trauma.

Image Features: The green line represents a normal, ideal cervical alignment. The red line represents the actual posterior tangent lines of the C2-C7 vertebrae.

Findings: NLC image shows normal cervical alignment, cervical curvature C2-C7 measures -21.8° (-22.5° is ideal), Tz C2-C7 measures -0.5 mm (0.0 mm is ideal), |STz| C2-C7 measurements < 0.3 mm (0.0 mm is ideal).

Technique: 30 mAs, 200 mA, 76 kVp, 72" focal-film distance (FFD), Central Ray (CR) at C4.

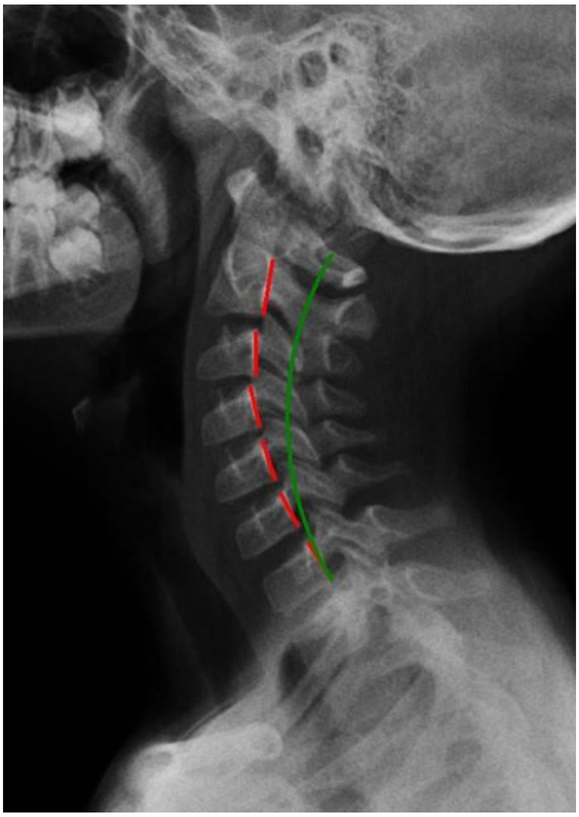

Figure 3 (left): NLC Radiograph of a Pediatric Patient with a CS Measuring Greater than 2.0 mm

Description: 12-year-old female with reported headaches and neck pain and no reported history of trauma.
Image Features: The green line represents a normal, ideal cervical alignment. The red line represents the actual posterior tangent lines of the C2-C7 vertebrae.

Findings: NLC image shows cervical curvature C2-C7 measures -41.7° (21.5° is ideal), Tz C2-C7 measures -16.6 mm (0.0 mm is ideal), STz measurements of C2-C3, C3-C4, C4-5, C5-C6, and C6-C7 are -2.9 mm, -2.5 mm, -1.5 mm, -1.0 mm, and -0.7 mm respectively (0.0 mm is ideal and CS is greater than 2.0 mm).

Technique: 30 mAs, 200 mA, 76 kVp, 72" FFD, CR at C4.

