Interrater Reliability and Age-Based Normative Values for Radiographic Indices of the Ankle Syndesmosis in Children

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Background: While recent research has investigated the normative values, discriminative capacity, and interrater reliability of radiographic indices for the evaluation of the syndesmosis in adults, no such data exist for children. The purposes of the present study were (1) to determine the interrater reliability of common radiographic measures of syndesmosis and deltoid ligament competency in children and (2) to establish age-based normative values.

Methods: A consecutive series of patient radiographs from a Level-I pediatric trauma center were identified and were used to create an age and sex-balanced cohort of 282 patients. Subjects between 2 and 17 years of age were randomly selected from a pool of patients who had a complete 3-view (anteroposterior, lateral, and mortise) radiographic ankle series and a final diagnosis without osseous or ligamentous injury. Eight age and sex-balanced groups were created for analysis. Three independent raters evaluated all radiographs and recorded radiographic indices that are commonly used for the evaluation of ankle trauma: width of medial clear space, width of superior clear space, tibiofibular clear space, tibiofibular overlap, and medial clear space/superior clear space ratio. Interrater reliability was calculated with use of the intraclass correlation coefficient (ICC); means and standard deviations were used to report age-group normative values.

Results: Two hundred and eighty-two patients (mean age [and standard deviation], 9.6 ± 4.6 years) were analyzed. The superior clear space and tibiofibular overlap demonstrated excellent interrater reliability (ICC = 0.915 and 0.964, respectively), the medial clear space and tibiofibular clear space demonstrated substantial agreement (ICC = 0.656 and 0.635, respectively), and the medial clear space/superior clear space ratio demonstrated moderate agreement (ICC = 0.418). The medial clear space could not be reliably measured until the age of 8 years because of insufficient ossification of the medial malleolus. Tibiofibular overlap demonstrated a linear increase over time, ranging from −1.4 mm in 2 and 3-year-old patients to 6.7 mm in 16 and 17-year-old patients (R² = 0.995). Normative values varied by age and sex.

Conclusions: The medial clear space and medial clear space/superior clear space ratio could not be reliably assessed for children under 8 years of age and were thus characterized by suboptimal interrater reliability. Tibiofibular overlap had excellent interrater agreement, changed predictably with skeletal growth, and may be useful for future research as well as the clinical assessment of pediatric ankle injuries to guide clinical decision-making.

Level of Evidence: Diagnostic Level III. See Instructions for Authors for a complete description of levels of evidence.

Peer Review: This article was reviewed by one of the Co-Editors, and it underwent blinded review by two or more outside experts. The Co-Editor reviewed each revision of the article and performed a final review prior to publication. Final corrections and clarifications occurred during one or more exchanges between the author(s) and copyeditors.

A nkle sprains are among the most common conditions treated by orthopaedic surgeons, comprising as many as 30% of sport-related injuries and 3% to 5% of all emergency room visits5,9. Children and adolescents are at higher risk for sustaining an ankle sprain compared with adults4. Higher-energy ankle syndesmosis injuries are particularly morbid and can be a cause of persistent disability in young patients5. However, the radiographic diagnosis of syndrometic disruptions

Disclosure: The authors indicated that no external funding was received for any aspect of this work. The Disclosure of Potential Conflicts of Interest forms are provided with the online version of the article.
in pediatric populations is challenging. Although the existing literature has described several imaging characteristics that can be used to delineate these injuries in adults, to our knowledge no such data exist for children. Traditionally, increased tibiofibular clear space, decreased tibiofibular overlap, and enlarged medial clear space have been used as discriminatory radiographic parameters for adults. However, Bozic et al. questioned the utility of tibiofibular overlap and tibiofibular clear space for the assessment of pediatric ankle injuries. In addition, although Schottel et al. described the normal values for the medial clear space and medial clear space/superior clear space ratio, we are not aware of any study that has characterized these measurements for children. Because of age-related ossification changes during skeletal growth, indices that have been validated through osseous measurements of the tibia, fibula, and talus in adults may not be applicable to children.

