COMPARISON OF SCOLIOSIS DIAGNOSTIC CAPABILITIES IN SCREENING OF SCHOOLCHILDREN BY COMPUTER OPTICAL TOPOGRAPHY AND VIDEO RASTERSTEREOGRAPHY USING TODP AND FORMETRIC TOPOGRAPHS

V.N. Sarnadskiy[1], D.Y. Batorov[2], O.A. Shchuchkina[2]
[1]*Medical Topographic Systems METOS, Novosibirsk, Russia*
[2]*Polyclinic Hippocrates LLC, Dimitrovgrad, Russia*

Objective. To analyze the results of scoliosis diagnostics during the examination of the same group of schoolchildren by TODP and Formetric topographs.

Material and Methods. A total of 364 schoolchildren (197 girls and 167 boys, mean age 8.92 ± 1.9 years) were examined, divided into 3 age groups: 6–8 years old (n = 135, mean age 7.22 ± 0.7 years), 8–10 years old (n = 134 children, mean age 8.95 ± 0.56 years), 10–12 years old (n = 95 children, mean age 11.35 ± 1.59 years). Schoolchildren were examined in turn by computer optical topography (TODP, released in 2021, WTOPO 5.4-2021 software) and video raster stereography (Formetric 4D released in 2015, DICAM2.6.4 software). Three standard screening poses were used for TODP, and one pose with averaging 12 frames – for Formetric.

Results. The obtained statistics on the distribution of topographic analogs of the Cobb angle (the angle of lateral asymmetry for TODP and the angle of scoliosis for Formetric) showed a significant discrepancy in the percentage of detected scoliosis cases: 0–5° – 50,0 % (TODP) and 4.1 % (Formetric); 5–7° – 33.8 % and 9.3 %; 7–9° – 12.4 % and 17.9 %; 9–15° – 3.8 % and 51.6 %; 15–25° – 0.0 % and 16.2 %; 25–50° – 0,0 % and 0.8 %, respectively. Clinically significant cases of scoliosis (9° or more) in the age groups was 3.7 %, 2.2 %, 6.6 % (mean – 3.8 %) for TODP and 71.1 %, 70.1 %, 63.2 % (average – 68.7 %) for Formetric. At the same time, only 14 cases of clinically significant scoliosis (from 9° to 15°), including 9 structural and 5 compensatory scoliosis, were detected by TODP, and 250 scoliosis cases (188 – from 9° to 15°, 59 – from 15° to 25°, 3 – from 25° to 37°) – by Formetric. For 9 structural scoliosis cases (according to TODP), the Formetric diagnosis coincided completely only in 2 cases and partially in 3 (55 %), and in 5 cases of pelvis tilt scoliosis (according to TODP) it coincided completely in 3 cases and partially in 1 (80 %).

Conclusion. According to the results of topographic screening of 364 schoolchildren using the TODP topograph, 3.8 % of scoliosis cases of 9° or more was detected, which corresponds to the average screening data in a number of countries around the world. Examination of the same schoolchildren using the Formetric topograph revealed 68.7 % of cases of scoliosis of 9° or more, which allows us to judge about overdiagnosis and conclude that Formetric is poorly suited for topographic screening of scoliosis in schoolchildren.

Key Words: scoliosis, screening of schoolchildren, computer optical topography, video rasterstereography.

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Idiopathic scoliosis remains the most severe and unsolved problem of pediatric orthopedics in the 21st century [1].

The major point to consider when deciding on scoliosis prevention is whether non-invasive (non-radiological) diagnostics are possible at an early stage. Therefore, in the mid-60s of the last century, a medical screening of scoliosis using the Adam's forward bend test was started at school [2]. Through the publication of Takasaki [3] on the possibility of using moire topography for the examination of living people, the idea of screening for scoliosis became even more popular at the end of the last century. All the experts engaged in screening have witnessed something in common. There were a large number of false positives results as well as an abundance of initial forms of scoliosis with a Cobb angle of 5–10°. The high percentage of initial forms revealed during screening forced SRS in the 1980s to revise the definition of scoliosis and establish that scoliosis should be considered a lateral curvature of the spine with a Cobb angle of 10° or more. Cases with a Cobb angle less than 10° should be considered to have spinal asymmetry. Even so, the percentage of false positive screening results remained high and posed the question of the appropriateness of screening (mostly economic). In light of this, many foreign countries, such as Austria, Canada, France, Germany, Israel, Norway, Poland, Spain, and the United Kingdom, have abandoned scoliosis screening programs [4]. Nonetheless, in Greece, South Korea, Hong Kong, Malaysia, and half of the US states, screening was continued. In Japan, it is performed as tantamount to law [4].

Since the mid-80s of the 20th century, as a further development of moire topography, computer systems of surface topography (ST) have appeared [5–12]. They made possible to obtain a digital 3D-model of the trunk surface and use it to evaluate the spinal deformity. This approach has created opportunities for the screening of scoliosis with the advances of computer technology.

The first medical computer system for determining the shape of a person's trunk was the English system ISIS, created by Turner-Smith in 1983 [5]. The accuracy of the reconstructed topography was ±3 mm, the scanning time was 2 seconds, and the processing time was 10 minutes. Nevertheless, when creating ISIS, a very elegant technique for evaluation of the angle of scoliosis according to topography data was proposed [13]. In this technique, firstly, a line of spinous processes of the spine was marked on the skin with a marker; secondly, the rotation of the surface (in the horizontal plane) was calculated along it; and thirdly, the model of the spine axis was reconstructed considering the data obtained. Like an X-ray, the lateral asymmetry angle (LA), a topographic analogue of the Cobb angle, was defined from the frontal projection of this model. The technique had a clear physical interpretation and showed a high correlation with the data of the X-ray examination. According to the examination findings of 52 patients with scoliosis (from 10 to 50°), a correlation was found for the LA and Cobb angles equal to 0.82 [13]. The technique turned out to be very promising. Nowadays, it is widely applied in most modern topography devices, including the German Formetric [8] and the Russian TODP [9], which are the most popular in medical practice.

