Computed tomography morphometric analysis of anterior instrumentation in the pediatric thoracic spine

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OBJECTIVE The authors' goal in this paper was to quantify reference data on the dimensions and relationships of the maximum posterior screw angle and the thoracic spinal canal in different pediatric age groups.

METHODS One hundred twelve pediatric patients were divided into 4 age groups, and their thoracic vertebrae were studied on CT scans. The width, depth, and maximum posterior screw angles with different screw entrance points were measured on a Philips Brilliance 16 CT. The statistical analysis was performed using the Student t-test and Pearson's correlation analysis.

RESULTS The width and depth of the thoracic vertebrae increased from T-5 to T-12. The width ranged from 18.5 to 37.1 mm, while the depth ranged from 16.1 to 28.2 mm. The maximum posterior screw angle decreased from T-5 to T-12 in all groups. The ranges and mean angles at the entrance points were as follows: initial entrance point, 6.9° to 12.3° with a mean angle of 9.1°; second entrance point, 20.6° to 27.0° with a mean angle of 24.2°; and third entrance point, 29.2° to 37.5° with a mean angle of 33.7°. There were no significant age-related differences noted for the maximum posterior screw angles.

CONCLUSIONS The angle decreased from T-5 to T-12. No significant age-related differences were noted in the maximum posterior screw angles. Screws should be placed between the initial and second points and parallel to the coronal section or at a slight anterior orientation.

<http://thejns.org/doi/abs/10.3171/2015.6.PEDS14523>

KEY WORDS pediatric spine; computed tomography; morphometric analysis; anterior instrumentation

THE anterior instrumentation fixation system for thoracolumbar stabilization was first introduced by Dwyer² to correct idiopathic scoliosis in adolescents. With advancements in radiology and biomechanics, various internal fixation device systems have been developed, and most of them are composed of screws or plates and rods.^{6,8,13,18} However, regardless of the chosen fixation device, the anterior screws are always placed laterally or anterolaterally into the vertebral body. The anterior procedure carries a risk of injury to the neurovascular structures, and several studies reported that the vertebral screw invaded the spinal canal.^{7,12,16,20} Therefore, it is important to understand the relationship between screw orientation and the spinal canal during anterior instrumentation placement.

In many earlier studies, CT imaging has been used to define the anatomical requirements of instrumentation and provide a guide for clinical practice within the spine, and these studies examined the relationship between the aorta and screw positions for the sake of accurate screw placement.^{1,14,17,21} In addition, some cadaveric anatomical studies on the anterior instrumentation of the thoracic and lumbar spine in adults have quantitatively evaluated the relationship between the screw placement angle and the spinal canal since the screw may penetrate the spinal canal if its angle exceeds the maximum.^{3,4}

To the best of our knowledge, no reports have documented the maximum posterior screw placement angle into the spinal canal in a pediatric population in order to consider age-dependent differences and other variations

TABLE 1. Summary of group design

Group	Age (yrs)	Male	Female	Total
1	7–9	16	15	31
2	10–12	13	13	26
3	13–15	17	10	27
4	16–18	15	13	28

in ossification. Thus, this CT-based morphometric analysis of pediatric patients grouped by age was performed to provide reference data and ensure safe anterior instrumentation in children.

Methods

Clinical Materials

This study was approved by our hospital's institutional review board. We retrospectively reviewed the thoracic spinal CT scans of Chinese pediatric patients who were treated at our institution between January 2005 and December 2013. The patients who had thoracic spinal abnor-

malities, such as congenital deformities, trauma, or primary or secondary tumors, were excluded. The included children were classified into 4 groups (Table 1): Group 1 (7–9 years of age; 31 patients); Group 2 (10–12 years; 26 patients); Group 3 (13–15 years; 27 patients); and Group 4 (16–18 years; 28 patients).

Measurement Methods

The thoracic spine CT scans were performed using a Philips Brilliance 16 CT scan machine (Philips Medical Systems). The scan parameters included a layer thickness of 1.0 to 1.5 mm, 0.75 to 1.5 mm collimation, 0.7 mm pitch, and a reconstruction level of 1 mm. The original data were entered into an MXV workstation, and 2-dimensional image reconstruction was performed using multiplanar reconstruction methods. Bone windows were used for the analysis.