Understanding normative values of commonly used ankle indices in children and adolescents would help to guide treatment as well as the intraoperative evaluation of surgical reduction. The purposes of the present study were (1) to determine the interrater reliability of common radiographic measures of syndesmosis and deltoid ligament competency in children and (2) to establish age-based normative values.

**Materials and Methods**

The present study was approved by the institutional review board at our institution and was conducted in full accordance with all applicable federal and state regulations. A pool of potential subjects was created by means of a review of imaging and clinical data obtained at a single urban Level-I pediatric trauma center. The inclusion criteria consisted of (1) a complete 3-view (anteroposterior, lateral, and mortise) radiographic series with adequate resolution and full visualization of the ankle joint and (2) the absence of osseous or ligamentous injury in the final diagnosis. A review of clinical charts and advanced imaging studies was conducted to ensure the creation of a repository of ankle radiographs for patients without substantial osseous or ligamentous injury. With use of an electronic radiographic database, patients were screened in reverse chronological order and 8 age and sex-balanced groups of patients between 2 and 17 years old were created (in 2-year increments). Skeletal maturity was evaluated by characterizing patients as having open physes, closing physes, or closed physes.

Three independent observers, including a pediatric musculoskeletal radiologist, an attending pediatric orthopaedic surgeon, and an orthopaedic research associate trained in assessing radiographic indices, evaluated all radiographs and recorded the following measurements as previously described (Fig. 1): the width of the medial clear space, the width of the superior clear space, the tibiofibular clear space (the distance from the incisura to the medial aspect of the fibula 1 cm proximal to the tibial plafond), and the tibiofibular overlap 1 cm proximal to the level of the tibial plafond (recorded as a negative value if no overlap was present). Medial clear space/superior clear space ratios were subsequently calculated. Measurements were made with use of computerized digital software (iSite Enterprise software; Philips), which measures to a precision of 0.1 mm. Each radiograph was subsequently examined for ossification of the medial malleolus. The proportion of patients with a medial malleolus that was sufficiently developed to measure the medial clear space was calculated for each age and sex grouping.

The intraclass correlation coefficient (ICC), representing a 2-way analysis of random effects and based on absolute agreement (ICC[2,1]), was calculated for each measurement and was classified with use of the criteria described by Landis and Koch. Means and standard deviations were used to report normative measurement values by age group. Linear regression analysis was used to investigate for changes in normative values over time after visual inspection of scatterplots for apparent linearity.

**Results**

A total of 282 patients with a mean age (and standard deviation) of 9.6 ± 4.6 years were included in the final...
The proportion of patients in each group who presented with a medial malleolus that was sufficiently ossified to assess the medial clear space is depicted in Figure 3. No patient had a sufficiently developed medial malleolus before the age of 6 years, and the medial clear space could be measured in all children who were at least 12 years of age. For groups of patients between 6 and <12 years of age, there tended to be a greater proportion of females than males who presented with a developed medial malleolus.

**Discussion**

Radiographic evaluation is an essential component in the diagnosis and subsequent treatment of pediatric ankle injuries. Detecting syndesmosis and/or deltoid ligament injury on radiographs is vital when caring for children with ankle injuries. Furthermore, intraoperative evaluation of syndesmotic and tibiotalar reduction requires an understanding of measurement reliability and normative values by age and sex. Although several recent reports have described the normative values of the relevant indices for adults, to our knowledge these data do not currently exist for the pediatric and adolescent population. While investigations in the adult literature have suggested the potential utility of the medial clear space and medial clear space/superior clear space ratio, our data demonstrate that insufficient ossification of the medial malleolus limits their value in the evaluation of children. In contrast, we found that tibiofibular overlap changed predictably in a linear fashion through skeletal development and was characterized by excellent interrater reliability.

