Original Article

Hand skeletal features of children and adolescents with different growth statuses and periods

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Background: The hand skeletal features of children and adolescents at different growth statuses and development periods, and the correlation between these skeletal features and hand asymmetric force are currently unclear. Thus, this study sought to investigate the hand skeletal features of children and adolescents at different growth statuses and at different periods of development, and the correlation between these skeletal features and asymmetric force in hands.

Methods: A retrospective study was performed on subjects aged 4–20 years with good growth status (group A) or short stature (group B). Additional subjects aged 4–20, 21–40, and >40 years were enrolled in groups C, D, and E, respectively. All the subjects underwent left-hand posteroanterior X-ray radiography. Brachymesophalangia-V (BMP-V), conical epiphysis, epiphysis/metaphysis symmetry of the proximal phalanx (ESP), and the angle of the metacarpal-phalangeal axis were analyzed.

Results: Of the 654 children and teenagers aged 4–20 years (median: 11 years) enrolled in the study, 432 were allocated to group A, of whom 237 (54.9%) were male and 195 (45.1%) were female, and 222 matched cases were allocated to group B, of whom 112 (50.5%) were male and 110 (49.5%) were female. The first to third ESPs were significantly (P<0.05) greater in group A than in group B, while the first to third angles of the metacarpal-phalangeal axis were significantly (P<0.05) smaller in group A than in group B. The correlation analysis revealed a highly significant (P<0.01) negative correlation between the ESP and angle of the metacarpal-phalangeal axis (r=−0.948, −0.926, −0.940, −0.885, and −0.848, respectively). The incidence of BMP-V was 15.4% in all patients, while that of conical epiphysis was 19.5%. The incidence of BMP-V and conical epiphysis was significantly (P<0.05) smaller in group A than in group B (11.1% *vs.* 23.8% for BMP-V and 16.6% *vs.* 25.2% for conical epiphysis, respectively). Additionally, 216 subjects were enrolled in group C (108 male and 108 female), 185 subjects were enrolled in in group D (93 male and 92 female), and 176 subjects were enrolled in in group E (104 male and 72 female). The second to fifth ESPs in group C were significantly (P<0.05) smaller than those in both groups D and E, while the second to fifth angles of the metacarpal-phalangeal axis were significantly (P<0.05) larger in group C than in both groups D and E. A BMP-V was present in 35 (16.2%) patients in group C, 8 (4.3%) in group D, and 2 (1.1%) in group E, and the difference among the three groups was statistically significant (P<0.05).

Conclusions: The epiphyseal symmetry of the proximal phalanges is poor in short stature children and adolescents, and the angle between the metacarpal and phalangeal axes is larger in children and adolescents with short stature than those with normal height and good growth status. A negative correlation was found between the epiphyseal symmetry of the proximal phalanges and asymmetrical stress.

Keywords: Children; adolescent; skeletal features; left hand; posteroanterior radiograph

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Introduction

The development status of the hand and wrist bones reflect the overall growth and development status of the body. In clinical practice, left-hand posteroanterior X-ray radiography are often taken for patients with short stature to observe the development status of the ossification center of the hand and wrist and to evaluate their growth and development stage and potential (1-4). Based on these clinical and imaging data, we compared the phalanx epiphyseal morphology and joint alignment between children and adolescents with short stature and those with good growth and development status. We found that the symmetry of some proximal phalangeal epiphyses in short stature children and adolescents was slightly worse, and we also found a significant deviation in the force line of the metacarpophalangeal bones.

Various factors, including genetic factors, metabolic diseases, and mechanical stimulation, influence the growth and development of the epiphysis of the metacarpal and phalangeal bones (5-7). Mechanical stimulation plays an important role in the formation and development of bone tissue (8). Based on Volkman's law (9), an increase in the tensile stress promotes bone growth, an increase in the compressive stress inhibits bone growth, and uneven stresses can lead to uneven growth of the epiphysis. Therefore, we speculated that the symmetry of the proximal phalangeal epiphysis might be related to the deviation of the force line of the metacarpophalangeal bone. When the metacarpophalangeal joint forms an angle toward the radial side, the tensile stress on the radial side of the epiphysis increases, and the compressive stress on the ulnar side increases, resulting in the thickness of the epiphysis being greater on the radial side than on the ulnar side. To investigate the relationship between the morphology of the proximal phalangeal epiphysis and the angle of the metacarpophalangeal joint or the force line of the metacarpophalangeal bone, this study proposed the metacarpal phalangeal axis angle, which is the angle formed between the long axis of the metacarpal bone and the corresponding long axis of the phalangeal bone, using the methods of hip-knee-ankle joint angle and hallux valgus angle to represent the changes in hand metacarpophalangeal bone force lines. Thus, this study sought to analyze the hand bone characteristics of two groups of children and adolescents (one group with good growth status and one group with hand skeletal features) and to explore the correlation of hand skeletal features and asymmetric force in the hand to provide a theoretical basis for correcting hand and body asymmetry in children and adolescents with short stature.

