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ORIGINAL ARTICLE

Superior odontoid migration in the Klippel–Feil patient

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Abstract Klippel–Feil syndrome (KFS) is an uncommon condition noted primarily as congenital fusion of two or more cervical vertebrae. Superior odontoid migration (SOM) has been noted in various skeletal deformities and entails an upward/vertical migration of the odontoid process into the foramen magnum with depression of the cranium. Excessive SOM could potentially threaten neurologic integrity. Risk factors associated with the amount of SOM in the KFS patient are based on conjecture and have not been addressed in the literature. Therefore, this study evaluated the presence and extent of SOM and the various risk factors and clinical manifestations associated therein in patients with KFS. Twenty-seven KFS patients with no prior history of surgical intervention of the cervical spine were included for a prospective radiographic and retrospective clinical review. Radiographically, McGregor's line was utilized to evaluate the degree of SOM. Anterior and posterior atlantodens intervals (AADI/PADI), number of fused segments (C1–T1), presence of occipitalization, classification-type, and lateral and coronal cervical alignments were also evaluated. Clinically, patient demographics and presence of cervical symptoms were assessed. Radiographic and clinical evaluations were conducted by two independent blinded observers. There were 8 males and 19 females with a mean age of 13.5 years at the time of radiographic and clinical assessment. An overall mean SOM of 5.0 mm (range = –1.0 to 19.0 mm) was noted. C2–C3 (74.1%) was the most commonly fused segment. A statistically significant difference was not found between the amount of SOM to age, sex-type, classification-type, AADI, PADI, and lateral cervical alignment ($P > 0.05$). A statistically significant greater amount of SOM was found as the number of fused segments increased ($r = 0.589$; $P = 0.001$) and if such levels included occipitalization ($r = 0.616$; $P = 0.001$). A statistically significant greater amount of SOM was also found with an increase in coronal cervical alignment ($r = 0.413$; $P = 0.036$). Linear regression modeling further supported these findings as the strongest predictive variables contributing to an increase in SOM. A 7.20 crude relative risk (RR) ratio [95% confidence interval (CI) = 1.05–49.18; risk differences (RD) = 0.52] was noted in contributing to a SOM greater than 4.5 mm if four or more segments were fused. Adjusting for coronal cervical alignment greater than 10°, five or more fused segments were found to significantly increase the RR of a SOM greater than 4.5 mm (RR = 4.54; 95% CI = 1.07–19.50; RD = 0.48). The RR of a SOM greater than 4.5 mm was more pronounced in females

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(RR = 1.68; 95% CI = 0.45–6.25; RD = 0.17) than in males. Eight patients (29.6%) were symptomatic, of which symptoms in two of these patients stemmed from a traumatic event. However, a statistically significant difference was not found between the presence of symptoms to the amount of SOM and other exploratory variables ($P > 0.05$). A mean SOM of 5.0 mm was found in our series of KFS patients. In such patients, increases in the number of congenitally fused segments and in the degree of coronal cervical alignment were strongly associated risk factors contributing to an increase in SOM. Patients with four or greater congenitally fused segments had an approximately sevenfold increase in the RR in developing SOM greater than 4.5 mm. A higher RR of SOM more than 4.5 mm may be associated with sex-type. However, 4.5 mm or greater SOM is not synonymous with symptoms in this series. Furthermore, the presence of symptoms was not statistically correlated with the amount of SOM. The treating physician should be cognizant of such potential risk factors, which could also help to indicate the need for further advanced imaging studies in such patients. This study suggests that as motion segments diminish and coronal cervical alignment is altered, the odontoid orientation is located more superiorly, which may increase the risk of neurologic sequelae.

Keywords Klippel–Feil · Cervical · Spine · Odontoid · Migration · Pediatric · Congenital · Developmental · Radiographic · Fusion · Epidemiology · Symptoms · Risk factors · Scoliosis

Introduction

Superior odontoid migration (SOM) is defined as an upward/vertical migration of the odontoid process into the foramen magnum with depression of the cranium. Excessive SOM could increase the threat of neurologic compromise and potentially death [11, 12, 30, 39, 50]. SOM has been associated with various disorders, such as rheumatoid arthritis [13, 17, 35, 42, 48], Down's syndrome [34, 52], osteogenesis imperfecta [30, 47], and Klippel–Feil syndrome (KFS) [1, 10, 18].