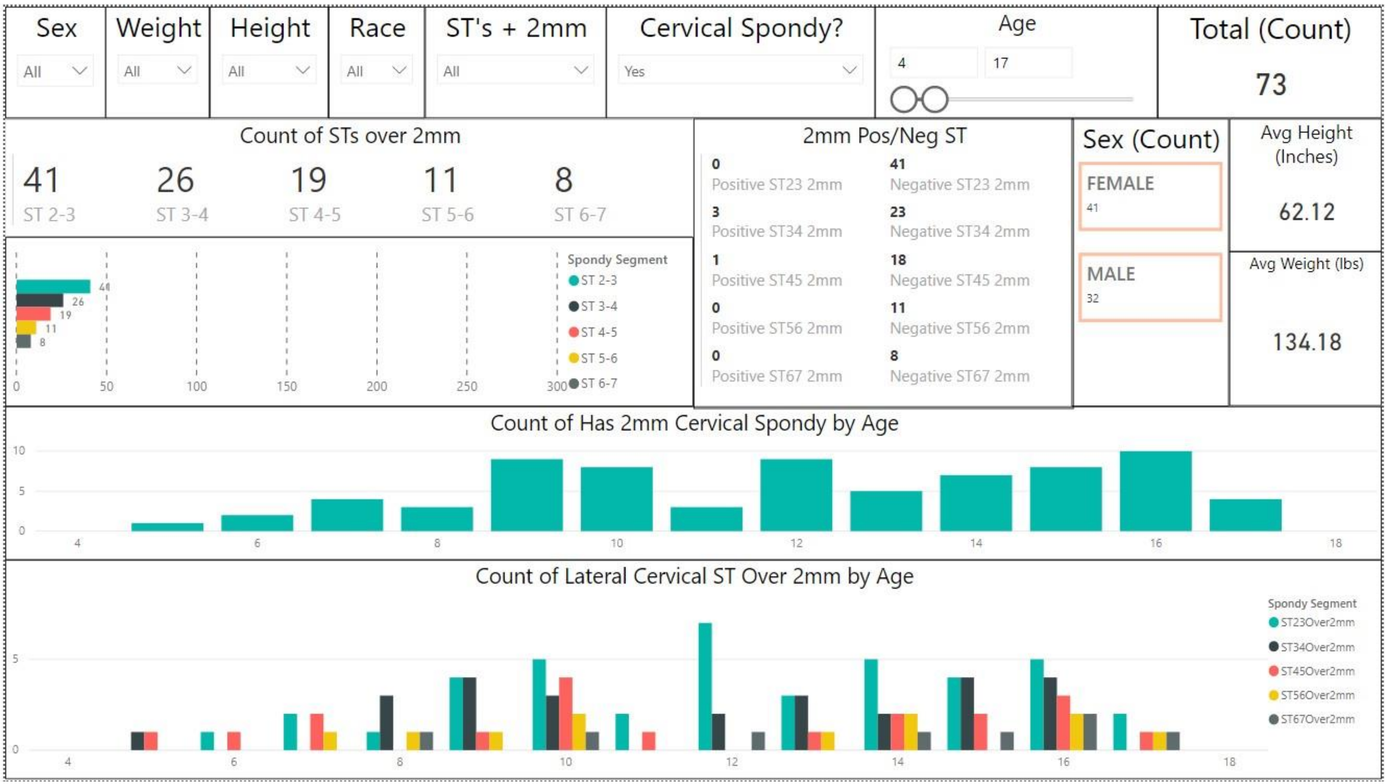

Figure 4: Pediatric Patients with CS Measuring Greater than 2.0 mm
Image Features: This is a Microsoft Power BI interactive visualizations of pediatric patients with all CS measuring greater than 2.0 mm. Pediatric patients with CS measuring greater than 2.0 mm of any sex, weight, height, and race between the ages of 0 through 17 years of age (the youngest age in this dataset is 4 years). This visualization provides counts of CS over 2.0 mm by cervical segments involved, age of the pediatric patients, and counts of CS over 2.0 mm by cervical segments involved as well as by age of the pediatric patients.

Findings: 73/342 radiographs (41 female and 32 male patients) revealed the presence of a CS greater than 2.0 mm (21.3%) comprised of 4 anterolistheses and 101 retrolistheses (105 CS in total). Within the 73 radiographs, 41 CS were located at C2-C3, 21 at C3-C4, 19 at C4-C5, 11 at C5-C6, and 8 at C6-C7. The greatest number of pediatric patients with CS measuring greater than 2.0 mm were between 9 and 16 years of age with the greatest number of CS at 10, 14, and 16 years of age.

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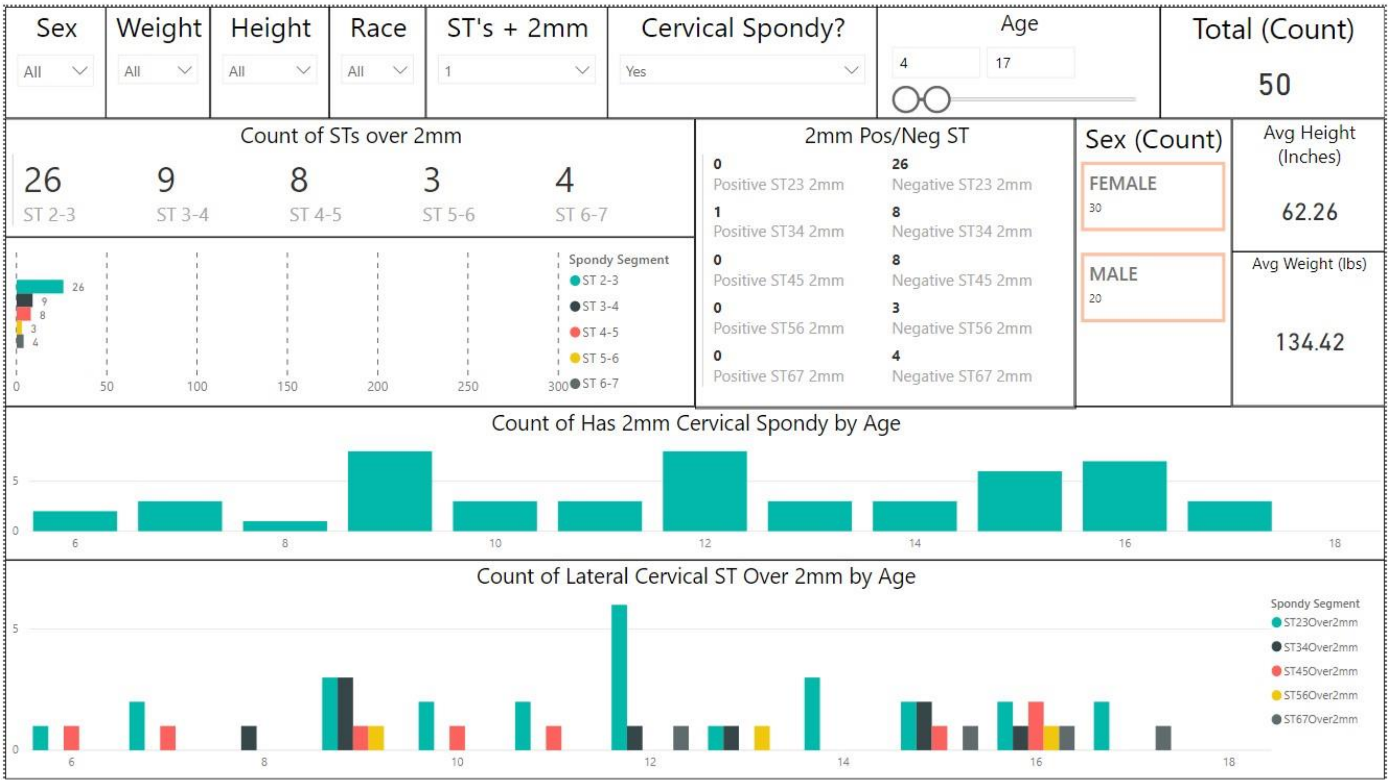

Figure 5: Pediatric Patients with 1 CS Measuring Greater than 2.0 mm

Image Features: This is a Microsoft Power BI interactive visualizations of pediatric patients with 1 CS measuring greater than 2.0 mm. Pediatric patients with 1 CS measuring greater than 2.0 mm of any sex, weight, height, and race between the ages of 0 through 17 years of age (the youngest age in this dataset is 4 years) were included. This visualization provides counts of CS over 2.0 mm by cervical segments involved, age of the pediatric patients, and counts of CS over 2.0 mm by cervical segments involved as well as by age of the pediatric patients.