The influence of hand labor habits and living environment on adolescent bone development is also undeniable. The development of hand bones is an important component of the overall growth and development of the body and can reflect, to some extent, the growth and development of adolescents. Due to rapid developments in China over the past 60 years, there have been significant changes in the living environments and labor habits of different generations, including a decrease in manual farming labor, replacement with mechanized operations, an increase of wrong pencil grip, and an increase in the learning time of children and adolescents. Therefore, this study included participants from different age groups to further explore the influence of living environments and labor habits on hand bone characteristics.

Methods

This retrospective study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the Ethics Committee of Hebei Medical University Third Hospital (No. W2022–056-1), and the patients or their legal guardians signed the informed consent form. Between January 2021 and December 2021, children and teenagers who underwent left hand posteroanterior X-ray radiography at Hebei Medical University Third Hospital were enrolled in the study. To

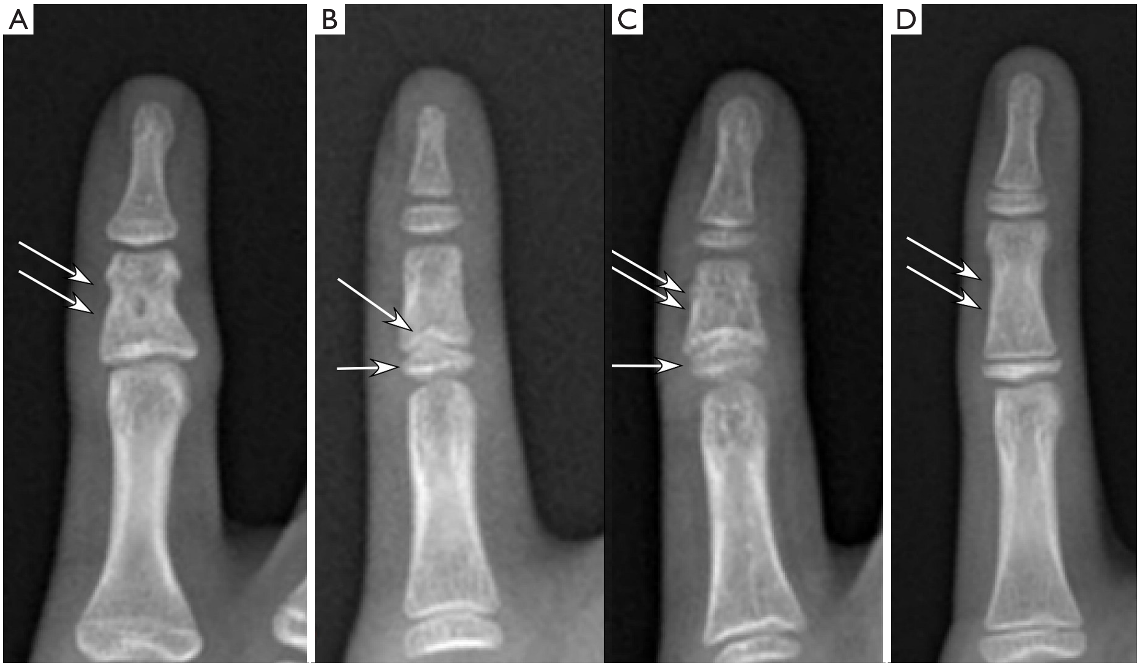

Figure 1 BMP-V and conical epiphysis. (A) BMP-V can be observed in the short and broad middle phalanx of the fifth digit (double arrows). (B) A conical epiphysis can be observed in the middle phalanx (short arrow), with a tip in the center and a depression in the corresponding metaphysis (long arrow). (C) Conical epiphysis (single arrow) was associated with BMP-V (double arrows). (D) Normal fingers without BMP-V or conical epiphysis. The double arrows indicate the normal finger without any abnormalities. BMP-V, brachymesophalangia-V.