Klippel–Feil syndrome is primarily characterized as improper segmentation or congenital fusion of two or more cervical vertebrae [28]. This developmental condition is uncommon and believed to occur in 1 in 40,000–42,000 births [22, 26]. Various spinal and extraspinal anomalies have been associated with KFS, but vary between individuals [10, 23, 25, 36, 37, 44, 46, 53]. Moreover, up to 68% of KFS patients, primarily noted in adulthood, report symptoms related to their syndrome [2, 20, 43, 44, 46]. However, the development of SOM is a tremendous concern for the KFS patient, which left unnoticed could potentially complicate the complex course and management associated with this syndrome.

Various diagnostic methods have been proposed to evaluate the amount of SOM on plain radiographs [6, 7, 16, 31, 33, 40, 41, 55]. Many of these methods entail identification of the odontoid tip and its relation to the osseous and neural elements at the craniovertebral junction [6, 16, 31, 33, 35]. Although advanced imaging is helpful to validate the presence and extent of resultant neural compression from excessive SOM, such an imaging modality is costly and not widely available. Conversely, plain radiography is more widely accessible and has been shown to be a useful, inexpensive screening tool in the evaluation of SOM [42].

Although SOM has been noted to occur in KFS, various risk factors and their role with regards to SOM in this syndrome have not been quantitatively addressed in the literature. Understanding the extent or potential for neurologic demise associated with SOM in KFS patients is critical and could further assist in the design of preventative measures and treatment options. Thus, the following study addressed via a plain radiographic and clinical analyses the various risk factors associated with KFS that could potentially contribute to SOM and associated symptoms.

Materials and methods

This study was a prospective radiographic and retrospective clinical chart review conducted at the Shriners Hospitals for Children in Chicago, Illinois, USA. Following approval by the Institutional Review Board, a clinical database was utilized to identify KFS patients clinically evaluated between November 1986 and January 2004. Thirty-five patients with no prior history of cervical spine surgery were identified, of which 30 patients had available plain radiographs and clinical records, and were initially selected for review. However, three patients (10%) were excluded due to the inability to distinguish appropriate anatomical landmarks to assess SOM. Thus, 27 KFS patients were included for review in this study. Patients initially presented to the clinic and radiographs were obtained as part of the syndromic work-up of their condition, to verify the clinical diagnoses of KFS as proposed by physicians not related to the institute, or if preanesthesia clearance was needed for surgery not related to the cervical spine.

Radiographic assessment of various parameters was conducted by a fellowship-trained, orthopedic spine surgeon. Such radiographic assessment was blindly conducted to the patients' demographics, clinical history, and symptomatic status. Congenitally fused vertebral segments (C1–T1) were noted by the presence of bone bridging across the interbody space or posterior elements and corroborated by the absence of motion on flexion, extension, and neutral radiographs. The presence of occipitalization (fusion of the atlas to the basion) was also noted and confirmed with dynamic radiographs. Radiographic fusion patterns were further stratified based upon classification-type. Classification patterns entailed Types I–III and were defined as follows: Type I was noted as the presence of a single fused block; Type II was noted as fusion of multiple, non-contiguously fused segments; and Type III was noted as multiple, contiguously fused segments [20, 45].

