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Review article

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Evolution of optical diagnosis of spinal deformity. Methods and future development (literature review)

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Abstract

Introduction Diagnosis of spinal deformities in children and adolescents is important for continuous development of modern traumatology and orthopaedics. Methods of optical diagnosis of scoliosis and postural disorders have been rapidly developing along with optical and digital assessment technologies over the past centuries and required a structural analysis of the accumulated data. **The purpose** was to explore clinical and technical aspects of optical diagnosis of spinal deformities. **Material and methods** The original literature search was conducted on key resources including the National Library of Medicine (PubMed) and Scientific Electronic eLibrary. The search depth was 10 years. **Results** The article presents a review of the methods historically developed in optical diagnosis of spinal deformities. Major methods and systems of optical diagnosis presented included moire topography, the ISIS system, modern methods of computer optical topography (raster stereography) photogrammetric methods used in clinical medicine and in trauma and orthopaedics. Characteristics of the methods and systems are described with advantages and disadvantages discussed. The article reports evaluated accuracy, reliability and reproducibility of optical diagnostic methods. The article presents the latest information about the possibilities of introducing technology for assessing spinal deformity using modern personal telecommunication devices. **Conclusion** The evolution of modern trends in optical diagnosis of spinal deformity is important for medicine to facilitate safety, greater accuracy, ease of operation, digitalization and development of the Internet of Medical Things.

Keywords: spinal deformity, scoliosis, optical diagnostics, photogrammetry

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INTRODUCTION

A quote from Professor Nicolas Andry de Bouaregard "Haec est regula recti" [1] is on the frontispiece of the first volume of his pioneering work. The Latin phrase translates as "This is the rule for straightness" or "This is the rule for the vertical". One of the illustrations in the book, that of the crooked tree was adopted throughout the world as the symbol of traumatology and orthopaedics. The term became attached to an important surgical specialty that deals with the detection and utilization of the reference values of spatial characteristics of the spinal column as a "reference point" for assessing the severity of the curve.

Excluding imaging assessment with routine radiography and computed tomography methods of optical or visual assessment of spinal deformity were reduced to a subjective visual examination of the back configuration or a comparison of the location of topographic formations with invariably true reference parameters. A typical example of such a standard in modern traumatology and orthopedics included a plumb line, a certain object of sufficient weight, suspended on a thread that was used to characterize a curve employing a relative position. The severity of the physiological curvatures relative to could be identically assessed in relation to the wall of the room [2]. Visual and optical diagnostic methods have been improved in the course of the last few centuries based on advances in optical, imaging and digital technologies.

MATERIAL AND METHODS

The original literature search was conducted on key resources including Scientific Electronic Library (www.elibrary.ru) and the National Library of Medicine (www.pubmed.ncbi.nlm.nih.gov) between 2012 and 2022.

RESULTS AND DISCUSSION

The concept of photogrammetry that is logically interpreted as graphic measurement using light is essential for modern interpretation of the optical principles of diagnosis in traumatology and orthopaedics [3, 4]. Photogrammetry is defined by the American Society for Photogrammetry and Remote Sensing (ASPRS) as the science of obtaining precise information about the surface structure of an object by a recording device which is not in direct contact with the object that is being studied [5].

Based on the definition, photogrammetry should include other imaging modalities that are used in clinical practice: radiography, computed x-ray tomography, magnetic resonance imaging and even 3D ultrasound modeling (for objects that are not in direct contact with the sensor [6]). And it is logical to offer a broader interpretation of the term clinical photogrammetry suggesting that the subject of clinical photogrammetry includes optical effects of an object (patient) obtained as a result of recording and objective assessment of the properties of a light beam irradiating an object in the visible range. Luhmann [7] suggested that photogrammetry can be applied in every circumstance where the object of interest can be photographically documented. Methods of modern clinical photogrammetry (PM) will be reviewed here in accordance with the interpretation. Technologically all methods of modern FM can be divided into groups:

1) PM with single camera: the parameters of the object image in one plane are analyzed with the camera being immobile. If a stereoscopic camera is used for PM to take two pictures from different angles at the same time, a partial three-dimensional reconstruction of an object can be produced using two images. In modern biometrics, stereoscopic camera effects are provided with multi-lens camera or lens splitter technologies. Stereoscopic photography is equivalent to PM using several cameras;

2) PM with several cameras: images from cameras located in the vicinity of the object are used for the three-dimensional reconstruction. Multiple cameras can be used depending on the purpose of the study;

3) PM with SFM technology: SFM (structure from motion) technology in PM is automated process using key points to match large sets of images with overlapping areas. 3D object model reconstruction is based on information obtained from images of a video stream or a set of photos taken from different angles. SFM has been shown to be the most promising technology in applied biometrics [8] without requiring multi-camera setups, special devices and equipment for the placement [3].