The method of video rasterstereography and the prototype of the Formetric topograph created on its basis were developed by a group of German authors from the University of Munich [14, 15]. In 1994, the Jenoptik Technologies Company (Germany) mastered the batch production of this topography device, and then the rights to manufacture were transferred to Diers International, another German company, which reworked the design of the topography device, and since 2003 devices have been produced under the brand name Diers Formetric. During the examination on this topography device, a static image of a set of horizontal light lines is projected onto the patient's back (their width is less than the interval between them). Processing of the images of these lines captured by the computer is performed by determining the coordinates of the centers of the lines. Using the obtained coordinates, the height of the surface is computed using triangulation for the points of the surface on which the lines hit. Considering the distance of 10 mm between the lines, it is possible to obtain from 10 to 15 thousands points on the patient's body with the measured values of the surface height, and the remaining points of the 3D model of the surface are reconstructed by interpolation. Unlike the Turner-Smith technique, the authors of Formetric rejected marking the line of spinous processes. Instead, the symmetry line of the dorsal trunk surface was automatically selected, which divides each horizontal section into left and right halves according to the criterion of the minimum of the total difference in curvature. Using this line of symmetry as an assessment of the spinous process line position, the authors implemented the proposed Turner-Smith technique for building a model of the spine axis. For evaluation of the efficiency of this approach and compliance of its outcomes with X-ray data, they examined 113 patients with a Cobb angle up to 52° and received a standard deviation of the difference between the Cobb angle and the Formetric scoliosis angle equal to 7.9° [15]. In 2012, Frerich et al. [16] performed a study of the comparability of X-ray and topography data on the modern version of the Diers Formetric 4D topograph. They obtained a correlation with X-ray for thoracic curves equal to 0.872 and for lumbar curves equal to 0.758. Meanwhile, the average difference between the topographic angle and that of Cobb was +7.0° for the thoracic curves and +9.4° for the lumbar curves, and the error range was 0–19° and 0–22°, respectively. In 2019, Bassani et al. [17] compared the data of Formetric 4D and the low-dose radiological system EOS Imaging (France), which reconstructs a 3D-model of the spine using anteroposterior and lateral images. They got a correlation with the Cobb angle equal to only 0.55, and the average difference between the Cobb angle and the Formetric scoliosis angle was 18° ± 11° (with the average Cobb angle equal to 33° ± 15°, which means the topographic estimate was underrated by 2.2 times). The data given by Frerich et al. and Bassani et al. suggests that Formetric might not be considered for the diagnosis of scoliosis as an alternative to X-ray.

The foundation of the computer optical topography (COMOT) technique was laid by the first author of this article while working on his Doctorate's dissertation (1990), within the framework of which a prototype of a topographic system for measuring the topography of the human body was developed. The first experimental model for the examination of patients with scoliosis was designed and successfully tested in 1993 together with specialists of the Novosibirsk Research Institute of Traumatology and Orthopaedics n.a. Ya.L. Tsivyan. When using the COMOT technique, a static image of vertical black and white stripes of the same width is projected by precision raster onto the human body. To receive the relief of the surface, the spatial phasometry technique developed by the first author is used, which enables to identify the height of the relief at each pixel of the image of the stripes captured by the computer (150–200 thousand points on the patient's trunk). In terms of the quality of the restored 3D-model of the trunk, TODP considerably outperforms all currently known medical topographic devices, including Formetric.

To determine the topographic angle of lateral asymmetry (LA) by TODP at the initial stage, the Turner-Smith approach was used with marking the line of spinous processes with light-reflecting markers (4 4 mm). Nevertheless, when performing mass screening, marking had to be rejected due to an additional delay and, most importantly, due to incorrect marking, which was performed by the nurses conducting the screening. Simultaneously, a different approach was used to detect the spinous process line without marking, in contrast to the Drerup and Hierholzer approach: the detection of this line by local topographic points, namely the C7 spinous process, the posterior median furrow of the back and the spinous processes protruding along it, as well as by the intergluteal cleft. It should be noted that this approach is correctly realized only with a high-quality 3D-surface model being reconstructed and functions well in the presence of clearly visible anatomical landmarks, which does not happen in all patients. Also, there may be false landmarks – artifacts (interfering hair, tattoos, scars, etc.). In this regard, any topographic device should be monitored by a physician to interpret possible errors for processing and correction, and the effectiveness of a particular topography device can be evaluated by the percentage of cases requiring human intervention.

In 2009, S.N. Baldova [18], in her Doctorate's paper, evaluated the reliability of the diagnosis of idiopathic scoliosis on TODP and found that, in 92 % of cases, the topographic diagnosis of the grade of scoliosis according to Chaklin coincided with the radiological one. In 2014, I.L. Bagrinovskaya, an orthopedist [19], performed a study of the comparability of Cobb angle and LA by TODP at the children's outpatient hospital No. 110 in Moscow. The study was carried out on a group of 50 patients suffering from idiopathic scoliosis (grade I: 32 individuals, grade II: 17 individuals, grade III: 1 individual; mean Cobb angle was 9.90° ± 5.70°; range was 2.5–33.3°). The mean value of the Cobb-LA difference according to Bagrinovskaya was -0.1° (which means that the estimate was unbiased); the standard deviation of the difference was 1.0°, and the Pearson correlation coefficient was 0.985. The obtained data showed a high degree of comparability between the angles of LA and Cobb in idiopathic scoliosis up to 50°. To broaden the range of accurate assessment, a nonlinear algorithm for constructing the spine axis under topographic data was designed in 2015–2017 [20, 21], which made it possible to achieve a Cobb-LA difference to be within ± 5° for 92 % of cases. For thoracic scoliosis (Cobb angle was 67.1° ± 33.2°, range was 6–145°), the mean value of the Cobb-LA difference was -0.23°, standard deviation was 2.96°, range was from -9.07° to +7.95°, Pearson correlation coefficient was 0.994. For lumbar and thoracolumbar scoliosis (Cobb angle was 34.66° ± 27.00°, range was 6-114°), the mean value of the difference was +0.72°, the standard deviation was 2.73°, the range was from -5.66° to +9.52°, and the Pearson correlation coefficient was 0.996°. The given data indicate that TODP provides high comparability with X-ray and may be used for the diagnosis of scoliosis.

Formetric was designed mainly for monitoring the condition of patients with scoliosis and evaluating the treatment results. TODP was designed to screen for scoliosis in schoolchildren and has been used since 1996. Today, a huge amount of experience has been accumulated (more than 500 thousand schoolchildren have been examined), which has allowed us to create a fully automatic technology for topographic screening. Quite recently, Formetric began to be applied for screening: for example, in the Gomel region of Belarus in 2014, a study was conducted on the early diagnosis of spinal deformities using Formetric [22]. At the suggestion of "Hippocrates Outpatient Hospital" LLC (Dimitrovgrad), a joint study was conducted with "Metos" LLC to evaluate the possibility of using Formetric for screening.