Radiographic assessment of SOM was assessed on lateral neutral radiographs via McGregor's line, which is noted as the line from the posterosuperior aspect of the hard palate to the caudal aspect of the opisthion (Fig. 1) [31]. SOM based on McGregor's line was assessed as the number of millimeters (mm) that the apex of the odontoid was noted above the line. Furthermore, the degree of SOM was further stratified into patients who exhibited greater (Group I) or less (Group II) than 4.5 mm. Such a criteria was selected based on previous reports that SOM associated with neural compression is noted with a 4.5 mm or greater odontoid tip migration past McGregor's line [31]. Furthermore, the anterior and posterior atlantodens intervals (AADI/PADI) were assessed on lateral neutral radiographs [49]. The AADI was defined as the distance in millimeters from the posterior margin of the anterior arch of C1 to the anterior border of the odontoid, whereas the PADI was noted as the distance in millimeters from the posterior border of the odontoid to the anterior aspect of the posterior arch of C1. The difference between lateral flexion and extension AADI and PADI values was also assessed. The lateral cervical alignment was assessed on neutral radiographs and was noted as the resultant angle of the lines intersecting the anterior tubercle to the posterior arch of C1 and the inferior vertebral endplate of C7. On anteroposterior radiographs, the coronal cervical curvature was assessed as the resultant angle intersecting the line from C1 to the line at the inferior vertebral border of C7. To account for the affects of coronal cervical malalignment upon the number of fused segments with relation to a SOM greater or less than 4.5 mm, patients were noted as scoliotic if their cervical curvature was equal or greater than 10°. To remain consistent with the radiographic measurements, the same measurement device was utilized in all assessments.

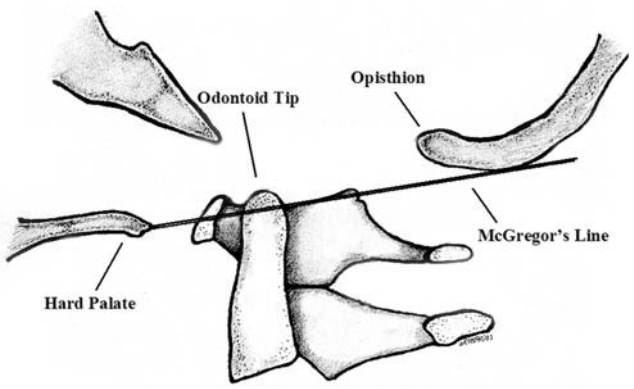

Fig. 1 Illustration of the assessment of superior odontoid migration based on McGregor's line

Clinical chart review was conducted by an independent observer, blinded to the radiographic assessment of each patient. The clinical chart review entailed assessment of patient demographics, clinical history, and current clinical status. The presence of cervical spine-related symptoms was correlated at the same interval of the radiographic assessment. Symptoms were noted, but particular attention was paid to the presence of headache, dizziness, visual disturbances, loss of equilibrium, tinnitus, dysphagia, nystagmus, irregular respirations, lower cranial nerve dysfunction, bowel and bladder dysfunction, and radiculopathy and/or myelopathy.

All the data was collected and entered onto a spreadsheet. Statistical analyses were conducted via SPSS vr. 14.0, Intercooled STATA vr. 8.2, and EpiSheet (November 2005) software. Descriptive and frequency analyses were conducted on all the data sets. The presence of normal distribution was evaluated to determine the appropriate statistical test. For normally distributed data, independent sampled *t*-tests and ANOVA were considered for single or multiple independent samples. Conversely, for such samples that were non-parametric, Mann–Whitney *U*- and Kruskal–Wallis *H*-tests were conducted. A Jonckheere–Terpstra test for several independent samples that were ordinally arranged was considered for non-parametric data. Pearson's or Spearman's correlation coefficient testing of continuous data was conducted, which was dependent on the presence of normality. Pearson's and Fisher's exact Chi-square tests were considered for various categorical data sets. Linear standard and backward stepwise regression analyses were performed based on various exploratory variables. Risk differences

(RD), relative risk (RR) ratios, and 95% confidence intervals (CIs) were also performed to evaluate risk estimates associated with various dichotomous parameters. Stratification was performed to evaluate the potential effects of confounding upon strata regarding variables of interest. Mantel–Haenszel RR adjusted analyses were conducted to obtain pooled risk estimates based on stratum-specific potential confounds. Statistical significance was established at $P < 0.05$.