meet the following inclusion criteria: (I) have a trauma; (II) be aged 4 years and above; and (III) have undergone left-hand posteroanterior X-ray radiography. Patients were excluded from the study if they had images of poor quality due to an internal or external fixation, an imaging artifact, unclear anatomical structures, or the mispositioning of the hand, or a hand disease, including hand tumors, hand developmental malformation, dislocation, and rheumatoid arthritis. Patients with good growth status were assigned to group A, and those with short stature were assigned to group B. Moreover, based on their age, the subjects were divided into the following three groups: group C, which comprised patients aged 4–20 years; group D, which comprised patients aged 21–40 years, and group E, which comprised patients aged over 40 years.

Examination methods

Standard X-ray posteroanterior radiography of the left hand: the left hand was placed flat on the radiography table and kept relaxed. All fingers were naturally open, and the thumb was naturally relaxed (rotated about 30°) to ensure no abduction or adduction of each finger. The axis of the middle finger was kept consistent with the axis of the forearm, with its center being put at the distal end of the third metacarpal bone.

Parameters measured

The following parameters were measured through the hospital picture archiving and communication systems (PACS): brachymesophalangia-V (BMP-V): the short and broad middle phalanx of the fifth digit (*Figure 1*) (10); conical epiphysis: a cone-shaped phalangeal epiphysis with a tip at the center, and a corresponding depression at the adjacent metaphysis similar to a cone (*Figure 1*); epiphyseal/metaphysis symmetry of the proximal phalanx (ESP): the thickness on the radial and ulnar sides of the epiphysis/metaphysis of the proximal phalanx was measured on the left-hand posteroanterior film (*Figure 2*). The ESP was calculated based on the ratio of the radial thickness to the ulnar thickness; angle of metacarpal phalangeal axis (AMPA): the angle formed by the extension line of the metacarpal axis and the corresponding phalangeal axis (*Figure 3*).

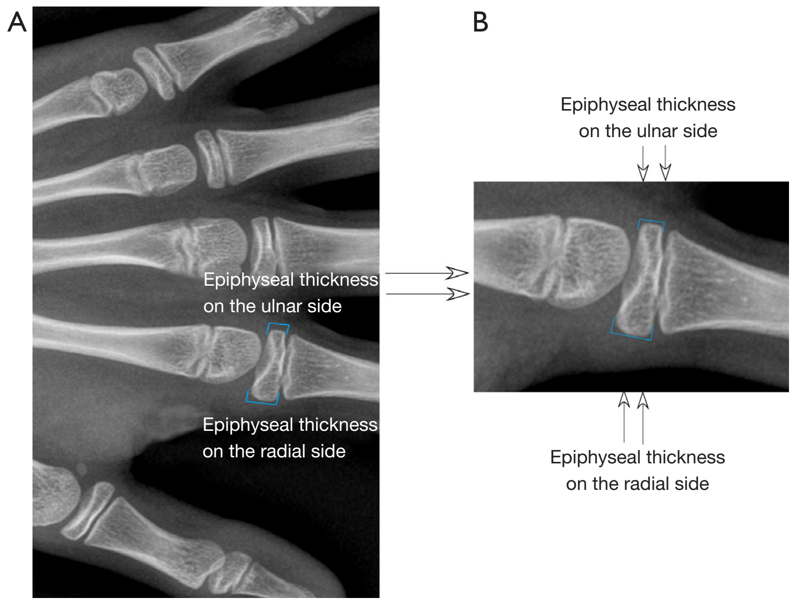

Figure 2 Measurement of the ESP. (A) A left-hand radiography film showing the measurement of the ESP. (B) Enlargement of the epiphysis for the exact measurement of ESP. The epiphyseal thickness on the radial and ulnar sides was measured to calculate the ESP, which is the ratio of the thickness on the radial side to that on the ulnar side. ESP, epiphyseal/metaphysis symmetry of the proximal phalanx.