Vertebral width and depth were measured at each thoracic vertebra using the methods depicted in Fig. 1. The initial screw entrance point was set at the most anterior edge of the upper costal facet, while the second and third points were located 5 mm and 10 mm anterior to the initial point, respectively. The common point was located 3

FIG. 1. Measurement of the thoracic vertebrae. Axial CT scan showing vertebral width and depth (A), and axial CT scan showing the maximum posterior screw angle at the level of the initial entrance point (IA) (B). The spot 5 mm anterior to the initial point (SA) is shown (C), and the spot 10 mm anterior to the initial point (TA) and the common point 3 mm anterior to the corner of the spinal canal are also shown (D). Figure is available in color online only.

mm anterior to the contralateral corner of the spinal canal (Fig. 1). Thus, the line connecting the entrance point with the common point was defined as the screw trajectory, and the maximum posterior screw angle was measured between the screw trajectory line and the coronary horizontal line on the axial CT scan (Fig. 1). There were 3 maximum posterior screw angles: the initial entrance, second point, and third point. The position of the plane is parallel to the endplates in our study, and the length of the screws ranged from 25 mm to 35 mm in 5-mm increments.

All measurements were collected and analyzed using an Excel spreadsheet (Microsoft). Graphical representations of our data were created using SPSS (version 16.0, SPSS Inc.). The mean values and standard deviations were calculated for all parameters. The sex differences in these parameters were examined using the independent t-test, while the correlation between age and angles was analyzed using the Pearson's correlation coefficient.

Results

The vertebral dimension measurements and maximum posterior screw angles at the different entrance points are described below.

Vertebral Width

The mean values and standard deviations for vertebral width are presented in Table 2. The vertebral widths increased from T-5 to T-12 in all groups. There were no significant differences between girls and boys at each level ($p > 0.05$). Age appeared to be associated with vertebral width (r range: boys, 0.870–0.910; girls, 0.735–0.817; $p < 0.05$).

Vertebral Depth

The mean values and standard deviations for vertebral depths are presented in Table 3. The vertebral depths increased from T-5 to T-12 in all groups. There were no significant differences between girls and boys at each level ($p > 0.05$). Age appeared to demonstrate an associative effect, along with vertebral width (r range: boys, 0.752–0.818; girls, 0.758–0.869; $p < 0.05$).

Maximum Posterior Screw Angle

The mean values and standard deviations for the maximum posterior screw angle at the initial screw entrance point are presented in Table 4. At the initial entrance point, the angles in boys and girls were 12.3° to 6.9° and 12.2° to 7.0°, respectively. There were no significant differences between female and male patients at each level ($p > 0.05$). Age was not associated with the maximum posterior screw angle measured (r range: boys, –0.003 to 0.324; girls, –0.106 to 0.410; $p < 0.05$).

The mean values and standard deviations for the maximum posterior screw angle at the second screw entrance point are presented in Table 5. At the second entrance point, the angle demonstrated a decreasing dimension from T-5 to T-12, and the angle in males and females ranged from 27.0° to 20.9° and 27.5° to 20.6°, respectively. There were no significant differences between the female and male groups at any level ($p > 0.05$). Age had no associative effect on the maximum posterior screw angle measured (r range: boys, –0.072 to –0.294; girls, –0.163 to –0.391; $p < 0.05$).

The mean values and standard deviations of the maximum posterior screw angle at the third screw entrance point are shown in Table 6. At the third entrance point, the angle decreased from T-5 to T-12, and the angles in the boys and girls were 37.4° to 29.4° and 37.5° to 29.2°, respectively. There were no significant differences between the girls and boys at most levels ($p > 0.05$). Age was not associated with the maximum posterior screw angle (r range: boys, –0.041 to 0.351; girls, –0.125 to –0.441, $p < 0.05$).

Discussion

Anterior instrumentation fixation and fusion is a relatively new technique for the treatment of spinal disorders, including scoliosis, spondylolisthesis, fractures, tumors, and iatrogenic or degenerative instability. Compared with the traditional posterior approach to the spine, the anterior approach is considered a direct visualization and complete anterior decompression method. Therefore, anterior instrumentation is a viable option for the treatment of thoracic injury and deformity in children.