Modern integration of PM into clinical traumatology and orthopaedics can be divided into two main stages. The first stage is the PM analysis of shadow images projected on the surface of the human body. Methods of the first stage are proposed to be called topographic to simplify the logical presentation.

The moiré topography (1970) became the debut at the stage integrating analysis of shadows on a three-dimensional object obtained with a light beam passing from a single light source through a grating at the exact known distance from the light source to the object. The term of moiré topography is associated with the subject of the research method, which is the deformation of the shadow grating resembling the effect of "overflows" with changes in the angle of incidence with a piece of dense silk or semi-silk fabric ("moiré") [9]. The innovation was developed by H. Takasaki, an employee of the National Bureau of Standards and Technology (Washington, USA) that supported reference standards in metrology, and previously engaged in other developments in the field of optical measurements [10]. Takasaki improved the method over the course of three years and published first results of living objects explored with the moiré topography in 1973 [11], and first results of the relief and contours of the human body assessed two years later (1975) [12]. Despite a good start the moiré topography has not been widely used in clinical practice continues to be widely used in various industries and metrology [13]. Economic inefficiency and variable accuracy are the main limitations of the moiré topography [6].

Television/computer three-dimensional surface shape measurement system (ISIS-scanning) was developed by A.R. Turner-Smith at the Oxford Orthopedic Engineering Centre (1988, Oxford, United Kingdom) as the next method at the first stage of development of optical diagnostic technologies. The proposed device was a projector and television camera placed below the light source mounted together in a box which could rotate about a horizontal axis. A record of a surface shape of human back was built up by scanning the object in about 2 s. Sets of algorithms were described which derived geometric parameters [14] with the accuracy of measurement exceeding the design aim of ± 3 mm. The method was primarily introduced at the Nuffield Orthopaedic Centre, University of Oxford. Over the course of two years, the value of surface topographical measurements in the assessment of curve progression was demonstrated in a group of 51 patients, and a significant correlation was found between the magnitude of the lateral deviation of scoliotic spine at ISIS scanning and the Cobb angle ($p < 0.0001$) [15]. ISIS scanning can be used for measurement of height in scoliotic patients that is complicated by changes in spinal shape in both the coronal and sagittal planes. The resultant height change may be of use in the prediction of respiratory function [16]. ISIS2 surface topography has been successfully adapted to complement the Lenke classification of adolescent idiopathic scoliosis, which is mainly used for the choice of surgical strategy for scoliotic patients. Based on the results of ISIS2, the subjects were divided into 5 clusters based on the assessment of spinal deformity in the frontal and sagittal planes and asymmetry of the torso. The automated segregation into clusters presented a new aspect of description of adolescent idiopathic scoliosis graded by Lenke and can be applied for prospective clinical use [17].

Computer optical topography (COT, ComOT / TODT, computer optical topograph) has become a significant milestone in the development of a three-dimensional assessment of the geometry of the spinal column in Russia and is a recognized effective tool in pediatric spinal surgery at the international level and is recommended for use in achieving “harmony” of 3D correction of spinal deformities [18]. COT was developed by V.N. Sarnadsky (LLC "METOS", Novosibirsk, RF) and is based on the analysis of the pattern of vertical black-and-white stripes projected onto the surface of the patient's back. Over the past decades, COT method has proven itself as a method for one-time screening of a large flow of patients [19]. A program of annual continuous surveys of individual groups of schoolchildren was introduced in the city of Novosibirsk. About 45 thousand children were examined during one academic year and the methodology was recommended to be implemented in the regions of Russia by the resolution of the Xth Anniversary Trauma and Orthopaedic Meeting (Moscow, 2014) [20, 21]. A of COT was integrated into pediatric screening on a large scale on the territory of the Perm Region under the guidance of Professor M.G. Dudin at LLC Clinical sanatorium-dispensary "Rodnik" (Perm, RF). A group of authors reported new milestones in the etiopathogenesis of adolescent idiopathic scoliosis [22, 23, 24] with eight pathogenetic models of spinal deformity identified, between which “migration” of children occurred over several years [25]. The EOS™ X-ray machine (Tamas Illes) is practical for diagnosing spinal deformities as the most approximate method in the assessment of the COT accuracy using ultra-low radiation doses [26].

COT has been applied in the study of the static and dynamic stability of the spine as a single biomechanical system [27] and in the research hypothesis of non-coupling of the growth of the spinal cord and spine using optical and neurofunctional diagnostic methods [28, 29]. Application of the COT method is not limited to the study of spinal deformities in children and adolescents, since it is widely used for evaluating the effectiveness of surgical treatment of congenital musculoskeletal diseases including large joints [30, 31].