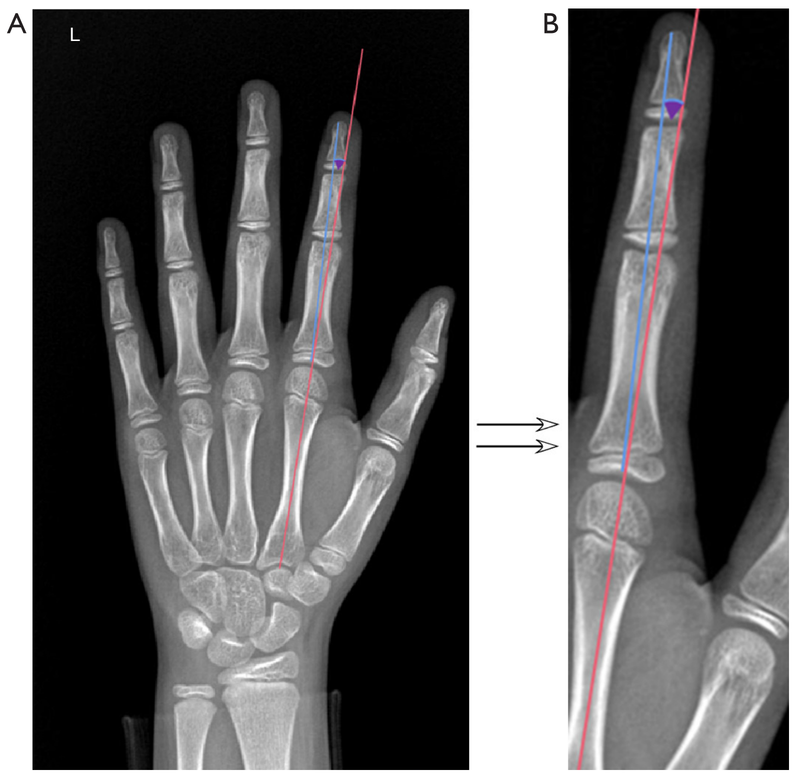

Figure 3 Measurement of AMPA. (A) The measurement of the AMPA on a left-hand radiograph. (B) Enlargement of the measurement on the finger; the red line indicates the axis of the metacarpal bone; the blue line indicates the phalangeal axis. The angle is formed between the two axes. AMPA, angle of metacarpal phalangeal axis.

Table 1 Parameters measured in groups A and B

Variables	Group A	Group B
Total number	432	222
M/F (number)	237/195	112/110
Age (years)	11 [3]	11 [5]
ESP		
1st	0.85 [0.18]	0.80 [0.20]
2nd	0.66 [0.18]	0.61 [0.17]
3rd	0.71 [0.18]	0.66 [0.15]
4th	1.00 [0.09]	1.00 [0.08]
5th	1.00 [0.09]	0.48 [0.06]
AMPA		
1st	2.7 [6.9]	6.4 [10.4]
2nd	17.5 [8.4]	19.4 [4.6]
3rd	7.6 [7.9]	10.3 [4.4]
4th	4.2 [10.6]	8.6 [7.1]
5th	8.4 [13.4]	11.3 [9.8]

Data are presented as median [IQR] if not otherwise specified. Group A: patients with good growth status; group B: patients with short stature. M, male; F, female; ESP, epiphyseal/metaphysis symmetry of the proximal phalanx; AMPA, angle of metacarpal phalangeal axis; IQR, interquartile range.

Table 2 The reliability of indexes in groups A and B

Parameters	Intraclass correlation	95% confidence interval	
		Lower bound	Upper bound
ESP			
1st	0.916	0.905	0.926
2nd	0.906	0.894	0.917
3rd	0.903	0.891	0.915
4th	0.839	0.819	0.858
5th	0.849	0.83	0.866
AMPA			
1st	0.945	0.938	0.952
2nd	0.914	0.902	0.924
3rd	0.844	0.825	0.862
4th	0.913	0.902	0.923
5th	0.945	0.937	0.951

Group A: patients with good growth status; group B: patients with short stature. ESP, epiphyseal/metaphysis symmetry of the proximal phalanx; AMPA, angle of metacarpal phalangeal axis.

Short stature was defined as a condition characterized by a height over two standard deviations below the corresponding average height for a given age, sex, and population, without findings of disease (11,12).

The above parameters were evaluated and measured by three imaging doctors. The measurement results were taken as the average value. If a disagreement arose, a consultation was performed to reach a conclusion. Next, the reliability of the measurements in different observers was tested.

Statistical analysis

The data were analyzed with the SPSS software (version 25.0, IBM, Chicago, IL, USA). The measurement data were not normally distributed and are all presented as the median (interquartile range). A Spearman correlation analysis was performed to analyze the correlations among the different parameters. The correlations were classified as follows: $|r| <0.3$ = weak; $0.3\leq |r| <0.5$ = moderately weak; a $0.5\leq |r| <0.8$ = moderate; $|r| \geq 0.8$ = high; and $|r| >0.95$ = very high The Mann-Whitney U and Chi-square test were used to perform comparisons between two groups. A P value <0.05 was considered statistically significant. To obtain a significant P value at <0.05 with a statistical power of 0.95 and two tails, a total sample of 134 patients was necessary. The intraclass correlation coefficients for the reliability of measurement in different observers were calculated.