Findings: 50/342 radiographs (30 female and 20 male patients) revealed the presence of 1 CS greater than 2.0 mm (14.6%) per pediatric patient comprised of 1 anterolistheses and 49 retrolistheses (50 CS in total). Within the 50 radiographs, 26 CS were located at C2-C3, 9 at C3-C4, 8 at C4-C5, 3 at C5-C6, and 4 at C6-C7. The greatest number of pediatric patients with 1 CS measuring greater than 2.0 mm were between 9 and 16 years of age with the greatest number of CS at 9, 12, and 16 years of age.

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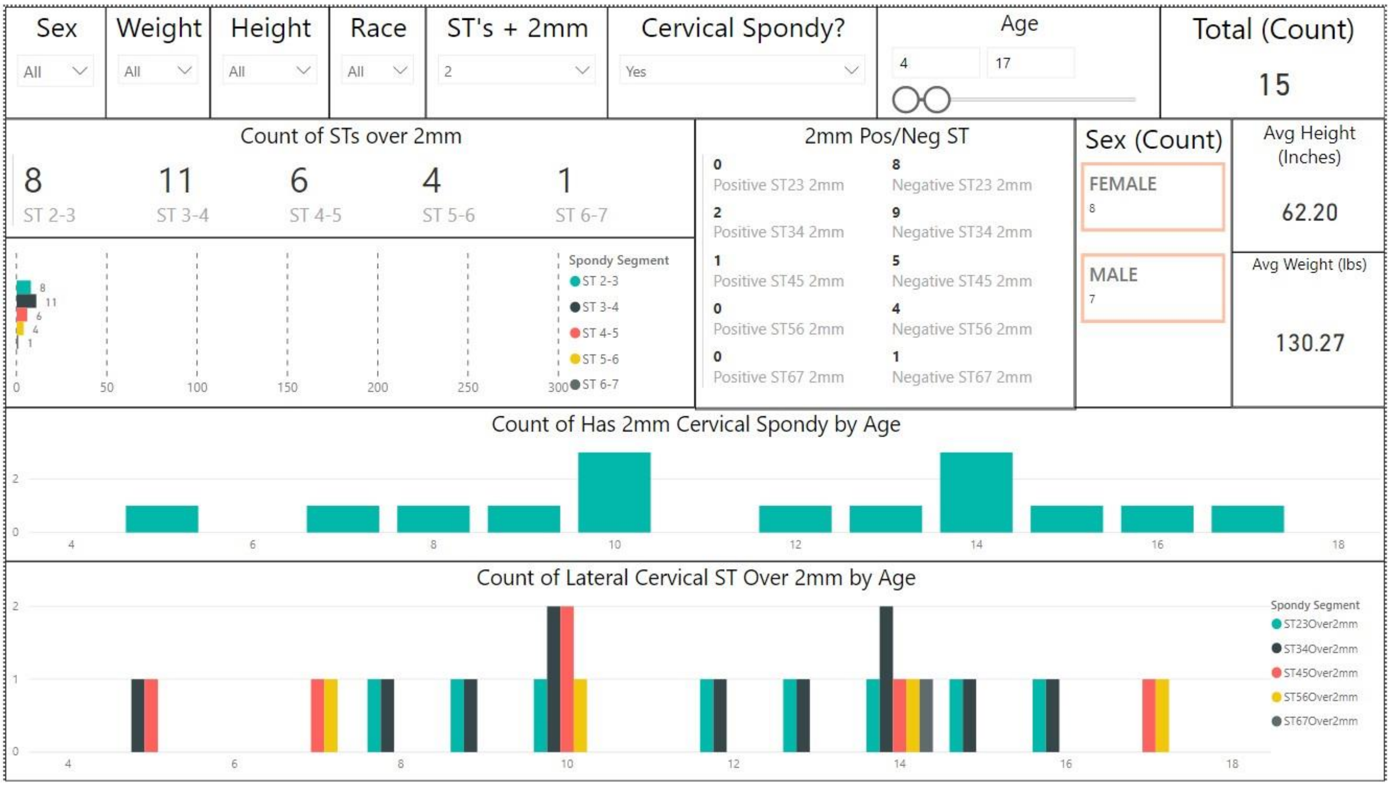

Figure 6: Pediatric Patients with 2 CS Measuring Greater than 2.0 mm

Image Features: This is a Microsoft Power BI interactive visualizations of pediatric patients with 2 CS measuring greater than 2.0 mm. Pediatric patients with 2 CS measuring greater than 2.0 mm of any sex, weight, height, and race between the ages of 0 through 17 years of age (the youngest age in this dataset is 4 years) were included. This visualization provides counts of CS over 2.0 mm by cervical segments involved, age of the pediatric patients, and counts of CS over 2.0 mm by cervical segments involved as well as by age of the pediatric patients.