The universality and integrativity of the COT method is expanding in related disciplines. So, for example, COT has been applied in the synergy of sports medicine and pedagogical sports technologies detecting causal relationships between the type of sports activity and progression of spinal deformity [32, 33, 34]. In addition to that, COT can be used in obstetrics. No significant differences in lumbar lordosis [35] were found in pregnant women in the third trimesters that is commonly believed to worsen in late pregnancy [36]. Fundamentally, the method of topographic assessment of surface topography is more widely used in general clinical practice. It is used in operative ophthalmology in the evaluation of corneal defects in the surgical treatment of cataracts [37].

In addition to COT, technologically identical German system DIERS Formetric 4D (DIERS, DIERS International GmbH, Spangenbad, Germany) is employed in our country to explore the prevalence of degenerative spine diseases in adults [38]. Significant experience in using the DIERS system in Russia has been accumulated by employees of the Institute of Experimental Medicine of the Russian Academy of Medical Sciences (St. Petersburg, RF) at the Laboratory of Optical Topography, Posturology and Clinical Biomechanics under the guidance of Professor B.Ya. Velichko. Based on the results of many years of cooperation, an agreement on the production of the German system on the territory of the Russian Federation was signed in the context of the state program No. 328 "Industrial development and increasing the competitiveness" dated April 15, 2014 [39]. The developers of the DIERS system recommend term the method used in the installation as raster stereography which is actually a special case of stereophotogrammetry with the subject of analysis being a shadow grating applied to the surface of the patient's back as in the COT. Like CAT, the DIERS system allows for 3D reconstruction of the spine based on the topography of the back surface.

The manufacturer of the DIERS system declares the possibility of a four-dimensional study of the spine with the "fourth dimension" indicating the possibility of a dynamic assessment of the spatial characteristics of the spine in time including comparison and analysis of parameters resulting from minor body vibrations or functional/postural tests. The DIERS system showed good results in comparative studies where X-ray of the spine acted as a reference tool: the correlation coefficient between the Cobb angles and similar values obtained with the DIERS system was 0.758-0.872, and the average difference between radiography and raster stereography was 6.98-9.42°. The reliability and reproducibility of the method compared to radiography, the "gold standard" for spinal deformity assessment has been reported in a number of studies [6, 40].

Rasterstereography offers a reliable method to detect the effects of lower limb discrepancy on spinal posture and pelvic position. The study of 115 subjects showed that there was a correlation between an artificial leg length inequality up to 15 mm and pelvic tilt or torsion, but only minor changes in the spinal posture were measured [41]. The results of the study demonstrated the need to explore the timing of occurrence of compensatory changes in pediatric spine in children with lower limb discrepancy. The evidence of the diagnostic effectiveness of the DIERS system was reported in a study with output rasterstereography parameters being confirmed with 3D laser scanning technology [6].

Summarizing the information about the DIERS system, rasterstereography can be recommended for examination of children and adolescents with spinal deformity:

1) for the initial assessment of spinal deformity when the need for radiography remains unclear;

2) for dynamic assessment of spinal deformity;

3) for quantitative assessment (including 3D) of spinal deformity;

4) every 3-6 months [6].

The use of the COT and DIERS systems is important for clinical orthopaedics. This is confirmed by the difference in the interpretation of the data, since the approach of foreign scientists to the optical and topographic examination of patients who do not suffer obvious spinal diseases differs from that in our country. The results that foreign authors recommend using as a “corridor” of the norm seem to be most valuable. General population of healthy women showed rotation of 2.2 ± 3.5° at the level of the eleventh thoracic vertebra and lateral deviation in the II–IV thoracic vertebrae. Standard deviation of the parameters obtained in the study exceeded the mean value of the parameters suggesting a possibly incorrect distribution of data indicating an even greater heterogeneity of clinical forms of spinal deformity within the "norm". The most remarkable in the work was the question that the authors asked: Is there a need to correct a disorder identified in a practically healthy individual [31]?

The second stage of modern PM research in traumatology and orthopaedics is associated with processing of native photos with no "special" optical effects (shadow) applied. Methods of the second stage can be considered logically closer to the term PM in general and the term PM can be understood as methods that evaluate native photos of objects. The use of detail measurements from a photographic object was initiated by the American physician Holmes who was the first to evaluate changes in the gait of Civil War invalids from a photographic image for optimal prosthesis manufacturing [3, 42]. That was a single use of PM with a single non-stereoscopic camera in the prosthetic practice and trauma and orthopaedics in general.