The objective is to analyze the results of scoliosis diagnostics obtained during the examination of the same group of schoolchildren by TODP and Formetric topography devices.

Material and Methods

Patients

A total of 364 schoolchildren (197 girls and 167 boys; mean age: 8.92 ± 1.90; interval: 4.2–16.9 years) from three educational facilities in Dimitrovgrad were examined. The parents signed an informed consent for a topographic examination of the children.

In order to perform further analysis, schoolchildren were divided into three age groups:

– junior group (6–8 years old): n = 135 (67 girls and 68 boys), mean age: 7.22 ± 0.70 years old (from 4.2 to 7.9 years old);

– middle group (8–10 years old): n = 134 (75 girls and 59 boys), mean age: 8.95 ± 0.56 years old (from 8.03 to 9.98 years old);

– senior group (10–12 years old): n = 95 (55 girls and 40 boys), mean age: 11.35 ± 1.59 years old (from 10.2 to 16.9 years old).

Techniques

Schoolchildren were examined in turn by 2 topography devices in the same room: TODP (released in 2021, WTOPO 5.4-2021 software) and Formetric 4D (released in 2015, DICAM2.6.4 software). The first author of the article conducted the examination on the TODP with the participation of a nurse to posture schoolchildren in three standard poses for screening: P1 – natural, P2 – active with straightened effort of the postural muscles of the spine, and P5 – with elbows joined in front of the trunk [23]. The examination of Formetric was performed by the second and third authors of the article in one natural pose using the averaging mode of 12 frames (according to the standard technique adopted for Formetric). Marking with light-reflecting markers was not applied in this study.

The processing of patient data during the survey on the TODP was done automatically with the simultaneous establishing of a formalized topographical diagnosis on three planes:

frontal, horizontal, and sagittal [24]. In the frontal plane, the topographical diagnosis was established by the mean angle of the LA over three poses. Meanwhile, the verification of the summed curves was performed: they should be at the same level of the spine, on the same side (left or right), and not significantly differ in the value of the LA. If one of these conditions is not met, then "SS1?" or "SS?" is displayed as a diagnosis, which signifies an error and requires correction by an interpreting physician. In the software version WTOPO 5.4-2021, a high level of proper auto processing of patients was achieved (more than 97 %), therefore, it was only four patients in the junior group which required for manual correction of the results of auto processing , one child in the middle group, and three children in the senior group, which is 2.2 % of all patients examined. The Formetric data was processed by the 3rd author after the examination: the percentage of cases for which correction was required (of the border and, more often, of points of the line of symmetry) was 31.6 %, and in groups starting from the junior, there were 42, 53, and 20 cases (31.1 %, 39.5 %, and 21.0 %, respectively).

Statistical analysis

For statistical processing and graphical analysis, Microsoft Excel was used, for which examination data was downloaded via the WTOPO export function and manually from Formetric display forms.

Results

Fig. 1a depicts the distribution of the examined individuals by the formalized topographic diagnosis of TODP in the frontal plane [24]. For the diagnosis of TODP in this plane, the following conditions are differentiated:

- without scoliosis: N (Normal, back posture close to harmonious); S (Subnormal, minor disorders), OD (Other Disorders, moderate disorders associated with twisted pelvis, asymmetry of the shoulder blades, trunk imbalance, etc.);
- functional scoliosis: FS (single lateral curvature of the spinous process line without rotation at the top of the curve and without a pelvis tilt conformed with the curve);
- pelvis tilt scoliosis: PTS (single lateral curvature of the spinous process line without rotation or with weakly pronounced rotation at the curve apex in the presence of a pelvis tilt conformed with the curve;
- structural scoliosis: SS (one or more lateral curvatures of the spine with the presence of rotation at the curve apex of at least one curve).

FS, PTS, and SS are divided into grades according to the LA angle [24]:

- 5–7° – FS0, PTS0, SS0 (grade 0–1, preclinical form, the subnormal level);
- 7–9° – FS1, PTS1, SS1 (grade 1, preclinical form, level of mild disorders);
- 9–15° – FS1-2, PTS1-2, SS1–2 (grade 1–2, risk group for scoliosis);
- 15–25° – FS2, PTS2, SS2 (grade 2 according to the updated Chaklin classification);
- 25–50° – PTS3, SS3 (grade 3 according to the Chaklin classification);
- ⩾50° – SS4 (grade 4 according to the Chaklin classification).

Fig. 1b shows the distribution of junior high school students by a formalized diagnosis, plotted according to the data of the screening program for schoolchildren in Novosibirsk, which was in effect in 2010–2017. The values of the graph samples for PTS2, SS2, PTS3, and SS3 are enhanced 100 times so that the presence of grade 2 and even grade 3 scoliosis can be better observed (the average sample size for the year is more than 8 thousand). The graph (Fig. 1b) proves that pronounced scoliosis at a junior age is extremely rare. By comparing Fig. 1a (6–8 years) and Fig. 1b, we can make sure that the data for Dimitrovgrad do not have significant differences from the data for Novosibirsk and represent an ordinary picture for Russia.

In Formetric device, a single angle is calculated for the main curve (with a maximum angle in the presence of several curves) and scoliosis itself does not differentiate into FS, PTS, and SS. Therefore, to compare the statistics of TODP, values N, S and OD were merged into the NS – none scoliosis group. FS, PTS and SS were divided into groups by grades: S0–S3. Fig. 1c for TODP and Fig. 1d for Formetric show graphs with the statistics obtained. These graphs prove significant and oppositely directed differences for the two topography devices. In TODP (according to the "All" column – statistics without age), none scoliosis cases (50.0 %) prevail. Then come preclinical scoliosis S0 (33.8 %) and S1 (12.4 %). After that, we can see the statistics for the scoliosis risk group S1–2 (3.8 %). Scoliosis of grades 2 and 3 was not revealed. As for Formetric data, there is a predominant risk group for scoliosis S1–2 (51.6 %), followed by S1 (17.9 %), S2 (16.2 %), and S0 (9.3%), and none scoliosis cases are extremely rare (4.1 %; in the senior group, only 1.1 %). Meanwhile, three cases of grade 3 scoliosis were revealed in the junior group. Clinically significant scoliosis (9° or more) detected by TODP in age groups was: 3.7 %, 2.2 %, and 6.6 % (on average, 3.8 %); and that detected by Formetric: 71.1 %, 70.1 %, and 63.2 % (on average, 68.7 %). Such a statistics received for the Formetric device differs significantly from the statistics on the prevalence of scoliosis (10° or more), known from the outcomes of screening in different countries (from 0.6 to 3.5 %) [21]. Data obtained for TODP on the scoliosis prevalence correspond to literature data. As for Formetric, it shows overdiagnosis with a 20-fold excess of cases of detected scoliosis.