Results

The study was composed of 8 males (29.6%) and 19 females (70.4%) with an overall mean age of 13.5 years (range = 2.7–26.3 years; SD = ±5.6 years) at the time of radiographic and clinical assessments. The mean age for males was 11.4 years (range = 4.8–18.3 years; SD = ±5.2 years), whereas the mean age for females was 14.4 years (range = 2.7–26.3 years; SD = ±5.7 years). Only five patients (18.5%; one male and four females) were older than 18 years of age. No statistically significant difference was noted between the ages of males and females ($P = 0.205$).

Assessment of radiographic fusion patterns noted that a mean of 3.5 vertebral segments demonstrated fusion. The most commonly fused vertebral segments were C2–C3 (74.1%) and C6–C7 (70.4%). Occipitalization occurred in 29.6% of the patients. Patients with and without occipitalization had a mean number of 3.4 and 3.6, respectively, of fused segments. A statistically significant difference was not noted between the presence of occipitalization and the number of fused segments ($P = 0.790$). A statistically significant difference was not noted between sex-type and the number of fused vertebral segments, including ($P = 0.345$) and excluding ($P = 0.767$) the presence of occipitalization.

A mean overall SOM of 5.0 mm (range = –1.0 to 19.0 mm; SD = ±5.7 mm) was noted. Additional radiographic parameters assessed are illustrated in Table 1. A greater amount of SOM was found in patients with occipitalization (mean = 6.3 mm; range = –1.0 to 19.9 mm; SD = ±7.3 mm) than patients without occipitalization (mean = 4.5 mm; range = –1.0 to 18.0 mm; SD = ±5.0 mm). However, no statistical significance was noted between the presence of occipitalization and the amount of SOM ($P = 0.709$). As the number of fused segments without occipitalization increased, a greater amount of SOM was noted ($r = 0.589$; $P = 0.001$). However, a greater correlation was present when the number of fused segments included the presence of occipitalization ($r = 0.616$; $P = 0.001$). Further testing for ordered differences between classes confirmed the statistically significant difference between the number of fused segments with occipitalization to the amount of SOM ($P = 0.001$). A statistically significant correlation was noted between amount of SOM and coronal cervical alignment ($r = 0.413$; $P = 0.036$). No statistically significant difference was found between SOM with regards to age, AADI and PADI intervals, and lateral cervical alignment ($P > 0.05$). Linear regression modeling further supported the findings indicating that increases in the number of fused segments with occipitalization followed by coronal cervical alignment are the greatest predictive variables associated with SOM.

Table 1 Descriptive statistical analyses of various radiographic parameters of the cervical spine in Klippel–Feil patients

Radiographic parameter	Mean (±SD)	Range
SOM (mm)	5.0 (5.7)	–1 to 19
AADI neutral (mm)	1.7 (0.7)	1–3
AADI flexion (mm)	2.5 (1.2)	1–6
AADI extension (mm)	1.1 (0.7)	0–2
Difference in AADI (mm)	1.4 (1.1)	0–4
PADI neutral (mm)	20.0 (4.4)	13–29
PADI flexion (mm)	19.4 (4.6)	11–28
PADI extension (mm)	20.1 (4.3)	13–30
Difference in PADI (mm)	–0.7 (1.6)	–3 to 2
Lateral cervical alignment (deg)	39.9 (16.0)	14–64
Coronal cervical alignment (deg)	18.9 (20.0)	0–67

SD standard deviation

Based on classification-type, 5 patients (18.5%) were Type I, 13 patients (48.1%) were Type II, and 9 patients (33.3%) were Type III. The mean degree of SOM stratified to classification-type was 1.2 mm (range = –1.0 to 5.0 mm; SD = ±2.3 mm), 5.8 mm (range = 0.0–19.0 mm; SD = ±5.9 mm), and 6.0 mm (range = –1.0 to 18.0 mm; SD = ±6.3 mm) for Types I, II, and III, respectively. Although Type III patients tended to exhibit a greater amount of SOM, no statistically significant difference was noted between the amount of SOM and classification-type ($P = 0.145$).