The use of anterior screws carries a significant risk of

TABLE 2. Thoracic vertebral width*

Vertebra	Group 1 (7–9 yrs)		Group 2 (10–12 yrs)		Group 3 (13–15 yrs)		Group 4 (16–18 yrs)	
	Male	Female	Male	Female	Male	Female	Male	Female
T-5	19.8 ± 1.3	18.5 ± 1.8	21.4 ± 1.4	21.6 ± 1.6	24.7 ± 1.7	20.4 ± 1.4	26.4 ± 1.9	22.9 ± 1.4
T-6	20.7 ± 1.5	19.3 ± 1.8	22.2 ± 1.3	22.0 ± 1.5	25.7 ± 2.0	23.3 ± 1.5	27.7 ± 1.9	24.1 ± 1.9
T-7	21.5 ± 1.5	20.0 ± 1.8	23.1 ± 1.3	22.8 ± 1.4	26.5 ± 1.9	24.6 ± 1.5	28.9 ± 2.0	25.1 ± 2.0
T-8	22.5 ± 1.5	20.7 ± 1.0	24.0 ± 1.3	23.3 ± 1.3	27.9 ± 2.0	25.6 ± 1.8	30.0 ± 1.6	26.2 ± 1.8
T-9	23.5 ± 1.5	22.0 ± 1.2	24.9 ± 1.3	24.5 ± 1.3	29.4 ± 1.9	26.9 ± 2.1	31.1 ± 1.8	27.5 ± 2.0
T-10	24.9 ± 1.5	23.6 ± 1.7	26.4 ± 1.4	25.8 ± 1.6	30.7 ± 1.9	28.5 ± 2.1	33.1 ± 1.7	28.8 ± 2.0
T-11	26.4 ± 1.7	25.2 ± 1.6	28.6 ± 1.7	27.3 ± 1.7	33.5 ± 2.3	30.6 ± 2.2	35.5 ± 2.1	31.2 ± 1.8
T-12	28.3 ± 1.3	27.0 ± 1.4	30.4 ± 1.5	29.2 ± 1.5	35.3 ± 2.9	32.7 ± 2.5	37.1 ± 2.4	33.5 ± 1.5

* Values are shown in millimeters as the mean ± SD.

TABLE 3. Thoracic vertebral depth*

Vertebra	Group 1 (7–9 yrs)		Group 2 (10–12 yrs)		Group 3 (13–15 yrs)		Group 4 (16–18 yrs)	
	Male	Female	Male	Female	Male	Female	Male	Female
T-5	17.8 ± 1.6	16.1 ± 1.2	18.7 ± 1.7	18.0 ± 1.1	20.7 ± 1.8	18.7 ± 1.3	21.6 ± 1.6	19.6 ± 1.5
T-6	18.5 ± 1.2	16.7 ± 1.1	19.5 ± 1.9	18.6 ± 1.1	21.9 ± 2.0	19.6 ± 1.3	22.6 ± 1.3	20.6 ± 1.7
T-7	19.3 ± 1.3	17.4 ± 1.3	20.3 ± 1.1	19.3 ± 1.2	22.8 ± 2.1	20.8 ± 1.5	23.7 ± 1.3	21.7 ± 1.7
T-8	20.0 ± 1.4	18.0 ± 1.3	21.3 ± 1.7	20.3 ± 1.2	23.7 ± 2.3	21.8 ± 1.6	24.9 ± 1.4	22.6 ± 1.6
T-9	20.4 ± 1.6	18.4 ± 1.5	22.0 ± 1.1	20.9 ± 1.2	24.5 ± 2.3	22.5 ± 1.8	25.8 ± 1.3	23.5 ± 1.6
T-10	20.9 ± 1.8	18.8 ± 1.5	22.7 ± 1.1	21.4 ± 1.3	25.2 ± 2.1	23.5 ± 1.9	26.7 ± 1.3	24.2 ± 1.4
T-11	21.6 ± 1.9	19.4 ± 1.6	23.5 ± 1.0	22.0 ± 1.5	25.9 ± 2.0	24.2 ± 1.9	27.4 ± 1.5	25.0 ± 1.4
T-12	22.4 ± 1.9	20.0 ± 1.8	24.2 ± 1.8	22.7 ± 1.5	26.9 ± 1.9	25.1 ± 2.0	28.2 ± 1.8	25.7 ± 1.7