Fig. 2 presents the distribution of the main curves by regions of the spine, including the total curve, obtained according to the examination on TODP and Formetric devices. It was Shulthess, a well-known Swiss orthopedist, who introduced the term "total curve" [25] in the classification of scoliosis created by him (the first one known from the literature). The total curve is not structural. It takes up the majority of the spinal column and manifests in cases of functional and pelvis tilt scoliosis. The curves on the graphs are indicated in accordance with the classification of scoliosis [26]. The given graphs demonstrate a significant discrepancy

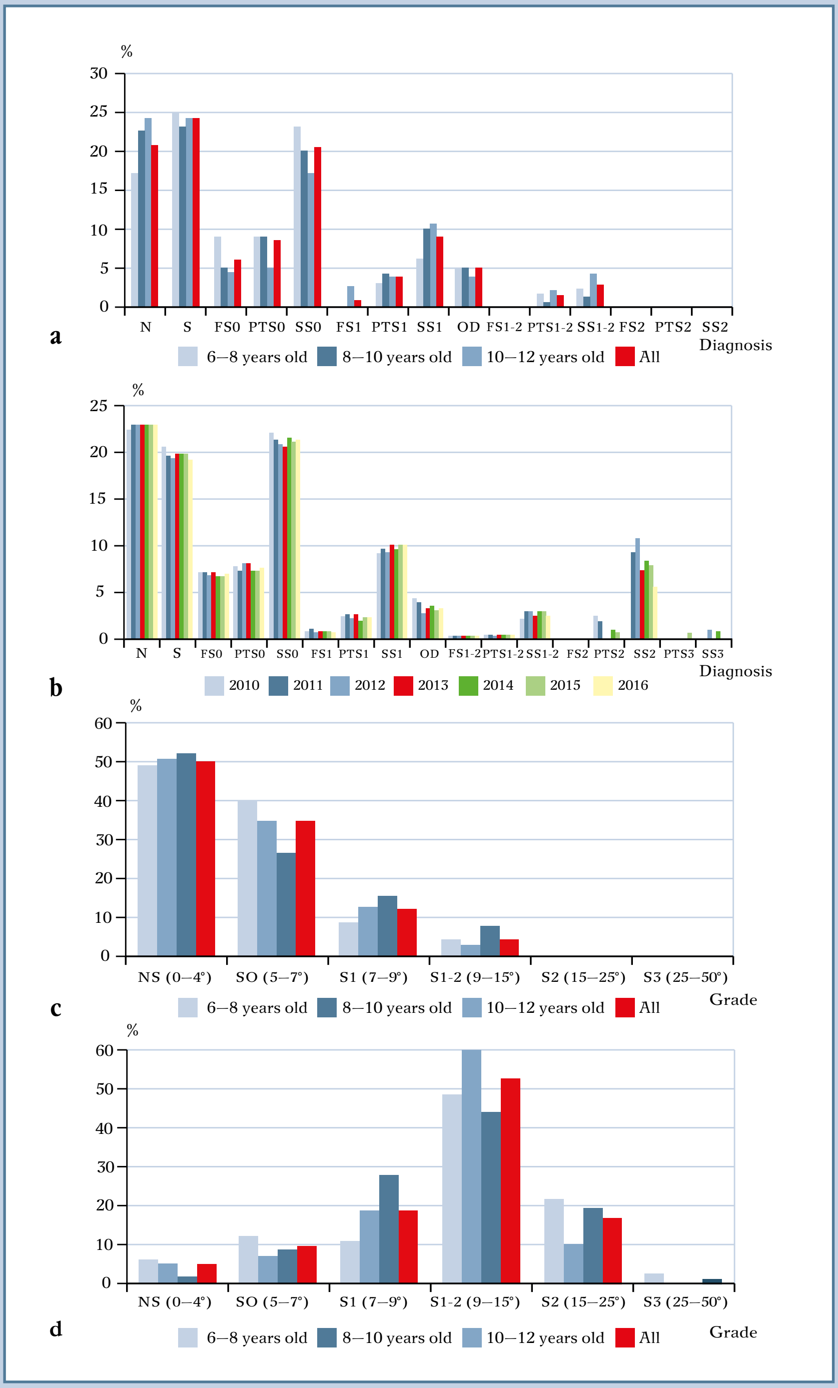

Fig. 1
Statistics on scoliosis: **a** – distribution of schoolchildren in Dimitrovgrad according to the formalized topographic diagnosis of TODP for the frontal plane; **b** – distribution of schoolchildren in Novosibirsk according to the formalized topographic diagnosis of TODP for the frontal plane according to screening data of 61,000 junior schoolchildren; **c** – distribution of schoolchildren in Dimitrovgrad: without scoliosis (NS) and with scoliosis according to TODP data; **d** – distribution of schoolchildren in Dimitrovgrad: without scoliosis (NS) and with scoliosis according to Formetric data

in the localization of the main curves for the compared topography devices: in TODP, lumbar (more than 20 %) and total (more than 15 %) curves predominate, and proximal thoracic curves are absent; in Formetric, thoracic (about 40 %) and total (more than 20 %) curves predominate, and more than 15 % of proximal thoracic main curves have been identified, which in practice are extremely rare (mainly in congenital forms of scoliosis).

Fig. 3a presents a graph illustrating the identified by TODP and Formetric data of the main scoliotic curves in all the examined individuals. Each of them has a graph report with the angle of the LA set on the axis of the TODP (averaged over three poses) and on the axis of the Formetric – the scoliosis angle. The convex side of scoliotic curves is indicated by the signs "+" for right-sided and "-" for left-sided curves. If the correspondence between LA and the scoliosis angle was good, then the reports of the graph would be placed near the diagonal drawn from left to right, from bottom to top, through the zero point of the axes. Nevertheless, in our case, such a picture is not observed, which suggests a significant discrepancy between the data on scoliosis detected by TODP and Formetric. This was reflected in the very weak Pearson correlation for LA and Formetric scoliosis angle, which for the age groups from junior to senior was 0.163, 0.093 and 0.123, respectively. In all age groups, the pattern of randomness is approximately the same (only in the "6–8-year-old" group is a slightly larger spread observed in Formetric). In Fig. 3a, arrows mark four schoolchildren, indicated as Ex1–Ex4. These clinical examples are shown in Fig. 4 and described in Table 1.