Findings: 15/342 radiographs (8 female and 7 male patients) revealed the presence of 2 CS greater than 2.0 mm (4.4%) per pediatric patient comprised of 3 anterolistheses and 27 retrolistheses (30 CS in total). Within the 15 radiographs, 8 CS were located at C2-C3, 11 at C3-C4, 6 at C4-C5, 4 at C5-C6, and 1 at C6-C7. The greatest number of pediatric patients with 2 CS measuring greater than 2.0 mm were between 10 and 14 years of age with the greatest number of CS at 10 and 14 years of age.

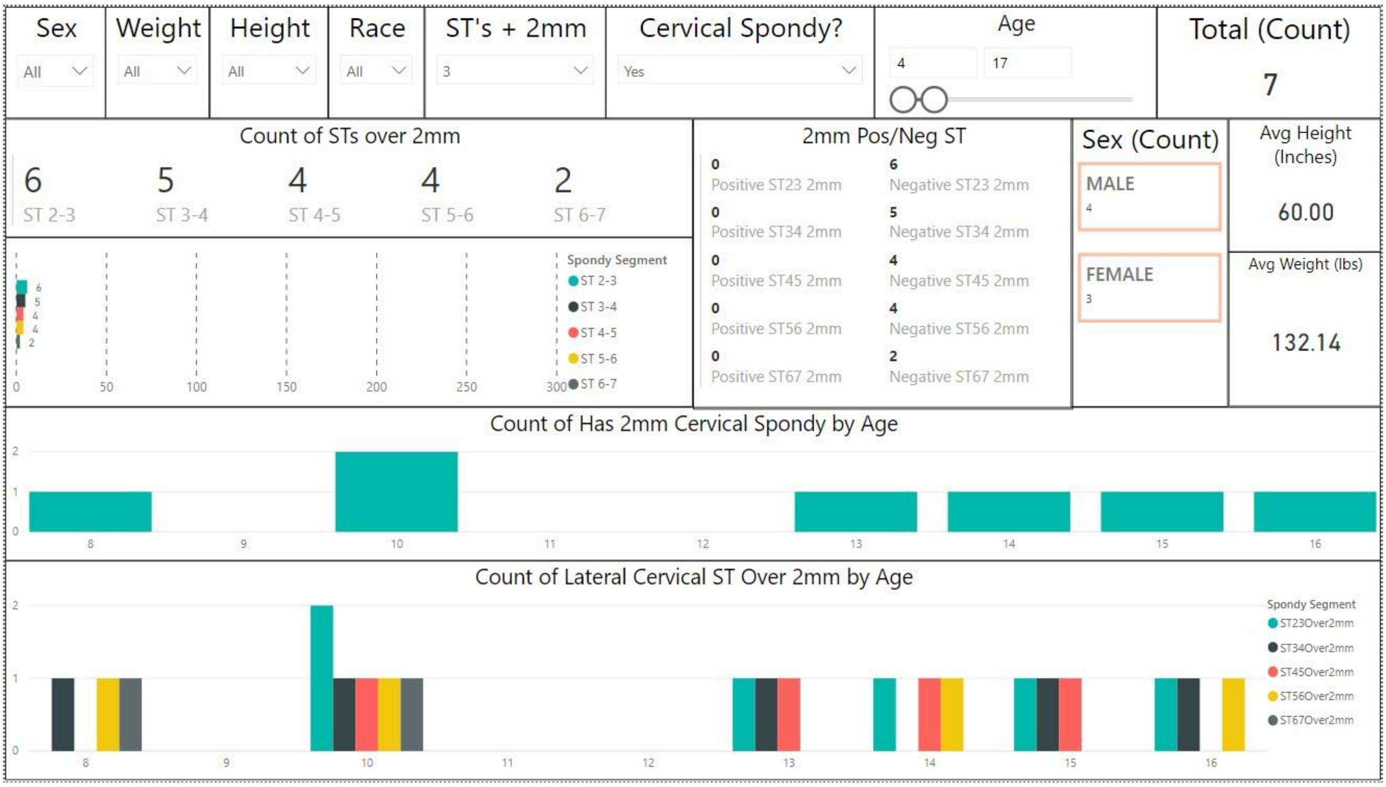

Figure 7: Pediatric Patients with 3 CS Measuring Greater than 2.0 mm

Image Features: This is a Microsoft Power BI interactive visualizations of pediatric patients with 3 CS measuring greater than 2.0 mm. Pediatric patients with 3 CS measuring greater than 2.0 mm of any sex, weight, height, and race between the ages of 0 through 17 years of age (the youngest age in this dataset is 4 years) were included. This visualization provides counts of CS over 2.0 mm by cervical segments involved, age of the pediatric patients, and counts of CS over 2.0 mm by cervical segments involved as well as by age of the pediatric patients.

Findings: 7/342 radiographs (3 female and 4 male patients) revealed the presence of 3 CS greater than 2.0 mm (2.0%) per pediatric patient comprised of 0 anterolistheses and 21 retrolistheses (21 CS in total). Within the 15 radiographs, 6 CS were located at C2-C3, 5 at C3-C4, 4 at C4-C5, 4 at C5-C6, and 2 at C6-C7. The greatest number of pediatric patients with 3 CS measuring greater than 2.0 mm were between 10 and 14 years of age with the greatest number of CS at 10 years of age.

Figure 8: Pediatric Patients with 4 CS Measuring Greater than 2.0 mm

Image Features: This is a Microsoft Power BI interactive visualizations of a pediatric patient with 4 CS measuring greater than 2.0 mm. Pediatric patients with 4 CS measuring greater than 2.0 mm of any sex, weight, height, and race between the ages of 0 through 17 years of age (the youngest age in this dataset is 4 years) were included. This visualization provides counts of CS over 2.0 mm by cervical segments involved, age of the pediatric patient, and counts of CS over 2.0 mm by cervical segments involved as well as by age of the pediatric patient.