Results

A total of 654 children aged 4–20 years (mean: 10.8 years, and median: 11 years) who underwent posteroanterior radiographs of the left hand were enrolled in the study, of whom 349 (53.4%) were male and 305 (46.6%) were female. Group A comprised 432 patients with good growth, of whom 237 (54.9%) were male and 195 (45.1%) were female. Group B comprised 222 patients with short stature, of whom 112 (50.5%) were male and 110 (49.5%) were female (*Table 1*). No significant (P>0.05) difference was found between the two groups in terms of age and sex. The reliability of the indexes measured is shown in *Tables 2,3*.

A significant (P<0.05) difference was found in the first to third ESPs and the first to third AMPAs between groups A and B (P<0.05) (*Table 4*). The first to third ESPs were significantly (P<0.05) greater in group A than in group B, while the first to third AMPAs were significantly (P<0.05) smaller in group A than in group B. The correlation

Table 3 The interobserver reliability of indexes in groups C, D, and E

Parameters	Intraclass correlation	95% confidence interval	
		Lower bound	Upper bound
ESP			
1st	0.895	0.881	0.908
2nd	0.884	0.868	0.898
3rd	0.885	0.869	0.9
4th	0.661	0.623	0.697
5th	0.339	0.287	0.391
AMPA			
1st	0.906	0.892	0.917
2nd	0.908	0.895	0.92
3rd	0.819	0.795	0.84
4th	0.878	0.861	0.893
5th	0.865	0.847	0.881

Group C: patients aged 4–20 years; group D: patients aged 21–40 years; group E: patients aged over 40 years. ESP, epiphyseal/metaphysis symmetry of the proximal phalanx; AMPA, angle of metacarpal phalangeal axis.

Table 4 Statistics of left-hand parameters between groups A and B

Parameters	Z	P
ESP		
1st	−3.522	<0.001
2nd	−4.562	<0.001
3rd	−5.515	<0.001
4th	−0.403	0.687
5th	−0.837	0.403
AMPA		
1st	−7.712	<0.001
2nd	−6.528	<0.001
3rd	−4.900	<0.001
4th	−1.772	0.076
5th	−1.319	0.187

Group A: patients with good growth status; group B: patients with short stature. ESP, epiphyseal/metaphysis symmetry of the proximal phalanx; AMPA, angle of metacarpal phalangeal axis.

Table 5 Correlation between the seal symmetry of the phalanx and its corresponding metacarpal-phalanx axis

Parameter evaluated	Corresponding parameter	r	P
1st ESP	1st AMPA	−0.948	<0.001
2nd ESP	2nd AMPA	−0.926	<0.001
3rd ESP	3rd AMPA	−0.940	<0.001
4th ESP	4th AMPA	−0.885	<0.001
5th ESP	5th AMPA	−0.848	<0.001

ESP, epiphyseal/metaphysis symmetry of the proximal phalanx; AMPA, angle of metacarpal phalangeal axis.

analysis showed a highly significant (P<0.01) negative correlation between the first to fifth ESPs and first to fifth AMPAs (r was −0.948, −0.926, −0.940, −0.885, and −0.848, respectively) (*Table 5*).

The incidence of BMP-V was 15.4% in all patients, while that of conical epiphysis was 19.5%. The incidence of BMP-V and conical epiphysis was significantly (P<0.05) smaller in group A than in group B (11.1% *vs.* 23.8% for BMP-V and 16.6% *vs.* 25.2% for conical epiphysis, respectively).

A total of 577 patients with left hand posteroanterior X-ray films were enrolled in groups C–E. Group C comprised 216 patients, of whom 108 were male (50.0%) and 108 were female (50.0%), group D comprised 185 patients, of whom 93 were male (50.3%) and 92 were female (49.7%), and group E comprised 176 patients, of whom 104 were male (59.1%) and 72 were female (40.9%) (*Table 6*). No significant (P=0.139) difference was found among the three groups in terms of sex, but a statistically significant difference was found among the three groups in terms of the measurement parameters of the hand characteristics (P<0.05) (*Table 6*).