In our country, the PM method was applied in various fields from modeling museum objects of geological heritage [43] to magnetic-ionospheric observations of forecasting and diagnosing natural and man-caused extreme events [44] however, the application of the method remains limited in medical practice. Foreign studies report PM being widely used in the assessment of spatial parameters in veterinary medicine [45] and clinical medicine. The 3D scanning is competing with PM in clinical medicine with obvious advantages of most accurate reproduction of geometric shapes, possibility of using glare and reflective objects, and objects of soft consistency. The PM method provides more realistic surface structures and a sufficiently high transfer of the geometric characteristics of objects [46].

An anthropological study of Australian scientists was the logical connection between the applied use of PM in veterinary medicine and clinical medicine demonstrating a close correlation between the parameters of the computed tomography and PM performed with a smartphone camera (digital tool – Agisoft PhotoScan, Agisoft Metashape, St. Petersburg, RF). The spatial performance of three skull models (Bone Clone, Los Angeles, USA) was evaluated in the study using PM and computed tomography. The authors reported that the correlation coefficients of the data obtained using both methods ranged from 0.9862 to 0.9980 ($p < 0.05$), and the PM method was a reliable and accurate alternative to computed tomography [47]. Agisoft PhotoScan was used by British scientists for creating accurate digital skeletal models. Approximately 200 photographs were taken of three different crania, and were separated into series consisting of 50, 75, 100, 150, and approximately 200 photos. It was recommended to create cranial models using 150 photographs and "high" settings. SfM photogrammetry was reported as a convenient, noninvasive, and rapid 3D modeling tool that can be used in almost any setting to produce digital models [48].

Greater prospects for the integration of the PM method into clinical practice were presented in a comparative study of forensic experts who compared and evaluated the measuring results of 86 forensic body surface injuries by the ruler method, structured-light scanning and single-camera photogrammetry. The the root mean square error value results were structured-light scanning < single-camera photogrammetry < ruler method. When the long-distance group 10-40 cm was measured, the results obtained by the ruler method were shorter than the standard value. Both structured-light scanning and single-camera photogrammetry can be applied in recording and measuring forensic body surface damage. The former has better performance in measurement accuracy and stability, while the latter has better color performance but longer post-processing time [49]. PM has been widely used in the context of modeling pathological processes of a surgical profile with applications in the field of digitalization of mastering practical skills by surgeons, recreating a "museum of digital pathology" and integrating with virtual reality environments and models of tissues and organs reproduced using 3D printing [50]. The use of PM in traumatology and orthopaedics should be described starting from the data indicating the use of PM in the analysis of the skeletal system in anthropological studies. A meta-analysis based on the results of 26 studies reported the use of PM for evaluation of the parameters of the skeleton, anatomical features of body development, and pathomorphology of injuries. The authors reported the PM method having great potential in skeletal anthropology, with many significant advantages: versatility in terms of application range and technical implementation, scalability, and photorealistic restitution [51].

The surface topograph was developed by the staff of the University Hospital RWTH, Aachen, Germany and presented in 2019 employing a two-camera system for imaging and evaluating the subjects front and back simultaneously. The system used images from eight different points located around the object for a complete 3D reconstruction of the model and the authors measured the Alderson phantom (The Alderson Radiation Therapy Phantom, Radiology Support Devices, Los Angeles, USA) with the a.p.-scan topography system and computer tomography to validate the whole-torso reconstruction. The reliability of the measurements performed on the phantom was confirmed by computed tomography [52]. The difference between the values obtained with the system and computed tomography did not exceed 0.61–10.52 %. Inter- and intra-rater reliability was tested in 35 healthy subjects by two observers. Inter- (0.9–0.98) and intra-rater reliability (0.8–0.95) testing revealed good and excellent results in the detection of almost all body surface structures and measurement of areas and volumes [53].

A meta-analysis performed by a group of Brazilian experts at the University of Rio Grande do Sul (UFRGS, Rio Grande, Brazil) included 21 studies reporting Twenty different methods of calculating cervical spine posture in the sagittal plane. The results of the work showed high intra-rater reliability with PM and radiography. The Cobb method (inferior C2 – inferior C7) and absolute rotation angle [54] presented very high intra-rater reliability. Another team of Brazilian scientists from Rio de Janeiro (CUAM, Brazil) successfully integrated the PM method as a tool for evaluating different methods of physical assessment of dorsopathy of the cervical spine [55]. A group of authors of the UFRGS University evaluated the sensitivity and specificity of the PM in assessing the trunk rotation, while a less accurate scoliometer was chosen as the reference instrument compared to radiography and optical topography, and the costal gibbus served as the subject of study. The authors reported a significant correlation between PM and scoliometry ($p < 0.05$) with the sensitivity and specificity of PM in assessing rotation being higher 83 and 78 % [56].