Findings: 1/342 radiographs (0 female and 1 male patients) revealed the presence of 4 CS greater than 2.0 mm (0.3%) per pediatric patient comprised of 0 anterolistheses and 4 retrolistheses (4 CS in total). Within the 15 radiographs, 6 CS were located at C2-C3, 5 at C3-C4, 4 at C4-C5, 4 at C5-C6, and 2 at C6-C7. The pediatric patient with 3 CS measuring greater than 2.0 mm was 10 years of age.

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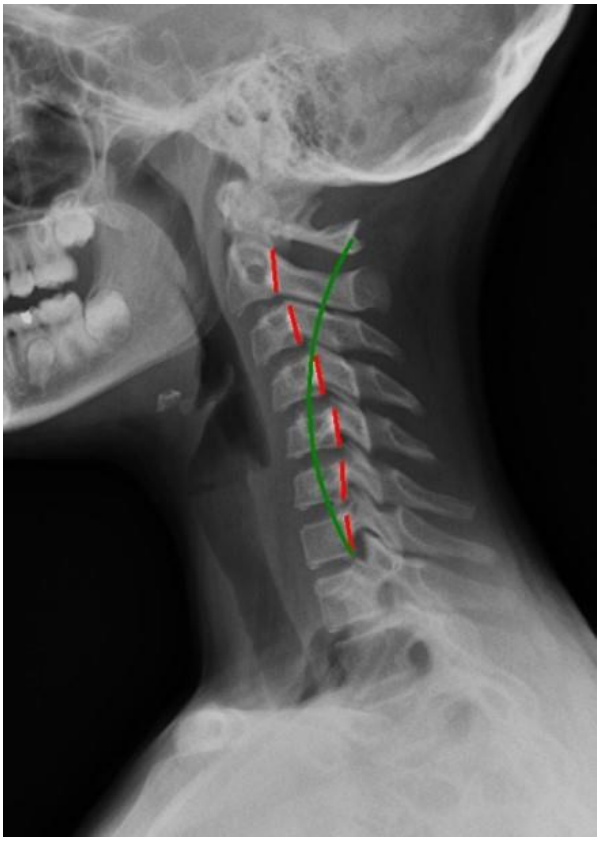

Figure 9 (left): NLC Radiograph of a Pediatric Patient with a CS Measuring Greater than 3.5 mm

Description: 13-year-old female with reported neck pain following a traumatic fall while horseback riding
Image Features: The green line represents a normal, ideal cervical alignment. The red line represents the actual posterior tangent lines of the C2-C7 vertebrae.

Findings: NLC image shows cervical curvature C2-C7 measures -3.4° (-25.3° is ideal), Tz C2-C7 is 23.9 mm (0.0 mm is ideal), STz measurements of C2-C3, C3-C4, C4-5, C5-C6, and C6-C7 are 1.6 mm, 3.6 mm, 2.0 mm, 0.2 mm, and 0.6 mm respectively (0.0 mm is ideal and CS is greater than 2.0 mm).

Technique: 30 mAs, 200 mA, 76 kVp, 72" FFD, CR at C4.