In the pairwise comparison (*Table 7*), a significant difference (P<0.05) was found between groups C and D or E. The epiphyseal symmetry of the second to fifth proximal phalanges in group C was significantly (P<0.05) lower than that in groups D or E, and the second to fifth metacarpal-phalangeal axis angle in group C was significantly greater than that in groups D or E. No significant difference was found in the measurement parameters between groups D and E. The reliability of those indexes is shown in *Tables 2,3*.

Table 6 Statistical description of the population measurement indicators in groups C, D, and E

Index	Group C (4–20 years)	Group D (21–40 years)	Group E (>40 years)	P
ESP				
1st	0.82 [0.17]	0.84 [0.16]	0.85 [0.18]	0.052
2nd	0.67 [0.18]	0.78 [0.11]	0.77 [0.10]	<0.001
3rd	0.69 [0.18]	0.79 [0.13]	0.78 [0.12]	<0.001
4th	242.07	328.11	305.49	<0.001
5th	247.67	314.67	312.68	<0.001
AMPA				
1st	7.4 [8.0]	8.8 [7.6]	7.5 [7.9]	0.115
2nd	17.7 [7.0]	10.8 [7.6]	13.2 [7.2]	<0.001
3rd	9.0 [5.9]	5.1 [5.3]	5.8 [5.3]	<0.001
4th	7.9 [9.6]	3.7 [4.7]	4.3 [7.1]	<0.001
5th	10.6 [4.0]	8.1 [2.8]	8.1 [2.9]	<0.001

Data are presented as median [IQR] or mean. ESP, epiphyseal/metaphysis symmetry of the proximal phalanx; AMPA, angle of metacarpal phalangeal axis.

Table 7 Analysis of population measurement index differences in groups C, D, and E

Index	Groups C–D		Groups C–E		Groups D–E	
	Statistics	P	Statistics	P	Statistics	P
ESP						
2nd	–179.604	<0.001	–148.448	<0.001	31.155	0.76
3rd	–145.696	<0.001	–130.937	<0.001	14.759	0.4
4th	–86.044	<0.001	–63.422	<0.001	22.622	0.079
5th	–67.055	<0.001	–65.016	<0.001	2.04	0.826
AMPA						
2nd	–172.64	<0.001	–140.506	<0.001	32.134	0.067
3rd	–118.873	<0.001	–102.305	<0.001	16.568	0.345
4th	–111.831	<0.001	–80.24	<0.001	31.591	0.072
5th	–139.453	<0.001	–130.366	<0.001	9.086	0.605

Group C: patients aged 4–20 years; group D: patients aged 21–40 years; group E: patients aged over 40 years. ESP, epiphyseal/metaphysis symmetry of the proximal phalanx; AMPA, angle of metacarpal phalangeal axis.

A statistical analysis on the occurrence of BMP-V in different age groups revealed that BMP-V was present in 35 (16.2%) patients in group C, 8 (4.3%) in group D, and 2 (1.1%) in group E, and the difference among the three groups was significant ($P<0.05$). The pairwise comparison found a statistical difference ($P<0.001$) in the occurrence of BMP-V between groups C and D or between groups C and E rather than between groups D and E.

Discussion

In this section, we discuss the major findings of this study. First, the children and adolescent patients with short stature had poorer symmetry of the proximal phalangeal epiphysis of the fingers than those with a normal height, and the angle between the metacarpal and phalangeal axes increased, resulting in a higher incidence of short and middle finger V. There was a negative correlation between ESP and AMPA, such that the larger the AMPA, the more asymmetric the epiphysis. The group of patients aged 4 to 20 years had a smaller ESP, larger AMPA, and a higher incidence of BMP-V than the other two groups of patients aged over 20 years old. The incidence of BMP-V was significantly ($P<0.05$) smaller in group A (patients with good growth status) than in group B (patients with short stature) (11.1% *vs.* 23.8%), which may indicate that BMP-V is a marker of skeletal dysplasia.