Fig. 3b presents the same graph as in Fig. 3a, but with samples colored (without considering age) according to the result of comparing the scoliotic curves of the Formetric with the main curves of the TODP. The Formetric curves are divided as follows: FC – false curves (the TODP has no curves, LA = 0), IC – inverse curves (the TODP curves are directed to one side, and the Formetric curves – to the other, which is incorrect), and UC – unidirectional curves (the direction of the curves is the same, and the Formetric curve can be correct if it is not significantly different from the TODP one in the angle and position of the apex). Additionally, UC are divided into three parts according to the absolute value of the difference d between the angles of scoliosis and LA: d < 5°, 5 ° ⩽ d < 10° and d ⩾ 10°. PT curves are excluded from the UC as obviously false. It should be noted that the affiliation of Formetric curves with the UC does not mean their true correctness in comparison with the TODP, since the analysis did not consider the position of the apex of the curves being compared. Thus, some of the curves may well be placed in different regions of the spine, which would also be incorrect when establishing a diagnosis of scoliosis. UC with d < 5°, colored green, can be considered correct (without considering the coincidence of the apex position).

Fig. 4 presents the clinical cases of Ex1–Ex4, marked with arrows in Fig. 3a, which revealed the maximum discrepancies in the diagnosis of scoliosis between the TODP and Formetric. Data on these clinical examples are shown in Table 1. The figure for each Ex shows 5 pictures (in a row from left to right): 3 for TODP and 2 for Formetric.

The TODP shows the following data:

- frontal projection of the spine model with the value of LA, derived at the level of the apex of main curve (with the sign "+" for the right-sided and "-" for the left-sided curves). The vertebral bodies are displayed on the model; their centers are indicated by dots, and the line of spinous processes is a continuous line;
- a model of the trunk in the form of paravertebral asymmetry in nude for areas without asymmetry and with color on the side with excess relief. The coloring depends on the difference in the height of the relief in paired points placed symmetrically on the same horizontal relative to the line of spinous processes (1.0–2.5 mm – gray, 2.5–5.0 mm – yellow, 5–10 mm – purple, 10–20 mm – dark red, and 20–40 mm – red);
- a model of the trunk, colored in proportion to the summarized (vertical and horizontal) curvature of the surface; in this case, blue color corresponds to concavities, red to the convexities of the relief, and white to zero curvature.

Formetric presents the following data:

- the model of the trunk, colored in proportion to the average curvature (the mean value of the main curvature), where the coloring is similar to the model of the curvature of the TODP;
- frontal projection of the spine model with the Cobb angle, drawn by the software on two extreme vertebrae of the curve with a maximum slope. The scoliosis angle, derived at the level of the apex of the curve, like the LA, is with a sign "+" for right-sided and "-" for left-sided curves.

The summarized curvature of TODP (3rd in a row) and the average curvature of Formetric (4th in a row) are close analogues. It can be seen by its similarity in the same patients. Nevertheless, the two topography devices show a significant difference in detail (spatial resolution) and the range (presence of semitones) of curvature. This clearly illustrates our statement that the TODP device is significantly superior to the Formetric one in the quality of the 3D-model of the trunk. In our opinion, this is the main reason for the incorrect construction of the spine model (5th in a row) according to the Formetric data and, as a consequence, the gross mistakes in estimating the scoliosis angle. The scoliosis of grade 3 was found in Formetric for Ex1 and Ex2 (+25° and -37°, respectively) while there was no scoliosis according to the TODP data.

Table 1, in addition to Ex1–Ex4, provides a description of Ex5–Ex18 – all clinically significant scoliosis cases

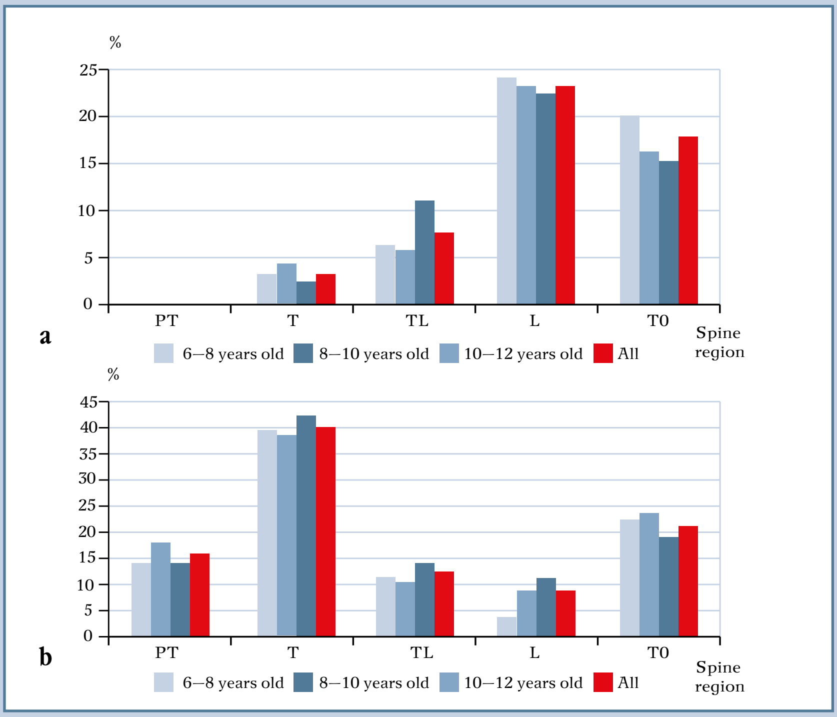

Fig. 2
Distribution of the main curves by spine regions (PT –proximal thoracic, T – thoracic, TL – thoracolumbar, L – lumbar and To – total curve), presented as a percentage of the examined schoolchildren: a – according to TODP data; b – according to Formetric data