The amount of SOM was further stratified into two groups which were distinguished as having SOM greater (Group 1) or less (Group 2) than 4.5 mm with regards to the number of fused segments and the degree of coronal cervical alignment (Table 2). Ten patients (37%) were noted in Group I, whereas 17 patients (63.0%) were noted in Group II. A statistically significant difference was noted between the groups and the degree of SOM ($P = 0.001$). Furthermore, a statistically significant difference was noted between the amount of SOM greater or less than 4.5 mm to the number of fused segments, with ($P = 0.007$) or without ($P = 0.008$) the presence of occipitalization. However, a statistically significant

Table 2 Distribution of SOM greater or less than 4.5 mm in Klippel–Feil patients stratified to the number of fused cervical segments, with or without the presence of occipitalization (O-C1), and the degree of coronal cervical alignment

SOM > 4.5 mm		Number of fused cervical segments (excluding O-C1)	Number of fused cervical segments (including O-C1)	Coronal cervical alignment angle (°)
YES (Group I)	Mean (±SD)	4.7 (1.6)	5.0 (1.6)	30.0 (22.7)
	Range	1–7	1–7	0–67
NO (Group II)	Mean (±SD)	2.8 (1.5)	3.1 (1.5)	13.0 (16.1)
	Range	1–5	1–6	0–47
Overall	Mean (±SD)	3.5 (1.8)	3.8 (1.8)	18.9 (20.0)
	Range	1–7	1–7	0–67

SD standard deviation

difference was not found between the amount of SOM greater or less than 4.5 mm to the degree of coronal cervical alignment ($P = 0.069$). RR analyses of three patterns of fused vertebral segments to the exposure of SOM greater than 4.5 mm were conducted (Table 3). RR analyses indicated a risk estimate of 7.20 (95% CI = 1.05–49.18; RD = 0.52), indicating that four or more fused segments in KFS patients is associated with the greatest probability of SOM greater than 4.5 mm (Table 3). Patients who were considered scoliotic exhibited a mean cervical alignment of 33.8° (range = 11–67°; SD = ±15.6°), whereas patients who were not characterized as scoliotic had a mean cervical alignment of 1.5° (range = 0–9°; SD = ±2.9°). As such, adjusted RR analyses were performed accounting for the presence of cervical scoliosis in the context of a SOM greater than 4.5 mm to the number of fused cervical segments (Table 3). In addition, RR analyses indicated that a risk estimate of 1.68 (95% CI = 0.45–6.25; RD = 0.17) was associated with females in comparison to males in relation to a SOM greater than 4.5 mm.

Clinical review for the presence of symptoms noted that eight patients (29.6%) with a mean age of 15.6 (range = 4.8–26.3 years; SD = ±6.9 years) were symptomatic. Non-symptomatic patients had a mean age of 12.6 years (range = 2.7–20.9 years; SD = ±4.9 years). Mean SOM of the symptomatic patients was 3.3 mm (range = –1.0 to 11.0 mm; SD = ±4.5 mm), whereas non-symptomatic patients were found to have a mean SOM of 5.8 mm (range = 0–19.0 mm; SD = ±6.1 mm). Two patients (33%) developed symptoms following a traumatic episode, resulting in one patient being myelopathic (age = 16.8 years; SOM = 2.0 mm) and the other quadriplegic (age = 15.2 years; SOM = –1.0 mm). Other patients in this review exhibited a Chiari malformation with vision problems, deafness, and headaches, whereas the remaining patients exhibited neck pain, headaches, radiculopathy, and myelopathy. Controlling for the event of trauma, mean SOM for symptomatic and non-symptomatic patients was 4.2 mm (mean age = 15.5 years) and 5.8 mm (mean age = 12.6 years), respectively. In this series, no statistically significant difference was noted between the presence of symptoms and SOM, with or without accounting for the event of trauma ($P > 0.05$). In addition, no statistically significant difference was noted between the presence of symptoms to age, sex, occipitalization, and the number of fused segments ($P > 0.05$).