During its development, the morphology of the epiphysis is influenced by multiple factors. As an important exogenous factor affecting the epiphyseal ossification, mechanical stimulation plays an important role in this process (8). The tension (i.e., the tensile stress) on the epiphyseal plate is beneficial for the growth of the plate in the direction of the tension, while compressive stress hinders growth. The force between different parts of the body is transmitted along the force line. We believe that uneven force distribution can affect the shape of the hand's epiphysis, and the force between various parts of the body is transmitted along the force line. To further examine the relationship between the shape of the epiphysis and force, we conducted relevant research on the force line between the metacarpal and phalangeal bones. However, previous researchers have mostly focused on the force lines of the lower limbs and feet, and paid less attention to the force lines of the palms and phalanges of the hands (13). We applied the relevant research methods of lower limb and foot force lines to the metacarpal and phalangeal bones to evaluate the relationship between the shape of the hand's epiphysis and force lines in this study.

The lower limb force line is the axis from the center of the femoral head to the center of the ankle joint, which should normally pass near the center of the knee joint (14). The lower limb force line is further subdivided into the femoral force axis and the tibial force axis, and the inner angle formed between the two is called the hip-knee-ankle angle, which roughly represents the force line of the lower limb, with an ideal angle of zero degrees (15,16). It has been suggested (17) that under the action of normal force lines, the knee joint can exhibit a nearly frictionless motion state. In adults, when the force line deviates from the axis, it will generate offset, which increases the pressure on the joint cartilage, causing uneven distribution of load on the joint surface, cartilage friction damage, and bone damage on the joint surface, and subsequent changes in bone morphology. These abnormal shapes will further increase the deviation of the gravity line. Lower limb force line offset can promote changes in subchondral bone structure by changing the stress load distribution of the knee joint. The side with high compressive stress increases the number and thickness of subchondral bone trabeculae, thereby accelerating joint degeneration and deformity (18,19). In children's epiphysis, the uneven stress may cause uneven bone growth. For the side with larger compression, the proliferation of chondrocytes may be suppressed, the proliferative and hypertrophic zones will be shortened, and tissue architecture is disrupted. All these can reduce the longitudinal growth (20).

Similar force lines have also been applied to the evaluation of the foot metatarsophalangeal joint. For example, the hallux valgus angle, which is the intersection angle between the long axis extension line of the first metatarsal bone and the proximal phalanx of the first toe on the weight-bearing plain film of the foot, is normally less than 15 degrees. When the toe valgus angle increases, the contact surface of the metatarsophalangeal joint changes, thereby changing the direction of the force line of the phalanx, resulting in an imbalance of force on the inner and outer sides of the phalanx (21). This study referred to the measurement method of the hip-knee-ankle angle and the hallux valgus angle and defined the metacarpal phalangeal axis angle, representing the force line of metacarpophalangeal joint, which is the angle formed by the extension line of the metacarpal axis and the corresponding phalangeal axis.

This study found that participants with short stature had a larger angle between the left metacarpal and phalangeal axes and poorer symmetry of the proximal phalangeal epiphyses. It also found a correlation between the metacarpal-phalangeal axis angle and the symmetry of the proximal phalangeal epiphyses. As the angle between the metacarpal and phalangeal axes increased, the symmetry of the proximal phalangeal epiphyses decreased, and the incidence of BMP-V and conical epiphyses was higher. The metacarpal-phalangeal axis angle in subjects with good growth and development status was closer to 0 degree. The development of the hand morphology in subjects with short stature was poorer than that of the well-developed subjects, which may indicate the bone growth and development status. From this perspective, it was speculated that a normal force line between the metacarpal and phalangeal bones maintains a good shape of the metacarpophalangeal joint bones. However, as the degree of deviation of the force line between the metacarpal and phalangeal bones from the axis increases, the uneven distribution of pressure load on the joint surface may lead to deformation of the joint bones, especially the obstruction of the local growth of the epiphyses and symmetry deterioration. Differences in the shape of the metacarpophalangeal joints in short-stature subjects may be related not only to poor physical development, but also to uneven stresses, which may be related to the way in which force is exerted when writing and lifting heavy objects. Currently, the height of desks and chairs used for reading and writing by children and adolescents in schools is the same. These desks and chairs are designed according to the height of most peers and may not be suitable for short-stature children, which may lead to differences in their reading and writing postures, and the way they exert forces, resulting in differences in the stresses on the epiphyses of their hands.

To further explore the effect of environmental factors on the morphological characteristics of the proximal phalangeal epiphysis and metaphysis of the hand, this study included different age groups in the analysis. Compared to the subjects aged older than 20 years in groups D and E, the epiphyseal morphology of the second to fifth proximal phalanges of the subjects aged under 20 years old in group C were more asymmetric, with greater angles between the second to fifth metacarpophalangeal axes and a higher incidence of BMP-V. This difference may be related to the social environments and lifestyles of different age groups during their growth and development periods (22,23).