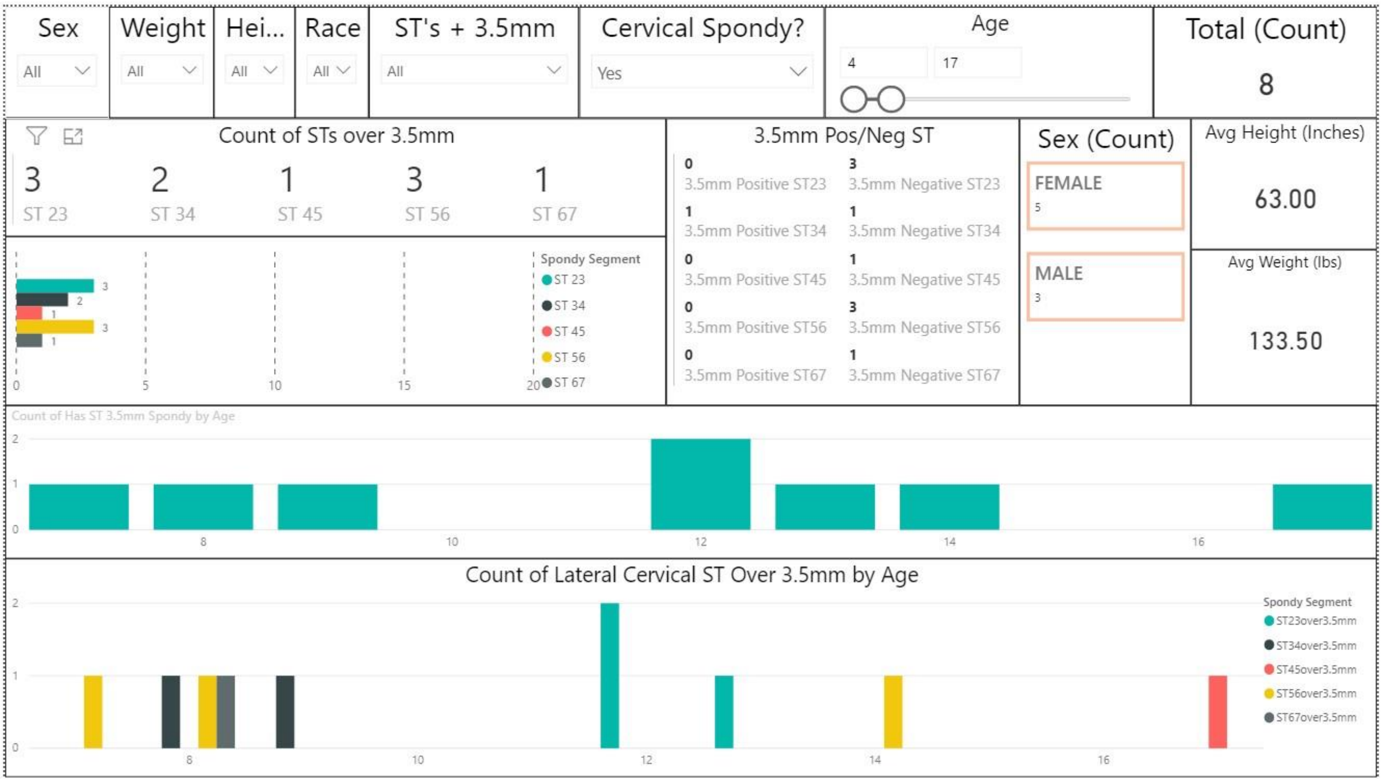

Figure 10: Pediatric Patients with CS Measuring Greater than 3.5 mm
Image Features: This is a Microsoft Power BI interactive visualizations of pediatric patients with all CS measuring greater than 3.5 mm. Pediatric patients with CS measuring greater than 3.5 mm of any sex, weight, height, and race between the ages of 0 through 17 years of age (the youngest age in this dataset is 4 years) were included. This visualization provides counts of CS over 3.5 mm by cervical segments involved, age of the pediatric patients, and counts of CS over 3.5 mm by cervical segments involved as well as by age of the pediatric patients.
Findings: 8/342 radiographs (5 female and 3 male patients) revealed the presence of a CS greater than 3.5 mm (2.3%) comprised of 1 anterolistheses and 9 retrolistheses (10 CS in total). Within the 8 radiographs, 3 CS were located at C2-C3, 2 at C3-C4, 1 at C4-C5, 3 at C5-C6, and 1 at C6-C7. The greatest number of pediatric patients with CS measuring greater than 3.5 mm were between 12 and 14 years of age with the greatest number of CS at 12 years of age.

Figure 11: Pediatric Patients with 1 CS Measuring Greater than 3.5 mm

Image Features: This is a Microsoft Power BI interactive visualizations of pediatric patients with 1 CS measuring greater than 3.5 mm. Pediatric patients with 1 CS measuring greater than 3.5 mm of any sex, weight, height, and race between the ages of 0 through 17 years of age (the youngest age in this dataset is 4 years) were included. This visualization provides counts of CS over 3.5 mm by cervical segments involved, age of the pediatric patients, and counts of CS over 3.5 mm by cervical segments involved as well as by age of the pediatric patients.

Findings: 7/342 radiographs (4 female and 3 male patients) revealed the presence of 1 CS greater than 3.5 mm (14.6%) per pediatric patient comprised of 1 anterolistheses and 6 retrolistheses (7 CS in total). Within the 7 radiographs, 3 CS were located at C2-C3, 1 at C3-C4, 1 at C4-C5, 2 at C5-C6, and 0 at C6-C7. The greatest number of pediatric patients with 1 CS measuring greater than 3.5.0 mm were between 12 and 14 years of age with the greatest number of CS at 12 years of age.