Table 3 Relative risk analyses of the number of fused cervical segments to the presence of SOM greater than 4.5 mm

	SOM > 4.5 mm; crude RR ratio (95% CI)	SOM > 4.5 mm; adjusted RR[a] ratio (95% CI)
Fused segments including O-C1		
3 or >	3.15 (0.48–20.61); RD = 0.31	2.07 (0.15–28.04); RD = 0.14
4 or >	7.20 (1.05–49.18); RD = 0.52	7.80 (0.65–93.81); RD = 0.45
5 or >	5.00 (1.30–19.30); RD = 0.53	4.54 (1.07–19.50); RD = 0.48
Fused segments excluding O-C1		
3 or >	4.50 (0.67–30.23); RD = 0.39	3.96 (0.26–60.31); RD = 0.27
4 or >	7.20 (1.05–49.18); RD = 0.52	7.80 (0.65–93.81); RD = 0.45
5 or >	3.00 (1.13–8.00); RD = 0.44	2.59 (1.03–6.52); RD = 0.39

O-C1 occipitalization, > indicates greater, *CI* confidence interval, *RD* relative difference

[a] Adjusted RR analyses accounts for the potentially confounding variable of cervical scoliosis noted as a cervical curvature equal or greater than 10° with respect to the number of fused segments and a SOM greater than 4.5 mm

Discussion

In 1912, Maurice Klippel and Andre Feil examined a 46-year-old male tailor at the Hospital Tenon who ''appeared to have no neck'' and whose ''head seemed to rest on his trunk'' [28]. Following radiographic evaluation of this patient, he was noted as having all cervical vertebral segments congenitally fused. According to Klippel and Feil, the patient subsequently died approximately 1 month following initial examination of ''pulmonary congestion complicated by pleurisy, albumin in the urine and a large heart with rapid beats (bruit de galop)'' [28]. In 1919, Feil [15] further elaborated on similar vertebral manifestations in additional patients. Thus, a condition entailing improper segmentation or congenital fusion of at least two or more cervical vertebrae has become synonymous with KFS. However, such congenital fusion that could lead to aesthetic manifestations as the appearance of no neck or the head resting on the trunk, as Klippel and Feil noted in their seminal paper, have brought considerable attention to the integrity of the craniovertebral junction and the risk to neural elements of the high cervical spinal cord and the brainstem. More specifically, the risk and effects of SOM have been of great concern in KFS patients; however, to the authors' knowledge, previous studies have not evaluated in a quantitative manner the risk factors that are at play, as in the case of this study, that contribute to such an undesirable manifestation in KFS patients.

Superior odontoid migration has been noted in various disease processes [1, 10. 13. 17, 18, 30, 34, 35, 42, 47, 52]. Excessive SOM could affect vascular flow, cerebral spinal fluid dynamics, neurological integrity, and could potentially lead to death [11, 12, 30, 39, 50]. Although various plain radiographic diagnostic methods have been proposed in assessing SOM [6, 7, 16, 31, 33, 40, 41, 55], McGregor's line has been noted to be a sensitive and reliable marker for evaluating SOM [31, 42]. Although Redlund-Johnell criteria, the Clark station, and the Ranawat criteria have also been advocated in the evaluation of SOM [27, 42], such measurements are primarily employed in the rheumatoid patient and may not be appropriate in the assessment of KFS patients. Furthermore, the congenitally fused segments can make identification of the bony landmarks of the upper cervical vertebrae difficult and, at times, impossible. This is particularly true in our study where the most commonly fused segment was C2–C3 (74.1%). Since other studies have also confirmed that the majority of fused vertebrae in KFS entail the C2–C3 segment [3, 4, 19], implementation of such diagnostic measurements would most likely diminish their sensitivity and reliability capabilities.

In our study, McGregor's line was used to evaluate the relation of the odontoid tip to the foramen magnum based upon plain radiographs. In our series, a mean of 5.0 mm of SOM was noted and ranged from –1.0 to 19.0 mm. Traditionally, a SOM greater than 4.5 mm was associated with symptomatic neural compression [31]; however, values have been based primarily on the rheumatoid patient [27, 31, 42]. In our study, 37% of the KFS patients exhibited a SOM of 4.5 mm or greater. Based on these findings, such an amount of SOM is alarming; however, interestingly no statistical association was found between the amount of SOM and the presence of symptoms at the time of evaluation. However, various fused patterns were evaluated with regards to contributing to the risk of SOM greater than 4.5 mm. As a result, our study noted that the highest RR contributing to such a SOM was highly associated if four or more fused segments were present.