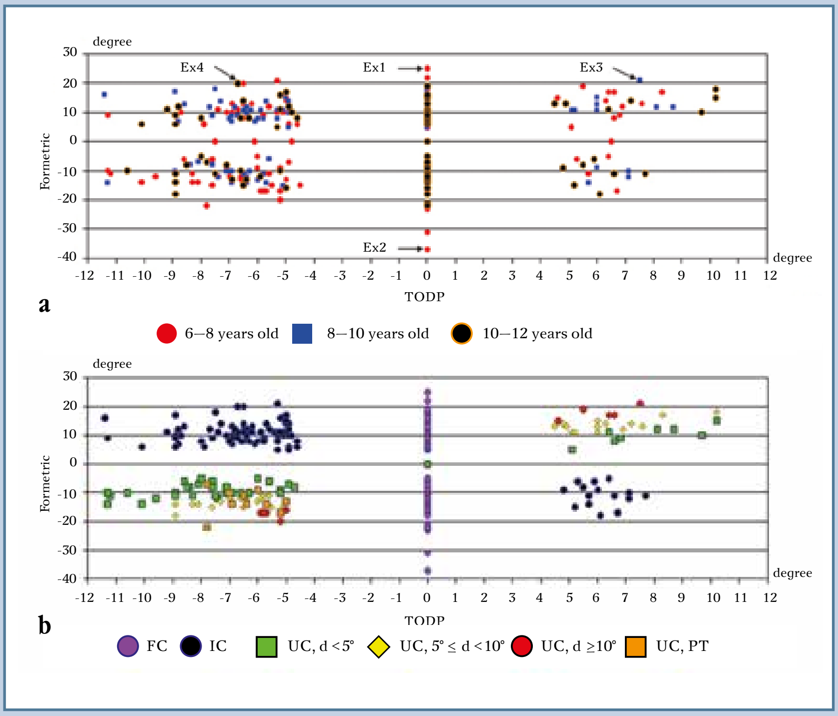

Fig. 3
Comparison of data from TODP and Formetric for the main (total) scoliotic curves: **a** – comparison of the LA angle (TODP) and scoliosis angle (Formetric) separately for three age groups; **b** – comparison of the LA angle (TODP) and the scoliosis angle (Formetric) for all ages, divided into FC – false curves, IC – inverse curves, UC – unidirectional curves along the side with deviation of the angle by d value

(9–15°) identified according to the TODP data. The 4th column of the table presents the diagnosis in the frontal plane (see “Results” section). The 5th column indicates the type of scoliosis according to the classification [26], pursuant to which, in the designation of scoliosis, the first field (a letter, R or L) describes the side of the main curve; the second field (digit, 1–4) is the number of scoliotic curves; the following fields (1-4) describe the localization of the curves along the spine (PT –proximal thoracic, T – thoracic, TL – thoracolumbar, L – lumbar, To – total). If there are two or more curves, the main curves (one or more, for example, Ex8) are indicated in uppercase, and the secondary curves (Ex6) are indicated in lowercase. In the 6th column, the LA angle of the main curve is indicated. The 7th column indicates the scoliosis angle grade according to Formetric (without separation between structural and pelvis tilt scoliosis); in the 8th: the type of scoliosis according to the classification [26], considering the additionally drawn curves by the model of the spine; in the 9th: the value of scoliosis angle according to Formetric, shown by the software; in the 10th: “+” or “-“ sign describes the side of the convex (on the left - TODP and on the right – Formetric); in the 11th: the dislocation of the apex by the number of vertebrae in the Formetric relative to the TODP (the “+” sign corresponds to the upward dislocation, and the “-“sign corresponds to the downward dislocation); and in the 12th, there is a discrepancy in the grade of scoliosis (on a scale of S0, S1, S1–2, S2 and S3) in the larger (“+”) or smaller (“-“) side.

In the rightmost column, “Conformity Assessment,” in the Table 1, an evaluation of the coincidence of the identified Formetric curve of scoliosis and the main curve of the TODP is given. Possible assessment options: FC – a falsely detected curve; IC – an inverse curve (not matching on the side of the convex); “--”– a weak match; “+-“ – a partial match; “++” – a complete match.

Using this assessment, it is possible to establish liability of scoliosis diagnosis by Formetric in comparison with TODP. For structural scoliosis SS1–2 (Ex5–Ex13) we have the following: “IC” – 3 (33 %) cases; “--” – 1 (11 %); “+-” – 3 (33 %); “++” – 2 (22 %), i.e., in 55 % of cases, we have a complete or partial match. For Ex5, Ex8, and Ex11, we have inverse curves, which enables us to consider the diagnosis of Formetric as incorrect. In Ex6, in the presence of unidirectional main curves, there is a weak coincidence in the diagnosis due to the different types of scoliosis detected: TODP – L-2_t_L and Formetric – L-2_T_tl, i.e., in both cases we have left-sided S-shaped scoliosis, but TODP shows a main lumbar curve (-9.9°); in Formetric, the main curve is thoracic (-12.0°), and its apex is shifted by 8 vertebrae relative to the main lumbar curve of the TODP. Thus, in this case, it is hardly permissible to consider the diagnosis of Formetric correct. For pelvis tilt scoliosis (Ex14–Ex18), we have the following: “IC” – 1 (20 %); “--”– 0 (0%); “+-” – 1 (20 %); “++” – 3 (60 %); i.e., in 80 % of cases, we have a complete or partial coincidence. In 20 % of cases (Ex17), we have a false negative result, i.e., the absence of clinically significant scoliosis.

Discussion

The results of the study show not only that the statistics of scoliosis revealed on Formetric is far from clinical practice, but also that main curves have atypical localization. It is well known from the literature on idiopathic scolioses that proximal thoracic (PT) curves are found only as counter curve for the main thoracic curve; the PT curve can be the