The study of a group of authors from another Brazilian Federal University of Sao Paulo (Sao Paulo, Brazil) enrolled 30 patients with scoliosis and 20 healthy subjects aged 11-18 years. The authors created thoracic markers shaped as angles (A) and distances (D) measured with PAS software as follows:

1) angles: right acromion/xiphoid/left acromion (A2), angle formed between the outer point of the smallest waist circumference and its upper and lower edges on the left side (A4L), angle formed by the intersection of the tangent segments of the upper and lower scapulae angles (A7);

2) «distances»: distance between the xiphoid process and the last false rib on the right and left sides (D1R/D1L); distance between xiphoid process and anterior superior iliac spine (D3).

The results of the work showed that the markers A2, A7 were significantly higher, while the A4L and D1R/D1L were significantly reduced in scoliosis group. Moderate correlations were found between A2, D1R/D1L and the Cobb angle. Despite some spareness of the information presented in the work, the value of the study is associated with the pioneering integration of "native" parameters of the markers and calculated values obtained from calculating the spatial relationships [57]. In addition, the topographic designations introduced by the authors can be considered pioneering in clinical PM nomenclature.

The third group of Brazilian scientists from the University of Minas Gerais (Belo Horizonte, Brazil) reported the use of the PM method in assessment of the dynamics in spinal deformity in children with scoliosis. Despite the fact that only the Cobb angle was chosen as the subject of study, the authors were able to compare the dynamic representativeness of radiographic and PM methods in a heterosexual sample of 91 subjects at least twice over an average period of 8.6 months. An increase of 5° or more between two radiographic exams was considered a progression of the curvature. The results of the study are to be set out in detail. The authors reported the average Cobb angle of the curves measuring 39.5 ± 16.7° and 39.5 ± 14.3° for radiographic and photogrammetric exams at the beginning of the study, respectively. At the end of the study, the measurements of the curves were 40.2 ± 16.2° and 41.3 ± 15.1° ($p > 0.05$ for both groups) for the radiographic and photogrammetric exams. The photogrammetric method had an accuracy of 89 % (Confidence interval [CI] 95 % = 82.5-95.5) for the detection of scoliosis progression, with a sensitivity of 94.4 % (CI 95 % = 89.6-99.2), a specificity of 86.7 % (CI 95 % = 79.7-93.7). PM could be seen as an alternative to radiography associated with excessive radiation exposure, and a method for diagnosing progression of scoliosis [58].

Methodological value in the development of a three-dimensional analysis of the geometry of the spinal column was shown by the studies performed by a group of Canadian scientists who estimated the reliability of 3-D trunk surface measurements for the characterization of external asymmetry associated with scoliosis using an optical system with two different postures: anatomical position (A) and "clavicle" position (B) with the arms roll up to the clavicles. The reliability was found to be fair to excellent for position A with an intra-rater correlation of 0.91 to 0.99 (0.85 to 0.99 for the lower limit of the 95 % confidence interval). The intra-rater correlation was 0.85-0.98 for position B (from 0.74 to 0.99 for the lower limit of the 95 % confidence interval). The data obtained are promising prospects for the development of the PM evaluation of deformities including the methodical simplification of the measurement devices and techniques [59].

The reliability of PM in orthopaedics is confirmed by the results of a study reported by David P. and Bliss Jr. who evaluated the correlation of PM method and X-ray computed tomography over 2 years and 4 months in nine volunteers with pectus excavatum. The authors of the study found that the spatial characteristics of length appeared to be more reliable than the parameters of chest volume and area measured with PM ($p = 0.0013$) [60]. The PM method is used to assess adolescent idiopathic scoliosis and spinal deformity as a symptom of some hereditary diseases. PM was shown to be practical in the assessment of spinal deformity and in the selection of rehabilitation measures and the diagnosis of postural stereotypes, facial asymmetry, and the myotonic symptom complex as part of the Schwartz–Jampel syndrome–chondrodystrophic myotonia [61]. PM is increasingly used not only in traumatology and orthopaedics, but also in the prosthetics of amputated limbs. The congruence of the tissues of the stump and the sleeve of the prosthesis of the amputated limb is essential. The use of PM in assessing the spatial characteristics of the stump and a lower limb prosthetic socket appeared to be a highly effective tool in manufacturing of individual prostheses. The printed socket was photographed from 360 positions to achieve the maximum congruence of the stump and the prosthesis fabricated on a 3D printer based on PM data [62].

The databases PubMed/Medline and LILACS were searched to review referential values for thoracic kyphosis and lumbar lordosis for radiography and photogrammetry analysis. Studies containing values of thoracic kyphosis and lumbar lordosis or a reliability test assessed by radiography and photogrammetry were selected. For the studies with radiography that calculated the angle by the same method of assessment, the mean was 44.07° for L1 to L5 and 58.01° for L1 to S1, and for T1 to T12 the mean was 48.33°. It was not possible to perform the same procedure with the photogrammetry studies because of the great discrepancy in procedures and angle calculations, which logically requires unification of the PM methodology in orthopaedics [63].