Our series was mainly comprised of pediatric and adolescent individuals, and may play a role in regards to SOM and the absence of symptoms, which may be attributed to the laxity of ligamentous structures or to the resiliency or tolerance of the central nervous system to neural compression, which may prove otherwise in older age. Although a statistically significantly greater amount of SOM was not noted in the symptomatic patients when compared to non-symptomatic patients, an increase trend in age was found in symptomatic patients. Non-symptomatic patients have also been reported in other conditions where neural compression was noted with SOM [35, 47]. Furthermore, various central nervous system anomalies, primarily reported to entail the medulla and spinal cord, have been associated with KFS, suggesting that an underlying neurologic interplay from a morphological and functional perspective may exist preventing or delaying symptoms associated with resultant neural compression from excessive SOM [3, 9, 14, 21, 51].

Like several previous reports, our study was comprised of mainly females (70.4%) [19, 20, 23, 38, 53]. Evaluating the role of sex-type in association with a historically established marker of 4.5 mm or greater considered as symptomatic SOM, our study had noted that females were associated with a 1.68 greater probability than males in developing such a SOM; however, this may be attributed to the higher incidence of the condition with relation to sex-type in the sample or population. Nonetheless, this association between sex-type was found to be non-significant in our series.

The role of occipitalization or specific fused vertebral segments upon the degree of SOM is currently unknown. In our study, occipitalization occurred in 29.6% of the patients. Shen et al. [49] had noted that the presence of occipitalization may increase the degree of motion at the atlantoaxial junction. Although a greater amount of SOM was noted in this study with the presence of occipitalization, the findings were not statistically significant. The presence of occipitalization coupled with the amount of fused segments yielded the strongest predictive variable in relation to the increase in SOM, suggesting that as the number of fused segments increases, so does the amount of SOM.

Various studies have noted that the AADI and PADI may contribute to neurologic compromise in patients [5, 24, 29, 32]. With respect to the more commonly noted rheumatoid arthritis patient, a decrease in AADI was associated with an increase in SOM [5]. Due to the fusion process associated with KFS, excessive motion may affect the atlantoaxial junction in patients, thereby potentially negatively affecting SOM. Although Shen et al. [49] noted that an increase in motion is noted with various fused cervical patterns with regards to AADI and PADI in KFS patients, such motion is not synonymous with the development of symptoms. With respect to our study, no statistically significant association was noted between the variables of AADI and PADI to the amount of SOM.

Since the presence of congenital scoliosis has been noted to occur in up to 78% of patients with KFS [25, 38, 53], this study attempted to evaluate the role of the coronal and lateral cervical alignment and its relationship to the amount of SOM. Although the study did not note a statistically significant association between lateral cervical alignment and the amount of SOM, a statistically significant correlation was noted between the increase in coronal cervical alignment and the increase in SOM. Overall, a mean coronal cervical alignment of 18.9° with a range of 0–67° was noted in our series. Furthermore, accounting for cervical scoliosis characterized as a coronal cervical alignment of equal or greater than 10°, the adjusted RR associated with a SOM greater than 4.5 mm were significantly greatest in the event five or more fused segments were present.

Various classification systems have attempted to elaborate upon the epidemiology and risk of neurologic injury in the KFS patient [8, 15, 20, 22, 37, 38, 45]. In our study, the authors utilized a classification system specific to the cervical spine as proposed by Guille et al. [20] and Samartzis et al. [45] in the adult and developing child, respectively. Our study noted that patients with multiple, contiguously fused segments were associated with the greatest amount of SOM; however, a statistically significant difference between classification-types was not noted. Nonetheless, such an observation further contributes to the notion that as fused segments increase, natural cervical biomechanics and motion are altered; thereby, displacing motion, which could result in an upward migration or orientation of the cervical spine.