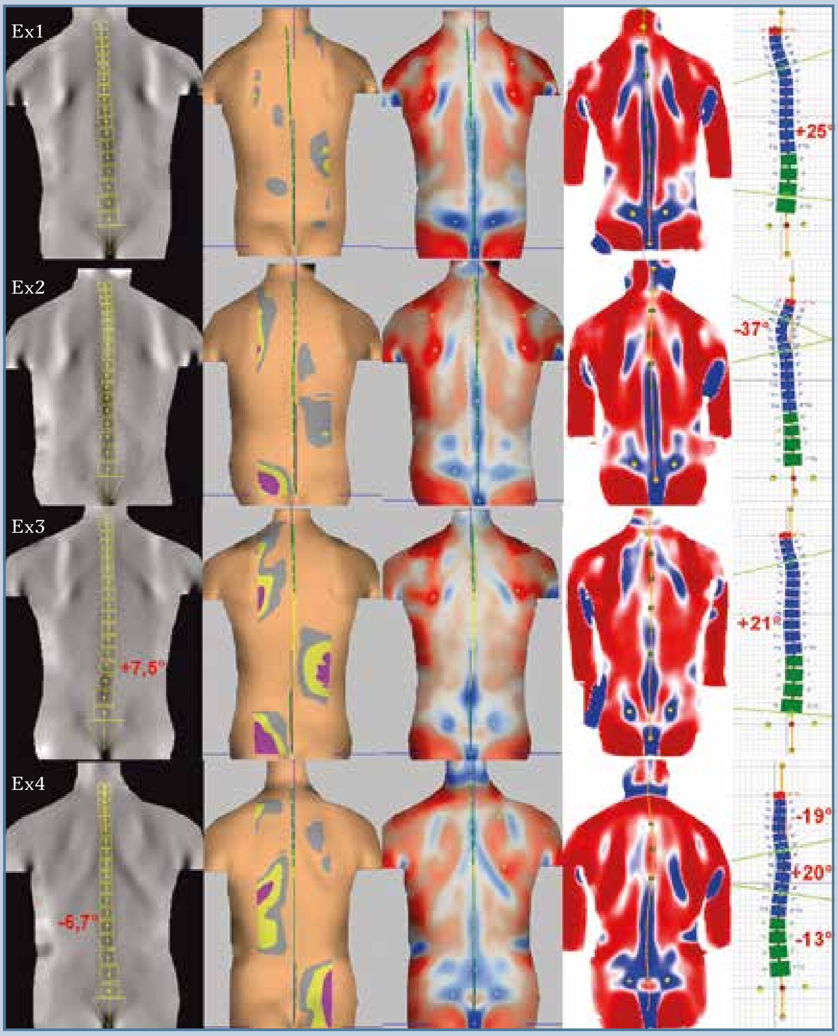

Fig. 4
Clinical cases of Ex1–Ex4, marked in Fig. 3a and having the maximum discrepancies in the diagnosis of scoliosis in TODP and Formetric, with data given in Table 1 and description in the text of the article

main one only for congenital scoliosis, which manifests itself extremely rarely. Therefore, all cases with PT curves can undoubtedly be attributed to misdiagnosed scoliosis. The thoracic (T) curves, according to the TODP, revealed only 3 %; according to the Formetric data, about 40 %, which also indicates a misdiagnosis of most of them. The thoracic spine is more stable to lateral curvature due to the ribs. Speaking of the progression of the curve, T curves are the most hazardous, and there simply cannot be so many of them in pre-adolescence. There are slight differences in TL curves: 7.4 % in TODP, and 12.3 % in Formetric. According to the TODP data, the maximum number of curves was revealed for the lumbar spine (23.0 %), and according to the Formetric data, their number is minimal (8.8 %) in other regions of the spine, which also does not correspond to the clinical picture of scoliosis. It's well known that the L curves are more common than others due to the greater mobility of the lumbar spine associated with the absence of ribs. For total curves, no large differences were detected between TODP (17.3 %) and Formetric (21.7 %) findings. Therefore, the distribution of the identified Formetric scoliotic curves across the spine in comparison with TODP looks abnormal and inappropriate for clinical practice.

The obtained outcomes demonstrate the poor suitability of the Formetric topography device for the screening of scoliosis in schoolchildren. It is verified by the data obtained by our colleagues from Belarus [22], who examined 252 schoolchildren aged 6–16 years (114 boys and 138 girls) using the Diers Formetric topography device and identified 180 (71.4 %) cases of scoliotic posture and 37 (14.8 %) cases of scoliosis, which in general is 86.2 %. The obtained data confirm the overdiagnosis.

Patients with clinically significant scoliosis identified on the Formetric topography device (29 schoolchildren, or 11.5 % of the number examined) were referred for X-ray examination. The following outcomes were obtained (according to the classification used in the Republic of Belarus):

- scoliosis is not confirmed – 14 individuals (48.3 %);
- scoliosis of grade 1 (from 5 to 10°) – 12 individuals (41.4 %);
- scoliosis of grade 2 (from 10 to 25°) – 2 individuals (6.9 %);
- scoliosis of grade 3 (from 25 to 45°) – 1 individual (3,4 %).

Consequently, only 3 (10.3 %) of the 29 patients who were referred for X-ray control had clinically significant scoliosis. According to the findings of incorrect detection of scoliosis on Formetric, 26 patients (89.7 %) were mistakenly referred for additional examination. The same paper describes the results of X-ray and Formetric examination of six children undergoing rehabilitation. Using these data and the classification of scoliosis [26], the Formetric data were compared with radiography (Table 2). According to Formetric, a false curve of 16° was found in one patient (not detected on the X-ray); in the results of three individuals, the curve turned out to be inverted (i.e., of different directions); in two patients, unidirectional Formetric

Table 1

Description of clinical cases of Ex1 –Ex4 (Fig. 4) and Ex5–Ex18 – clinically significant scoliosis identified on TODP

Patients	Gender	Age, years	TODP			Formetric			Comparability between TODP and Formetric			
			Diagnosis FP	Scoliosis type	Angle of the main curve, degree	Scoliosis grade	Scoliosis type	Angle of the main curve, degree	Side	Apex level	Grade	Conformity assessment
Ex 1	F	7.5	S	–	0.0	S3	R-1_To*	+25	–	–	+5	FC
Ex 2	M	7.3	N	–	0.0	S3	L-1_PT*	-37	–	–	+5	FC
Ex 3	F	8.6	SS1	R-1_TL	+7.5	S2	R-1_To*	+21	++	+3	+2	--
Ex 4	M	10.4	SS0	L-1_TL	-6.7	S2	R-3_PT_T_l*	+20	-+	+5	+3	c
Ex 5	M	6.9	SS1–2	L-1_L	-11.3	S1–2	R-1_T*	+9	-+	+7	0	IC
Ex 6	M	7.0	SS1–2	L-2_t_L	-9.9	S1–2	L-2_T_tl	-12	--	+8	0	--
Ex 7	M	7.6	SS1–2	L-1_L	-11.2	S1–2	L-1_T	-11	--	+7	0	+-
Ex 8	F	9.5	SS1–2	L-2_T_L	-11.4	S2	R-1_To*	+16	-+	+6	+1	IC
Ex 9	F	9.6	SS1–2	R-1_T	+12.9	S1–2	R-1_T	+11	++	-1	0	++
Ex 10	F	10.0	SS1–2	R-1_T	+10.6	S2	R-1_To*	+18	++	-1	+1	+-
Ex 11	F	10.1	SS1–2	L-1_L	-10.2	S1–2	R-1_To*	+11	-+	+6	0	IC
Ex 12	F	13.4	SS1–2	R-1_TL	+10.2	S2	R-1_L	+15	++	-2	+1	+-
Ex 13	F	15.0	SS1–2	R-1_TL	+9.9	S1–2	R-1_L	+10	++	-2	0	++
Ex 14	F	7.1	PTS1–2	L-1_To	-11.3	S1–2	L-1_T	-10	--	+3	0	++
Ex 15	F	7.1	PTS1–2	L-1_To	-10.1	S1–2	L-1_To	-14	--	0	0	++
Ex 16	F	12.3	PTS1–2	L-1_To	-11.1	S1–2	L-1_To	-14	--	+2	0	++
Ex 17	F	15.9	PTS1–2	L-1_L	-10.8	S0	R-1_L	+6	-+	+1	-2	IC
Ex 18	F	15.9	PTS1–2	L-1_L	-10.6	S1–2	L-1_T	-10	--	+7	0	+-