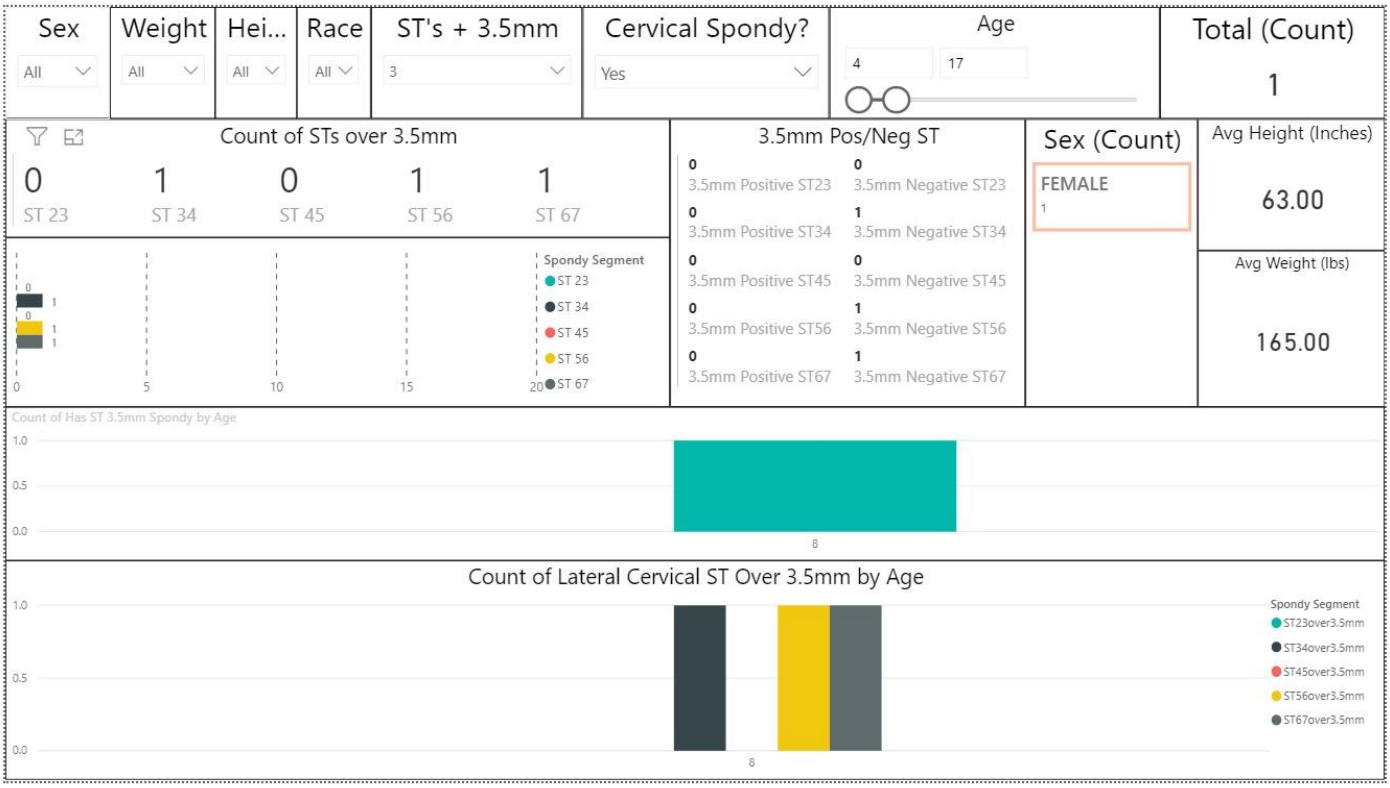

Figure 12: Pediatric Patient with 3 CS Measuring Greater than 3.5 mm

Image Features: This is a Microsoft Power BI interactive visualizations of a pediatric patient with 3 CS measuring greater than 3.5 mm. Pediatric patients with 3 CS measuring greater than 3.5 mm of any sex, weight, height, and race between the ages of 0 through 17 years of age (the youngest age in this dataset is 4 years) were included. This visualization provides counts of CS over 3.5 mm by cervical segments involved, age of the pediatric patient, and counts of CS over 3.5 mm by cervical segments involved as well as by age of the pediatric patient.

Findings: 1/342 radiographs (1 female and 0 male patients) revealed the presence of 4 CS greater than 3.5 mm (0.3%) per pediatric patient comprised of 0 anterolistheses and 4 retrolistheses (4 CS in total). Within the 1 radiograph, 0 CS were located at C2-C3, 1 at C3-C4, 0 at C4-C5, 1 at C5-C6, and 1 at C6-C7. The pediatric patient with 4 CS measuring greater than 3.5 mm was 8 years of age.

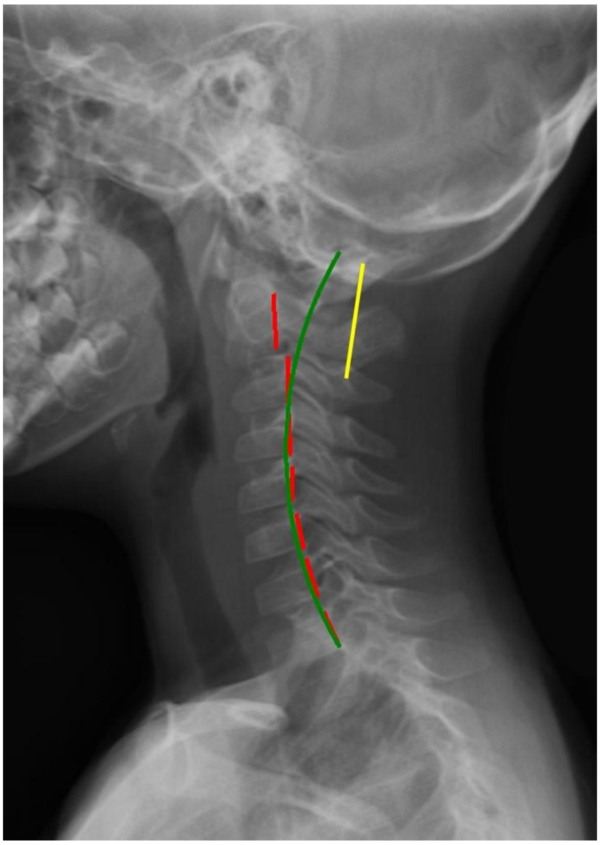

Figure 13 (left): NLC Radiograph of a Pediatric Patient with a C2-C3 Pseudosubluxation

Description: 5-year-old male with chief complaint of abnormal posture and no reported symptoms or reported history of trauma.

Image Features: The green line represents a normal, ideal cervical alignment. The red line represents the actual posterior tangent lines of the C2-C7 vertebrae. The yellow line represents the C1-C3 posterior cervical line (Swischuk line).

Findings: NLC image shows cervical curvature C2-C7 measures -13.6° (27.8° is ideal), Tz C2-C7 measures 11.9 mm (0.0 mm is ideal), Tz C2-C3 measures 2.4 mm but qualifies as a C2-C3 pseudosubluxation instead of a CS because the C1-C3 posterior cervical line (Swischuk line) passes through the C2 spinolaminar line, |STz| C3-C7 measurements < 0.4 mm (0.0 mm is ideal).

Technique: 30 mAs, 200 mA, 76 kVp, 72" FFD, CR at C4.