Previous studies have noted that magnetic resonance imaging (MRI) is preferred rather than plain radiographs in the diagnosis of SOM because of its ability to identify the odontoid tip and various anatomical landmarks [13, 17, 42]. Conversely, advocacy of MRI in evaluating the extent of SOM or true nature of basilar invagination may indeed have basis in such conditions as rheumatoid arthritis or metabolic bone diseases where multiple subluxations, erosions, or generalized osteopenic manifestations are present that could prevent proper identification of anatomical landmarks [27, 41, 42]. Our study noted that evaluation of SOM with McGregor's line was not possible in 10% of the patients due to the inability to identify anatomical landmarks. In contrast, Kawaida et al. [27] had noted that evaluation of SOM in rheumatoid arthritis patients via plain radiography was not possible in 18% of their cases with the use of McGregor's line. However, to decrease bias in the current study, two observers conducted either the radiographic or the clinical assessment independent from each other. Furthermore, utilization of plain radiography to assess SOM in KFS patients is an inexpensive screening tool that could facilitate evaluation of specific anatomical landmarks, which are otherwise, to a larger extent, obscured in other conditions associated with SOM.

Superior odontoid migration has been interchanged in the past with such terms as an upward/vertical translocation of the odontoid, cranial settling, and pseudo-basilar invagination. Although the term ''migration'' may have some applicability in certain disease processes noting SOM, in the case of KFS this term could be a misnomer. KFS is a well-known developmental disorder whose positioning of the odontoid could stem from several factors. For example, it has been postulated that the fusion process in KFS patients is not fully present at birth and could be ongoing until skeletal maturity [10, 54]. In that sense, migration or translocation of the odontoid could develop from physical strain applied upon the craniovertebral junction due to a lack of motion in the cervical region where fused segments are pronounced and where cervical alignment is compensated; thus, more or less a function of time could be involved

coupled with the deformity byproducts of the condition that contribute to the spatial orientation of the odontoid. Conversely, it is also fully plausible that the odontoid orientation could stem from a predetermined morphological orientation associated with this congenital condition.

Although the authors contend that this study sheds some light in the understanding of SOM and associated risk factors in the KFS patient, further studies need to be addressed to either validate or expand on the findings of such objectives and to determine the true nature of superior odontoid ''migration'' and the presence of associated symptoms. Understandably, KFS is an uncommon condition, which poses a challenge to address larger prospective studies. However, advanced imaging modalities could best verify the presence and extent of neural compression stemming from SOM. In addition, the authors recommend that such parameters as outlined in the current study should be assessed in the adult KFS population to determine the role, if any, of age-specific factors related to SOM.

Conclusions

Klippel–Feil syndrome is an uncommon, congenital condition presenting with a constellation of manifestations that are typically heterogeneous between patients. Nonetheless, accounting for such spinal variations in a quantitative manner in an effort to expound upon associated manifestations in KFS is essential. This study does seem to suggest that, based on plain radiographic assessment, as the number of fused segments increase or coronal cervical alignment is altered in the KFS patient, an absence or decrease in motion may exist that could potentially direct the spine to migrate upward/vertically or be associated with a more superiorly spatially oriented odontoid, which could increase the risk of resultant neural compression. However, based on this series of predominantly pediatric and adolescent patients, extensive SOM is not always synonymous with the manifestation of symptoms. This could be attributed to a delay in the response of symptoms stemming from an underlying neural mechanism inherent to the age group or the syndrome itself. Furthermore, additional cervical spine manifestations inherent to the condition over time may be at play that could contribute to the development of symptoms. Nonetheless, four or more fused segments and, to a lesser degree, the female sex are suggestive factors associated with a high-risk estimate of contributing to a historical SOM marker of 4.5 or greater in KFS patients; however, such a marker in KFS patients may not be synonymous with symptoms. In addition, following screening with plain radiography, advanced imaging modalities are advocated to verify the presence and extent of neural compromise associated with SOM.

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