Increasingly sophisticated advancements in noninvasive diagnostic imaging techniques are allowing for better characterization of the ankle syndesmosis in adults. Nault et al. described and evaluated several syndesmotic measurements on axial computed tomography (CT) scans and noted their potential utility for achieving reduction of the syndesmosis. However, although axial imaging may be easily performed in the outpatient setting, it is not always readily available intraoperatively, and the utility of such scans for the evaluation of pediatric patients is unknown because of the variable ossification of the distal tibia and fibula in children. To date, there is a paucity of evidence evaluating syndesmosis indices in children. Nault et al., in a study of pediatric patients, provided what we believe to be the first description of changes in the pediatric syndesmosis based on magnetic resonance imaging (MRI) of the ankle joint. Once again, although this method provides excellent utility for evaluation in the outpatient setting, it does not address our lack of understanding of radiographic changes over the course of skeletal development or address the need for normative radiographic indices for intraoperative and clinical use. In addition, the favorable cost-effectiveness and routine initial use of radiography as compared with MRI are advantages that increase the appeal of employing radiographic indices for the assessment of pediatric syndesmosis injury and reduction.

**TABLE I Demographic Characteristics (N = 282)**

| Age* (yr) | 9.6 ± 4.6 |
| Male:female ratio† | 142:140 |
| Age group‡ | |
| 2 to 3 yr | 33 (11.7%) |
| 4 to 5 yr | 34 (12.1%) |
| 6 to 7 yr | 36 (12.8%) |
| 8 to 9 yr | 35 (12.4%) |
| 10 to 11 yr | 36 (12.8%) |
| 12 to 13 yr | 36 (12.8%) |
| 14 to 15 yr | 36 (12.8%) |
| 16 to 17 yr | 36 (12.8%) |
| Skeletal maturity† | |
| Open physes | 197 (69.9%) |
| Closing physes | 25 (8.9%) |
| Closed physes | 60 (21.3%) |

*The values are given as the mean and the standard deviation. †The values are given as the number of patients.

Analyses of these, 197 (69.9%) presented with open physes, 25 (8.9%) had closing physes, and 60 (21.3%) had closed physes. Clinical and demographic characteristics are presented in Table I.

The ICC values for each of the 5 indices are presented in Table II. The superior clear space and tibiofibular overlap had excellent interrater reliability (ICC = 0.915 and 0.964, respectively), the medial clear space and tibiofibular clear space had substantial agreement (ICC = 0.656 and 0.635, respectively), and the medial clear space/superior clear space ratio had moderate agreement (ICC = 0.418). The medial clear space could not be reliably measured until the age of 8 years because of insufficient ossification of the medial malleolus. Tibiofibular overlap demonstrated a linear increase over time, ranging from −1.4 mm in 2 and 3-year-old patients to 6.7 mm in 16 and 17-year-old patients (R² = 0.995; Table III). Figure 2 displays the normative values for the study cohort over the range of ages studied (2 to 17 years).

**TABLE II Interrater Reliability for Select Measurements**

| Measurement* | ICC(2,1) | 95% Confidence Interval |
| MCSI† | 0.656 | 0.589 to 0.717 |
| SCS | 0.915 | 0.890 to 0.934 |
| MCSI/SCS‡ | 0.418 | 0.327 to 0.508 |
| Tibiofibular clear space | 0.635 | 0.566 to 0.696 |
| Tibiofibular overlap | 0.964 | 0.956 to 0.971 |

*MCS = medial clear space, and SCS = superior clear space. †One hundred and ninety-eight patients with complete data were included after list-wise deletion of patients in whom the MCS was immeasurable because of preossification or partial ossification of the medial malleolus in younger age groups. §The values pertain to subjects who were 8 to 17 years old because of inadequate ossification of the medial malleolus in younger age groups.