An optimal lateral displacement of the camera for minimizing the 3D data uncertainty is to be identified with overlaying images and three-dimensional images. The problem remains unresolved in clinical applications and can significantly affect the quality of the three-dimensional object and the absolute spatial characteristics, and also becomes more complicated due to photographic recording of minor movements of a living object (oscillations, respiratory movements). Technical aspects of this issue are being resolved developing the method on inanimate objects [64].

Trends in the development of PM in traumatology and orthopaedics are determined by simplification of the method integrated into clinical practice through the use of a camera of a personal telecommunication device (hereinafter referred to as PTD) as a photo registration tool. This is confirmed by a number of studies. One of the first PM studies in anthropology was performed using a smartphone camera [47]. A pioneering study reported PTU (iPad, Apple Inc., Cupertino, USA) used as a diagnostic tool for spinal deformity. Parameters of the absolute measurement of spatial quantities (mm) and the angles (°) as a "gold standard" for a comparative test were evaluated using the Qualisys motion capture system (Qualisys AB, Gothenburg, Sweden). The results of the study appeared to be encouraging: reliable correlation was more than 0.98, an error in measuring spatial quantities was not more than 3.8 mm and angles, 0.2° [65].

The use of a smartphone for measurements has a number of distinctive features:

1) a smartphone camera and a reflex camera can be used equally effectively as an optical measuring device [66];

2) the smartphone camera has accuracy limitations associated with a specific smartphone model [67];

3) 3D models built using a smartphone camera appear to be 2 mm larger than real objects [3].

PM has a number of advantages over other methods of optical diagnosis of spinal diseases:

1) PM is much cheaper than other imaging methods (computed tomography, magnetic resonance imaging, laser scanning) [68];

2) PM does not require training or the presence of a qualified specialist [69];

3) PM is completely safe, unlike radiography or computed tomography [70];

4) The PM technique is easy to perform and process the obtained images, including earlier developed software [71].

The history of optical diagnostics in traumatology and orthopaedics can be represented as a scheme (Fig. 1).

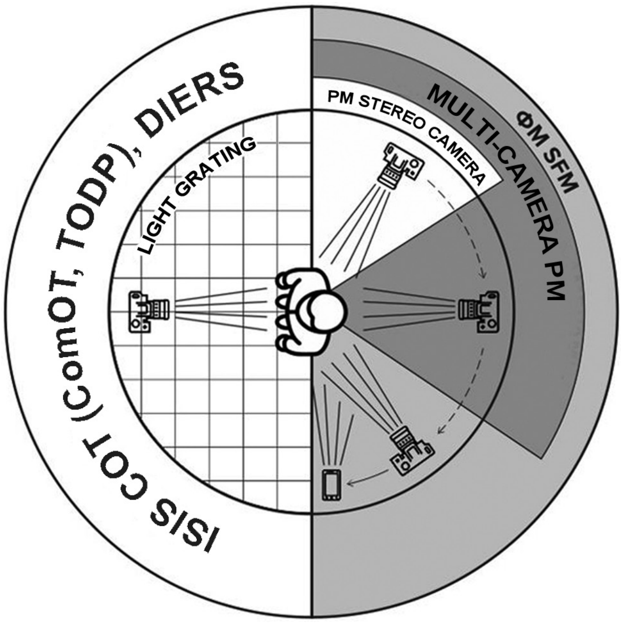

Fig. 1 Schematic representation of the development of photogrammetry in traumatology and orthopaedics

PM can be practical for clinical implementation in pediatric and adolescent spinal surgery. A PM system for clinical diagnostics of the spatial location of the spine using a smartphone camera was developed on the territory of the Perm Territory based on the experience of a large-scale assessment of spinal deformity in children and adolescents [62] and on results of computer optical topography, performed at LLC 'Yord Tech' (ScolView™, Perm, Russia) [72]. Technical performance included the following:

1) taking pictures of an object with PTD (technical requirements: optimal optical and technical properties of the camera; operating system Android, iOS) including at least 70 and no more than 200 pictures. Serial shooting is performed from a distance of about 1 m, while the operator moves along a semicircle facing the object, making sequential series of shots, moving the camera along the zigzag trajectory;

2) compilation of object snapshots. This extracts the distinctive visual effects of an object in one image from the series, which are compared with the visual effects of another image from the series and overlapping at stable points, regardless of angle, movement and scale. A three-dimensional object is formed based on the data received;

3) processing of a three-dimensional object is performed by a sequence of actions:

– calculation of the distance from the camera to the object (in units, which are converted to the metric coordinate system using augmented reality technology – Python 3.8 programming language (Python Software Foundation, Beaverton, Oregon, USA);

– post-processing of a three-dimensional object: cropping the background and environment, smoothing and getting rid of visual noise;

– selection of the horizontal plane of a three-dimensional object by simultaneously recording data from the inertial sensors of the PTD;

– selection of the frontal plane of a three-dimensional object by photographing the PTD of the back surface in a frontal plane from behind;

– positioning of a three-dimensional object with indicated top and bottom of the object image, the three-dimensional object is rotated according to the specified base planes with the origin of coordinates being determined and correction produced;

– determination of reference points with algorithmic search of reference points according to the mathematical algorithm developed;

4) calculation of the parameters of the back surface, analysis of the calculations performed using the mathematical algorithm developed (Python 3.8 programming language).

The logical scheme of the system is shown in Figure 2.

Analysis of the results of the clinical implementation of the ScolViewTM system is expected in subsequent publications.

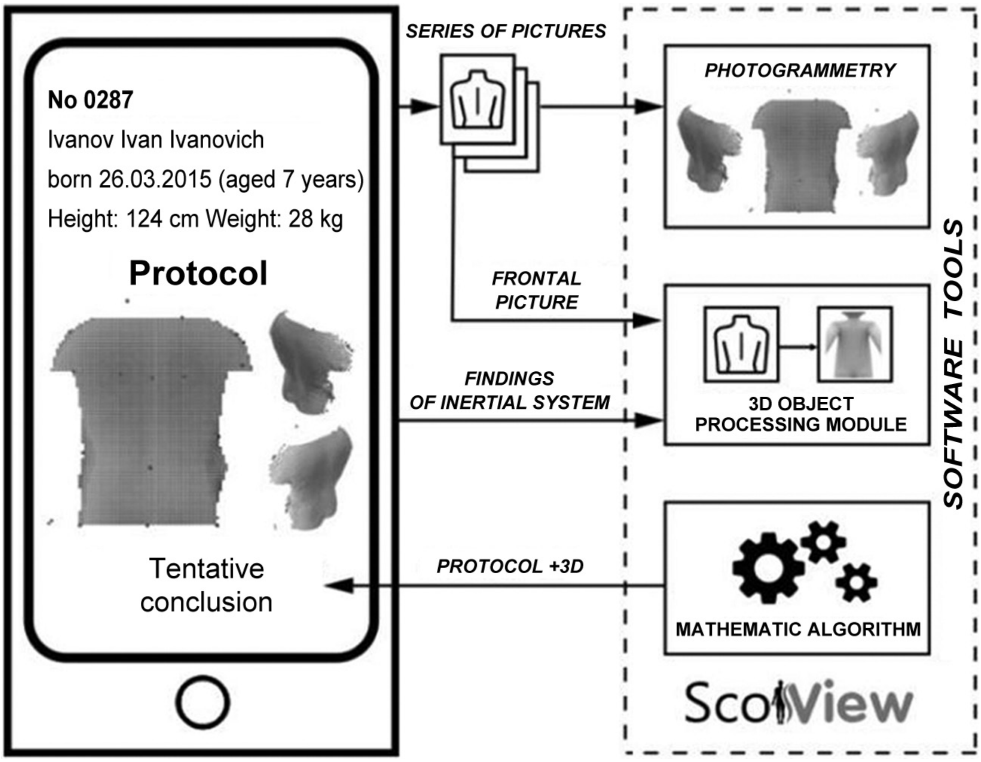

Fig. 2 Operation logic diagram of ScolViewTM

CONCLUSION

Summarizing modern methods of optical assessment of spinal deformity in children, it seems logical to single out the main trends in the medical and technical development of diagnostics in traumatology and orthopedics.

1. The safety trend includes leveling the radiation exposure to the patient.

2. The trend of increasing accuracy is associated with the development of optical digital photography technology.

3. The trend of ease of operation is ensured by the emergence of a tendency to reduce the requirements for the qualification of the diagnostic device "operator" and transformation of PTD into a proper medical device.

4. The digitalization trend arises as a cause and effect of the “roll” of the functional load for capturing and decoding data in favor of digital devices and algorithms.

5. The trend of The Internet of Medical Things" is a conceptual global phenomenon that has arisen on the

basis of expanding medical services implemented using digital and network technologies.

The trends described are being implemented everywhere in medical practice, they continue to improve and pass the "critical points" of the development, which are marked by the introduction of new technologies or a new application of an earlier method. The evolution of the process seems predictable, since the next stage in the development of optical and digital technologies in the assessment of spinal deformity will be associated with introduction of artificial intelligence (AI) technologies and use of Clinical Decision Support Systems (CDSS) specifically in the pediatric spinal surgery.