* Values are shown in millimeters as the mean ± SD.

complications because of the proximity to the adjacent neurovascular structures. The thoracoscopic approach, in particular, is technically demanding in order to ensure optimal screw purchase. Huitema et al.⁷ reported that of 17 patients with idiopathic scoliosis treated with anterior instrumentation, 3 screws violated the spinal canal, and leg pain occurred at 3 and 15 months after surgery. Sucato et al.²⁰ reported that 4 screws had penetrated into the spinal canal at a depth of < 2 mm, but no neurological injuries resulted. No studies have determined the safe margins for spinal canal violation when performing anterior instrumentation in children. Gertzbein and Robbins⁵ reported that canal violation less than 4 mm by posterior pedicle screws is safe. In our study, we set the common point at 3 mm anterior to the contralateral corner of the spinal canal, and a screw trajectory in the spinal canal that connects the screw entrance point and common point is safe.

To establish the safety of anterior instrumentation, the optimal screw entrance point and screw orientation are the major factors that require consideration. Many studies reported using the most anterior edge of the costal facet as the landmark when placing anterior instrumentation, and the ideal anterior screw entrance point in scoliosis is just anterior to the rib head with a slightly anterior orientation.^{10,19,23} Zhang and Sucato²² found that the position of the rib head was changed from a more anterior position in the superior thoracic spine to a more posterior position in

the caudal thoracic spine, and they suggested that a slightly anterior angle is required in the distal thoracic spine whereas a slightly posterior insertion angle is required for the proximal thoracic spine when the rib head is used as the starting point for anterior screw insertion. Qiu et al.¹⁷ recommended that the ventral excursion angle be no more than 5° when the entry point is close to the rib head, and the screws be inserted into the vertebral body 5 mm anterior to the rib head with a 10° ventral excursion angle or 10 mm anterior to the rib head with a 15° to 20° ventral excursion angle.

Several CT studies reported the importance of determining the relationship between the screw and neurovascular structures. Sucato et al.²⁰ reported differences in the aortic position, in that the descending aorta is positioned more laterally and posteriorly in patients with scoliosis and the average distance from the posterior aspects of the screw to the spinal canal was 5.3 mm. Kuklo et al.⁹ measured the distance and angle of the screw in the spinal canal and found that the screw-to-spinal-canal distance was an average of 5.3 mm with an average of 4.5° from the coronal axis. By analyzing the CT scans from T-4 to T-12, Qiu et al.¹⁶ measured the angle for safe screw placement—which is formed by the line passing the anterior edge of the bilateral rib head and the line from the anterior edge of the right rib head to the posterior wall of the aorta in the thoracic spine—and found that the angle ranged from

TABLE 4. Maximum posterior screw angle at the initial entrance*

Vertebra	Group 1 (7–9 yrs)		Group 2 (10–12 yrs)		Group 3 (13–15 yrs)		Group 4 (16–18 yrs)	
	Male	Female	Male	Female	Male	Female	Male	Female
T-5	10.4 ± 1.8	10.2 ± 1.9	10.8 ± 1.6	10.5 ± 1.1	11.3 ± 1.3	10.3 ± 1.5	12.3 ± 1.1	12.2 ± 1.5
T-6	9.4 ± 1.0	9.2 ± 1.9	9.5 ± 1.6	9.4 ± 1.9	10.6 ± 1.9	9.9 ± 1.5	11.2 ± 1.0	10.9 ± 1.7
T-7	9.0 ± 1.7	8.8 ± 1.2	9.7 ± 1.7	9.5 ± 1.8	9.7 ± 1.9	9.0 ± 1.8	10.7 ± 1.8	10.3 ± 1.6
T-8	8.9 ± 1.8	8.6 ± 1.7	9.2 ± 1.7	9.3 ± 1.9	8.9 ± 1.1	8.5 ± 1.8	10.0 ± 1.8	9.1 ± 1.5
T-9	8.8 ± 1.8	8.6 ± 1.9	8.6 ± 1.8	8.7 ± 1.7	9.3 ± 1.1	8.7 ± 1.7	9.3 ± 1.9	9.2 ± 1.4
T-10	8.4 ± 1.1	8.2 ± 1.8	8.0 ± 1.8	8.0 ± 1.7	8.9 ± 1.3	9.6 ± 1.9	8.7 ± 1.8	8.7 ± 1.5
T-11	7.8 ± 1.8	7.6 ± 1.9	7.5 ± 1.3	7.5 ± 1.7	8.2 ± 1.6	8.6 ± 1.8	7.9 ± 2.0	7.9 ± 1.4
T-12	7.4 ± 1.9	7.6 ± 1.0	6.9 ± 1.0	7.0 ± 1.7	8.0 ± 1.9	7.9 ± 1.9	8.0 ± 1.0	7.7 ± 1.6