Increasingly sophisticated advancements in noninvasive diagnostic imaging techniques are allowing for better characterization of the ankle syndesmosis in adults. Nault et al. described and evaluated several syndesmotic measurements on axial computed tomography (CT) scans and noted their potential utility for achieving reduction of the syndesmosis. However, although axial imaging may be easily performed in the outpatient setting, it is not always readily available intraoperatively, and the utility of such scans for the evaluation of pediatric patients is unknown because of the variable ossification of the distal parts of the tibia and fibula in children. To date, there is a paucity of evidence evaluating syndesmosis indices in children. Nault et al., in a study of pediatric patients, provided what we believe to be the first description of changes in the pediatric syndesmosis based on magnetic resonance imaging (MRI) of the ankle joint. Once again, although this method provides excellent utility for evaluation in the outpatient setting, it does not address our lack of understanding of radiographic changes over the course of skeletal development or address the need for normative radiographic indices for intraoperative and clinical use. In addition, the favorable cost-effectiveness and routine initial use of radiography as compared with MRI are advantages that increase the appeal of employing radiographic indices for the assessment of pediatric syndesmosis injury and reduction.
The temporal relationship between ossification of the medial malleolus and pediatric development has been investigated previously. LaMont et al. described the development of secondary ossification centers as part of the changes in the ossification of the medial malleolus, reporting that they were first visible on radiographs between 6 and 9 years of age, with earlier visualization in females. Our findings confirm those of previous studies, indicating nearly complete development of the medial malleolus by the age of 10 to 12 years, with a greater proportion of females between the ages of 6 and 10 having developed medial malleoli.

Interestingly, several of the metrics described in the adult literature were not found to be useful in this series of pediatric patients. Schottel et al. reported that the medial clear space and the medial clear space/superior clear space ratio had potential utility for the assessment of adult ankle injuries. Those authors demonstrated that a threshold value of 5.0 mm for the medial clear space on stress radiographs of the ankle optimized the sensitivity for the detection of a deep deltoid ligament injury. In the current study, however, the medial clear space and the medial clear space/superior clear space ratio could not be measured in any subject before the age of 6 years; in several subjects, they could not be measured until after the age of 10 years. In addition, the interrater reliability of these measurements was suboptimal (ICC = 0.656 and 0.418, respectively), likely because of poorly demarcated ossification fronts.

The interrater reliability of the tibiofibular clear space was substantially poorer (ICC = 0.635) than that for tibiofibular overlap (ICC = 0.964). Because tibiofibular overlap had excellent interrater agreement and changed predictably in a linear fashion with growth, it may be of greater utility than other indices for the clinical assessment of pediatric ankle injuries.

Our findings must be interpreted in the context of the limitations of the study design. First, given the retrospective methodology, the present study is at inherent risk for selection bias. We attempted to mitigate this limitation by obtaining a