In the past 20 years, China's society has undergone significant changes. The acceleration of urbanization and electronic product category updates and iterates has increased the academic burden placed on students, increased their sedentary time, and reduced their physical activity. The elevated academic burden has led to longer writing hours for students. In our research, we administered a questionnaire to some students and found that the majority of them had a poor pen-holding posture, mainly manifesting as poor hand posture and excessive finger force, especially in the first to third fingers, which may be the reason for the change in finger force. Holding the pen close to the tip of the pen may obstruct the line of sight and cause the head to tilt to read, resulting in the uneven use of both eyes, which can easily cause myopia and astigmatism (24,25). However, excessive force can make children's hands more prone to fatigue, making it more difficult for them to adapt to long-term writing assignments, and in severe cases, it may exacerbate their aversion to learning. After developing bad habits, long-term abnormal posture movements can cause adaptive changes in muscles and joints, exacerbating hand to body balance and abnormal stress. Once bad habits are formed, they are difficult to correct. Keller *et al.* found that the formation of new habits takes about two months, and only a portion of participants (27/192) can successfully form new habits (26).

The impact of environmental factors on human growth and development cannot be ignored. The expression of some traits depends on methylation modifications outside DNA and chromosomal conformational changes. Some of these changes will be preserved in cell division, and some may even remain stable in intergenerational inheritance. This theory is called epigenetics (27). In addition, young children have strong imitation abilities, and the habitual actions of their parents or grandparents can be spread through imitation behavior. The growth and development of children and adolescents directly affect their physical and health status in adulthood and may also affect the next generation (10,27) and the overall quality of the country and ethnic population. Therefore, attention should be paid to the development of hand bones. If growth problems can be detected in a timely manner, they can also be corrected in a timely manner during the stage of rapid growth and development.

Our previous research on scoliosis found that spinal balance affects physical balance and standing stability, as well as the balance of forces on the head, shoulders, and pelvis (28,29). We have also found clinically that spinal curvature was abnormal in subjects with short stature. Based on this, the "biomechanical pathogenic theory of asymmetric stress on symmetric structures" was proposed. The entire body's exercise system is inherently a whole. The movements and postures of the hands are closely related to the movements of the forearm, upper arm, and shoulders, while shoulder movements are influenced by the spine and pelvis, which in turn is closely related to lower limb movements. Poor hand posture and behavioral habits can lead to poor posture and movement adjustments throughout the body. Therefore, if poor hand posture needs to be corrected, the entire body's movement system requires coordination and needs to work together to achieve it. Future research should seek to gather more evidence in support of the biomechanical pathogenic theory of asymmetrical stress on symmetrical structures, while exploring effective methods for correcting poor posture and movements throughout the body.

Unlike other studies, our study analyzed the shape and force line of hand bones, revealed the characteristics of hand bones in different adolescent and adult populations, and provided valuable reference data for further exploring "biomechanical pathogenic theory of asymmetric stress on symmetrical structures". However, as a retrospective and one-center study, our study may have some selection bias. Other limitations of the study include that only Chinese patients were enrolled in the study, no continuous observation was undertaken of the changes of hand bones, and no investigation of the risk factors was conducted. These limitations may affect generalization of the study's outcomes. Future prospective, randomized, controlled, multicenter studies involving multiple races and ethnicities should be conducted to address these issues and ensure better outcomes.

Conclusions

The asymmetric growth of the proximal phalangeal epiphysis is related to asymmetric stress, which has laid the foundation for the "biomechanical pathogenic theory of asymmetric stress on symmetrical structures". Compared to children and adolescents with good growth status, short-stature children and adolescents have significantly lower symmetry of the proximal phalangeal epiphyses of the fingers, an increased angle between the metacarpal and phalangeal axes, a higher incidence of the BMP-V and conical epiphyses, and a negative correlation between ESP and AMPA. The larger the AMPA, the more asymmetric the epiphysis, and the growth of the epiphysis is related to its asymmetric stress. The patients aged 4 to 20 years had smaller ESPs, larger AMPAs, and a higher incidence of the short and middle finger V compared to the two groups of patients aged over 20 years old.

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Footnote

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://qims.amegroups.com/article/view/10.21037/qims-23-26/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. This retrospective study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the Ethics Committee of Hebei Medical University Third Hospital (No. W2022-056-1), and all the patients or their legal guardians signed the informed consent form.

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