* Values are shown in degrees as the mean ± SD.

TABLE 5. Maximum posterior screw angle at the second point*

Vertebra	Group 1 (7–9 yrs)		Group 2 (10–12 yrs)		Group 3 (13–15 yrs)		Group 4 (16–18 yrs)	
	Male	Female	Male	Female	Male	Female	Male	Female
T-5	26.7 ± 1.2	27.0 ± 2.9	27.0 ± 1.4	27.5 ± 1.6	26.3 ± 1.7	26.7 ± 1.4	26.2 ± 1.1	25.7 ± 1.3
T-6	26.1 ± 1.1	26.6 ± 1.2	26.1 ± 1.1	26.8 ± 1.8	25.3 ± 1.3	25.4 ± 1.8	25.7 ± 1.1	25.9 ± 1.5
T-7	25.9 ± 1.5	25.9 ± 2.8	26.5 ± 1.2	25.9 ± 1.8	25.0 ± 1.3	24.9 ± 1.7	24.6 ± 1.4	24.7 ± 1.1
T-8	24.6 ± 1.8	25.1 ± 1.1	25.0 ± 1.4	24.6 ± 1.1	24.4 ± 1.6	24.4 ± 2.0	23.7 ± 1.8	23.9 ± 1.4
T-9	24.2 ± 1.5	24.2 ± 1.4	24.3 ± 1.3	24.5 ± 1.5	23.9 ± 1.5	23.5 ± 1.5	23.6 ± 1.7	23.4 ± 2.0
T-10	23.1 ± 1.2	23.1 ± 1.2	23.5 ± 1.5	23.4 ± 1.0	23.8 ± 1.2	23.7 ± 1.3	23.5 ± 1.1	22.8 ± 1.5
T-11	21.5 ± 1.3	21.5 ± 2.2	22.0 ± 1.7	22.9 ± 1.3	22.5 ± 1.6	22.1 ± 1.5	22.3 ± 1.5	21.6 ± 1.6
T-12	20.9 ± 1.4	21.2 ± 1.9	22.1 ± 2.0	22.1 ± 1.4	22.6 ± 1.5	21.6 ± 1.5	21.2 ± 1.0	20.6 ± 1.3

* Values are shown in degrees as the mean ± SD.

5° to 35°, and the minimum angle was at T-7. In addition, radiological studies that refer to the posterior screw have been performed to ensure the safety and feasibility of using a posterior pedicle or translaminar screw, and these measurements provide a suitable screw angle and diameter for surgery.^{11,15} However, a thorough understanding of the relationship between the maximum posterior screw angles at different entrance points and the spinal canal in different age groups is still lacking.

In the present study, the vertebrae from T-5 to T-12 in the 4 age groups (7–18 years of age) were analyzed. A total of 896 vertebrae were measured in the present study, and the maximum posterior screw angle at the 3 screw entrance points was measured to determine the relationship between screw placement and safety in the spinal canal. The results show that the maximum posterior screw angles at the different screw entrance points demonstrated a consistently decreasing tendency in all groups. These findings are similar to those of a previous cadaveric anatomical study by Ebraheim et al.³ In addition, age had no associative effect on the maximum posterior screw angles measured.