| Age Group | Sex   | MCS (mm) | SCS (mm) | MCS/SCS | Tibiofibular Clear Space (mm) | Tibiofibular Overlap (mm) |
|-----------|-------|----------|----------|---------|------------------------------|--------------------------|
| 2 to 3 yr | Male  | NA       | 5.3 ± 0.6| NA      | 4.5 ± 1.1                    | −1.5 ± 1.7               |
|           | Female| NA       | 4.2 ± 0.8| NA      | 4.3 ± 1.2                    | −1.3 ± 1.8               |
| 4 to 5 yr | Male  | 4.1 ± 0.4†| 4.0 ± 0.5| 1.1 ± 0.1†| 4.1 ± 1.3                   | 0.8 ± 2.0                |
|           | Female| 3.6 ± 0.6‡| 3.6 ± 0.4| 1.0 ± 0.1‡| 4.0 ± 1.2                   | 1.3 ± 2.2                |
| 6 to 7 yr | Male  | 3.8 ± 0.6§| 3.7 ± 0.3| 1.0 ± 0.1§| 4.4 ± 1.1                   | 1.7 ± 2.2                |
|           | Female| 3.4 ± 0.6| 3.3 ± 0.4| 1.0 ± 0.1| 4.4 ± 1.9                   | 1.5 ± 1.9                |
| 8 to 9 yr | Male  | 3.7 ± 0.6| 3.5 ± 0.4| 1.1 ± 0.1| 4.2 ± 1.1                   | 3.4 ± 1.4                |
|           | Female| 3.4 ± 0.5| 3.2 ± 0.3| 1.1 ± 0.1| 4.2 ± 1.0                   | 3.1 ± 1.4                |
| 10 to 11 yr | Male  | 3.6 ± 0.7| 3.3 ± 0.4| 1.1 ± 0.2| 4.3 ± 1.4                   | 4.5 ± 1.3                |
|           | Female| 3.0 ± 0.4| 3.0 ± 0.4| 1.0 ± 0.1| 4.3 ± 0.8                   | 4.3 ± 1.2                |
| 12 to 13 yr | Male  | 3.4 ± 0.6| 3.4 ± 0.5| 1.0 ± 0.2| 4.6 ± 1.2                   | 5.8 ± 2.0                |
|           | Female| 2.9 ± 0.5| 2.9 ± 0.3| 1.0 ± 0.2| 4.1 ± 0.9                   | 5.7 ± 1.3                |
| 14 to 15 yr | Male  | 3.5 ± 0.5| 3.7 ± 0.4| 1.0 ± 0.2| 4.7 ± 0.9                   | 7.6 ± 2.0                |
|           | Female| 3.0 ± 0.5| 3.1 ± 0.4| 1.0 ± 0.1| 3.9 ± 0.8                   | 5.8 ± 1.4                |

*The values are given as the mean and the standard deviation. MCS = medial clear space, SCS = superior clear space, and NA = not applicable. † This value could not be measured for 11 of 18 patients in this age/sex subgroup because of preossification of the medial malleolus. ‡ This value could not be measured for 5 of 18 patients in this age/sex subgroup because of preossification of the medial malleolus. § This value could not be measured for 2 of 18 patients in this age/sex subgroup because of preossification of the medial malleolus.
recent, balanced cohort that was randomly selected from a pool of eligible patients by screening in reverse chronological order. Second, the measurements in the present study were made on non-stress radiographs in the absence of osseous or ligamentous injury. As such, no extrapolations can be made regarding (1) the values to be expected during stress radiography or (2) the relationship between deviant values and the diagnosis of pathological changes or injury. However, the findings of the present study suggest that utilizing tibiofibular overlap rather than medial clear space may be more useful when evaluating syndesmotic stability in children. Further study is needed to determine the association between thresholds of pathological indices on radiographs and findings on MRI scans and those of clinical and intraoperative evaluations. Despite these limitations, an understanding of the reliability and normative values of these indices is vital when exploring these relationships. Finally, previous studies have shown that several of the indices measured in the current study, including tibiofibular overlap and medial clear space, are altered with radiographic axial rotation. A high-quality, reproducible radiographic technique is paramount to the measurement of these syndesmotic indices. The current study evaluated images obtained in the clinical setting, which provided a true measure of the interrater reliability and normative values in the context of real-world imaging. While the radiographs did not undergo standardization, each was made according to institutional guidelines at a tertiary-care pediatric facility. Despite these limitations, we believe that the present report is the first to present a comprehensive array of normal syndesmotic measurements in the pediatric population with use of radiographic imaging.

In conclusion, tibiofibular overlap was characterized by particularly strong interrater reliability and changed predictably over the course of skeletal development. Therefore, tibiofibular overlap may be useful for future research as well as for clinically assessing pediatric ankle injuries and for guiding clinical decision-making. The medial malleolus is inconsistently ossified in children <8 years old and may be an unreliable
landmark when assessing ankle joint congruity. Additional research is needed to examine these measurements in the context of pediatric ankle and syndesmosis injuries.

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