Spondylolisthesis	Summary
Etiology	• Translation of vertebra with respect to vertebra below • Abnormal weight distribution, soft tissue laxity, and instability • Excessive joint play and degeneration of the intervertebral disc • Abnormal spinal alignment and positional loading of the cervical spine • May present with neck pain, radiculopathy, or no symptoms
Incidence	• 5.2 to 11%
Gender Ratio	• Male:Female is 3:2 in grade 1 and 11:5 in grade 2 spondylolisthesis.
Age Predilection	• Increase in prevalence after 60 years • 5% of 0-20-year-olds; 33.3% of 20-59-year-olds; 66.7% of 60–99-year-olds
Risk Factors	• Increased age, sex, facet hypertrophy, cervical hypolordosis/kyphosis, anterior head translation, cervical spondylosis/degeneration, history of cervical spine surgery • Abnormal spinal alignment • Correlation with cervicothoracic sagittal alignment factors
Treatment	• Spinal fusion surgery to stabilize • Non-surgical methods include active physical therapy, education or counseling for exercising, nonsteroidal anti-inflammatory drugs, homeopathic remedies, soft tissue massage, trigger point therapy, spinal mobilization techniques to restricted areas, cryotherapy, and chiropractic
Prognosis	• Degenerative condition unless the spine is stabilized
Findings on Imaging	• Most common levels are C3-C4, C4-5, and C5-C6 followed by C6-C7 • X-ray imaging shows extent of segmental translation • Magnetic resonance imaging shows extent of soft tissue damage

Table 1: Summary table of cervical spondylolisthesis in the sagittal plane.

	CS > 2.0 mm	CS > 3.5 mm
Total	73	8
With Head and(or) Neck Musculoskeletal Complaints	22	2
With Head and(or) Neck Musculoskeletal Complaints AND Mid-Back, Low Back, and(or) Pelvic Musculoskeletal Complaints	9	1
With ONLY Head and(or) Neck Musculoskeletal Complaints	13	1
With ONLY Mid-Back, Low Back, and(or) Pelvic Musculoskeletal Complaints	9	1
With NO Musculoskeletal Complaints	42	5

Table 2: Symptoms of pediatric patients with cervical spondylolisthesis.

Differential Diagnoses	Plain Radiography	Magnetic Resonance Imaging	Computed Tomography Myelography	Computed Tomography
Degenerative Cervical Spondylolisthesis	• Upright, weight-bearing lateral cervical view is most appropriate for detecting spondylolisthesis. • Lateral cervical flexion and extension views demonstrate cervical instability.	• Most appropriate for imaging spinal stenosis or facet joint arthropathy. • Provides a detailed view of the cervical spine, spinal cord, and soft tissue structures.	• Useful in assessing spinal stenosis or nerve roots and when magnetic resonance imaging is contraindicated or inconclusive. • Provides a view of the entire cervical spine and is done in the standing position (accentuates spinal stenosis).	• Useful when magnetic resonance imaging and computed tomography myelography are contraindicated or inconclusive. • Useful in assessing spinal stenosis or nerve roots and provides a detailed view of the facet joints.
Cervical Fracture	• Upright, weight-bearing lateral cervical view is most appropriate for detecting spondylolisthesis. • Lateral cervical flexion and extension views demonstrate cervical instability.			
Cervical Canal Stenosis		• Most appropriate for imaging spinal stenosis or facet joint arthropathy. • Provides a detailed view of the cervical spine, spinal cord, and soft tissue structures.	• Useful in assessing spinal stenosis or nerve roots and when magnetic resonance imaging is contraindicated or inconclusive. • Provides a view of the entire cervical spine and is done in the standing position (accentuates spinal stenosis).	• Useful when magnetic resonance imaging and computed tomography myelography are contraindicated or inconclusive. • Useful in assessing spinal stenosis or nerve roots and provides a detailed view of the facet joints.
Cervical Disc Degeneration		• Most appropriate for imaging spinal stenosis or facet joint arthropathy. • Provides a detailed view of the cervical spine, spinal cord, and soft tissue structures.		
Cervical Facet Dislocation	• Upright, weight-bearing lateral cervical view is most appropriate for detecting spondylolisthesis. • Lateral cervical flexion and extension views demonstrate cervical instability.			
Cervical Facet Arthropathy		• Most appropriate for imaging spinal stenosis or facet joint arthropathy. • Provides a detailed view of the cervical spine, spinal cord, and soft tissue structures.		• Useful when magnetic resonance imaging and computed tomography myelography are contraindicated or inconclusive. • Useful in assessing spinal stenosis or nerve roots and provides a detailed view of the facet joints.

Table 3: Differential diagnosis table for cervical spondylolisthesis in the sagittal plane and appropriate imaging.

ABBREVIATIONS

> – Greater than
ℓA – the length of the segmental anterior translation in an anterolisthesis (a CS where the superior vertebra moves anterior to the inferior vertebra).
ℓR – the length of the segmental posterior translation in a retrolisthesis (a CS where the superior vertebra moves posterior to the inferior vertebra).
C1 – First Cervical Vertebra
C2-C3 – Second to Seventh Cervical Vertebrae
C2-C7 – Second to Seventh Cervical Vertebrae
cm – centimeter
CR – Central Ray
CS – Cervical Spondylolisthesis
|CS| – Absolute value (positive value) of cervical spondylolisthesis measurement
CT – Computed Tomography
FFD – Film Focal Distance
IVD – Intervertebral disc
kg – kilogram
kVp – kilovoltage peak
mAs – milliampere second
mm – millimeter
MRI – Magnetic Resonance Imaging
n – number of participants, subjects, or patients
NLC – Neutral Lateral Cervical
STz – Segmental translation in the z-axis/sagittal plane
|STz| – Absolute value (positive value) of segmental translation measurement in the z-axis/sagittal plane
Tz – Translation in the z-axis/sagittal plane

KEYWORDS

cervical spondylolisthesis; pediatric spondylolisthesis; cervical spine; radiography; vertebral subluxation; prevalence; epidemiology; cervical instability