We set the initial screw entrance point at the most anterior edge of the upper costal facet. At this entrance point, the maximum angle at T-5 (10.2°–12.3°), which consistently decreased at T-12 (6.9°–8.0°), changed to 20.6° to 27.5° at the second entrance point and 29.2° to 37.5°

at the third entrance point. This study found that if the screw was placed more anteriorly, the margin of safety for the maximum posterior screw angle broadened. For a more posterior screw entrance point, the safety range of the posterior orientation angle is very narrow. When using the initial point as the starting point, the angle of the screw placement must be < 6.9° or the screw may encroach the spinal canal, and placing the screw parallel to the coronal section or at a slight anterior orientation is better. Although the maximum posterior screw angle at the level of the third entrance point is wide, the relationship between the entrance point and the dimension of the vertebrae must be considered a problem. At the level of the superior thoracic spine, especially at T-5 and T-6 in patients between the ages of 7 to 12 years, the width ranged from 18.5 mm to 22.2 mm and the depth ranged from 16.1 mm to 19.5 mm, which is so small that the third entrance point near the front edge of the vertebrae and the screw trajectory from the anterior to the posterior cannot be not recommended by the present study.^{19,23} In addition, there are many important structures, such as the azygous vein, descending aorta, and thoracic duct. Therefore, the third entrance point is not recommended for the superior thoracic spine.

Our study was limited by its design, which used a CT morphometric analysis of the relationship between the screw trajectory and the spinal canal in pediatric thoracic

TABLE 6. Maximum posterior screw angle at the third point*

Vertebra	Group 1 (7–9 yrs)		Group 2 (10–12 yrs)		Group 3 (13–15 yrs)		Group 4 (16–18 yrs)	
	Male	Female	Male	Female	Male	Female	Male	Female
T-5	37.4 ± 1.6	37.3 ± 1.1	36.1 ± 1.9	36.1 ± 1.4	37.3 ± 1.5	37.5 ± 1.4	36.6 ± 2.0	36.3 ± 4.6
T-6	37.0 ± 1.5	37.1 ± 1.4	35.0 ± 1.4	35.3 ± 2.3	36.0 ± 1.6	36.5 ± 2.0	35.0 ± 1.2	35.8 ± 1.6
T-7	36.5 ± 1.8	36.2 ± 1.0	34.9 ± 1.6	34.2 ± 1.6	35.4 ± 2.0	35.4 ± 1.7	34.4 ± 1.8	34.2 ± 1.3
T-8	36.6 ± 1.6	36.1 ± 1.8	34.7 ± 1.8	34.5 ± 1.4	34.3 ± 1.9	34.9 ± 1.9	32.9 ± 2.1	32.5 ± 1.4
T-9	34.5 ± 1.8	34.5 ± 1.8	32.4 ± 1.9	32.8 ± 1.4	34.4 ± 1.6	34.1 ± 1.5	31.9 ± 2.1	32.7 ± 2.0
T-10	34.5 ± 1.7	34.4 ± 2.0	31.0 ± 1.9	31.5 ± 1.4	32.3 ± 1.4	32.9 ± 1.1	31.9 ± 1.7	32.1 ± 1.3
T-11	32.7 ± 1.9	32.9 ± 2.3	31.3 ± 2.0	31.7 ± 1.4	30.7 ± 1.2	30.7 ± 1.7	30.1 ± 1.8	30.2 ± 1.7
T-12	30.2 ± 2.1	31.1 ± 1.7	29.6 ± 2.1	29.2 ± 2.1	29.5 ± 1.5	29.3 ± 1.7	29.4 ± 1.3	29.2 ± 1.6

* Values are shown in degrees as the mean ± SD.

vertebrae rather than cadavers. Since the focus was patients with normal vertebrae, a future specific analysis on patients with abnormal anatomy is required to confirm our results.

Conclusions

Our investigation provides insight into the relationship between the maximum posterior screw angle and the spinal canal in order to ensure safe screw placement in the pediatric population. No significant age-related differences were noted in terms of the maximum posterior screw angles. Screws should be placed between the initial and second point parallel to the coronal section or at a slight anterior orientation.

Acknowledgments

This work is supported by a grant from the National Nature Foundation of China (Grant No. 81371988) and the Natural Science Foundation of Zhejiang Province for Distinguished Young Scholars (Grant No. R12H060001).

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Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: X Wang, Li. Acquisition of data: Shen, HZ Xu. Analysis and interpretation of data: Shen, Zhou. Critically revising the article: YL Wang, HM Xu. Reviewed submitted version of manuscript: YL Wang, HM Xu. Statistical analysis: Zhu. Administrative/technical/material support: HM Xu.

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