* The model of the spine, built according to Formetric data, does not correspond to the shape of the dorsal surface of the trunk, reconstructed according to TODP data; the diagnosis of FP is a formalized diagnosis of TODP for the frontal plane; scoliosis type – an automatically set scoliosis type according to the classification [26] used in TODP (for example, L-1_L – C-shaped left-sided lumbar scoliosis or L-2_t_L – S-shaped scoliosis with a main left-sided lumbar curve and a right-sided secondary thoracic curve); angle of the main curve (TODP) – the angle of the main curve averaged over three poses; scoliosis grade – the Formetric grade established by the angle of scoliosis in accordance with the formalized diagnosis of TODP (without division into FS, PTS and SS); scoliosis type – the Formetric type of scoliosis established according to the frontal plane of the spine model according to the classification [26]; the angle of the main curve is the angle of scoliosis; side: "++", "--" – unidirectional (two right-sided or left-sided curves), "-+" or "+-" – inverse curves (TODP is left-sided, Formetric is right-sided or vice versa); apex level – displacement of the apex of the Formetric curve relative to TODP by the number of vertebrae with a "+" sign for upward displacement and "-" sign for downward displacement; grade – the difference in the grade of scoliosis according to the formalized diagnosis of TODP, "+" – an overestimation of the grade, "-" – an underestimation of the grade; conformity assessment – determination of the coincidence of the detected Formetric curve for the angle of scoliosis and the main curve of TODP: FC – false detected curve, IC – inverse curve (not coinciding along the side of the convexity), "--" – weak coincidence, "+-" – partial coincidence, "++" – good coincidence.

and radiographic curves were different by 2 grades (the difference in angles is 4°, referred to as the "full coincidence" variant) and 3 grades (the difference in angles is 25°, referred to as the "weak coincidence" variant). In this regard, only in one out of six cases did the Formetric topography device provide a comparable diagnosis of scoliosis compared to an X-ray. It should be noted that the average Formetric angle of scoliosis was 19.2°, and Cobb angle – 10.4°. In other words, for the initial forms of scoliosis, the Formetric angle gave an overestimate compared to the X-ray, which differs from the data of Frerich and Bassani [16, 17] in which, for clinically significant scoliosis, the Formetric angle gave an underestimate compared to the Cobb angle.

The conducted study and analysis make it possible to draw the following conclusion: the Formetric topography device cannot be recommended for screening schoolchildren since it does not provide an accurate diagnosis of the early forms of scoliosis and gives an overdiagnosis of scoliosis in healthy children. Our conclusion is consistent with the opinion of Weiss [27], which has been using Formetric since 1995. He said that the video rasterstereography seems to be useful for research. He also added that the limits of technical errors are too large to

Table 2

Comparison of X-ray examination and Formetric data of 6 patients [22]

Patients	X-ray examination			Formetric			Compliance between X-ray examination and Formetric		
	Scoliosis type	Scoliosis grade	Cobb angle, degree	Scoliosis type	Scoliosis grade	Scoliosis angle, degree	Side	Scoliosis grade	Conformity assessment
1	–	–	–	L-1_T	S2	-16	-	-	FC
2	L-1_TL	S1	-7	R-1_TL	S2	+18	-+	+2	IC
3	L-1_TL	S0	-6	L-1_T	S1–2	-10	--	+2	++
4	L-1_TL	S1	-8	R-2_T_l	S2	+22/-12	-+	+2	IC
5	L-2_t_L	S1–2	+6/-13	R-1_TL	S1–2	+13	-+	0	IC
6	L-1_TL	S1	-8	L-1_TL	S3	-33	--	+3	--

Designations in the Table 2 correspond to the designations in Table 1.

draw conclusions in an individual case, especially for patients with scoliosis.

Conclusion

Based on the results of topographic screening of 364 schoolchildren in Dimitrovgrad, 3.8 % of cases of scoliosis of 9° or more were detected on the TODP device, which corresponds to the average screening data in a number of countries worldwide. According to the outcomes of the examination on Formetric device, 68.7 % of scoliosis cases of 9° or more were revealed in the same schoolchildren. The obtained results suggest overdiagnosis and conclude that Formetric is poorly suited for topographic screening of scoliosis in schoolchildren.

The study had no sponsors.
Potential conflict of interest: V.N. Sarnadskiy is the author of the computer optical topography technique and the CEO and founder of "METOS" LLC, the manufacturer of the TODP device. D.Yu. Batorov and O.A. Shchuchkina are users of the Formetric system and apply it in their clinical practice.
The study was approved by the institution's local ethics committee.
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Address correspondence to:
Sarnadskiy Vladimir Nikolaevich
Medical topographic systems «METOS»,
31 Krylova str., office 54, Novosibirsk, 630091, Russia,
metos.org@gmail.com

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Vladimir Nikolaevich Sarnadskiy, PhD in Technical Sciences, General Director of the LLC "Medical topographic systems "METOS", 31 Krylova str., office 54, Novosibirsk, 630091, Russia, ORCID: 0000-0003-2514-7378, metos.org@gmail.com;

Dmitry Yuryvich Batorov, orthopedist, chief physician, Hippocrates Polyclinic LLC, 556 Aviastroitelei prospect, Dimitrovgrad, 433513, Russia, ORCID: 0000-0002-6128-6394, gippokrat-dd@yandex.ru;

Olga Aleksandrovna Shchuchkina, orthopedist, Polyclinic Hippocrates LLC, 556 Aviastroitelei prospect, Dimitrovgrad, 433513, Russia, ORCID: 0000-0003-3935-7480, gippokrat-dd@yandex.ru.