REFERENCES

1. De Bois-Regard N.A. *L'Orthopédie, ou, l'Art de prévenir et de corriger dans les enfans, les difformités du corps: Le tout par des moyens à portée des peres & des meres, & de toutes les personnes qui ont des enfans à élever*. Vol. 2. Chez George Friex, 1743. Université de Gand, 2008. 304 p.
2. Kotelnikov G.P., Mironov S.P., Miroshnichenko V.F. *Travmatologiia i Ortopediia: uchebnik* [Traumatology and Orthopedics: textbook]. M.: GEOTAR-Media, 2009, 400 p. (in Russian)
3. Struck R., Cordoni S., Aliotta S., Pérez-Pachón L., Gröning F. Application of Photogrammetry in Biomedical Science. *Adv. Exp. Med. Biol*., 2019, vol. 1120, pp. 121-130. DOI: 10.1007/978-3-030-06070-1_10.
4. Ey-Chmielewska H., Chruściel-Nogalska M., Frączak B. Photogrammetry and its potential application in medical science on the basis of selected literature. *Adv. Clin. Exp. Med*., 2015, vol. 24, no. 4, pp. 737-741. DOI: 10.17219/acem/58951.
5. Estes J., Kline K., Collins E. Remote sensing. In: Smelser N.J., Baltes P.B., editors. *International Encyclopedia of the Social & Behavioral Sciences*. Pergamon, 2001, pp. 13144-13150. DOI: 10.1016/B0-08-043076-7/02526-2.
6. Girdler S., Cho B., Mikhail C.M., Cheung Z.B., Maza N., Kang-Wook Cho S. Emerging Techniques in Diagnostic Imaging for Idiopathic Scoliosis in Children and Adolescents: A Review of the Literature. *World Neurosurg*., 2020, vol. 136, pp. 128-135. DOI: 10.1016/j.wneu.2020.01.043.
7. Robson S., Luhmann T., Kyle S., Harley I. *Close Range Photogrammetry: Principles, Techniques and Applications*, Whittles Publishing, Dunbeath, 2006, 528 p.
8. Villa C. Forensic 3D documentation of skin injuries. *Int. J. Legal Med*., 2017, vol. 131, no. 3, pp. 751-759. DOI: 10.1007/s00414-016-1499-9.
9. Revin A.I., editor. *Kratkaia Entsiklopediia Domashnego Khoziaistva* [Concise Encyclopedia of the Household]. In 2 Vol. M., Sovetskaia Entsiklopediia, 1960.
10. Takasaki H. Automatic ellipsometer. Automatic polarimetry by means of an ADP polarization modulator III. *Appl. Opt*., 1966, vol. 5, no. 5, pp. 759-764. DOI: 10.1364/AO.5.000759.
11. Takasaki. H. Moiré topography. *Appl. Opt*., 1973, vol. 12, no 4, pp. 845-850. DOI: 10.1364/AO.12.000845.
12. Chiang C. Moiré Topography. *Appl. Opt*., 1975, vol. 14, no. 1, pp. 177-179. DOI: 10.1364/AO.14.000177.
13. Li H., Cao Y., Wan Y., Li C., Xu C., Zhang H., An H. A super-grayscale and real-time computer-generated Moiré profilometry using video grating projection. *Sci. Rep*., 2021, vol. 11, no. 1, 19882. DOI: 10.1038/s41598-021-99420-8.
14. Turner-Smith A.R. A television/computer three-dimensional surface shape measurement system. *J. Biomech*., 1988, vol. 21, no. 6, pp. 515-529. DOI: 10.1016/0021-9290(88)90244-8.
15. Weisz I., Jefferson R.J., Turner-Smith A.R., Houghton G.R., Harris J.D. ISIS scanning: a useful assessment technique in the management of scoliosis. *Spine* (Phila Pa 1976), 1988, vol. 13, no. 4, pp. 405-408. DOI: 10.1097/00007632-198804000-00006.
16. Carr A.J., Jefferson R.J., Weisz I., Turner-Smith A.R. Correction of body height in scoliotic patients using ISIS scanning. *Spine* (Phila Pa 1976), 1989, vol. 14, no. 2, pp. 220-222. DOI: 10.1097/00007632-198902000-00014.
17. Gardner A., Berryman F., Pynsent P. A cluster analysis describing spine and torso shape in Lenke type 1 adolescent idiopathic scoliosis. *Eur. Spine J*., 2021, vol. 30, no. 3, pp. 620-627. DOI: 10.1007/s00586-020-06620-3.
18. Dubousset J. Dostizhenie garmonii v 3D-korrektsii deformatsii pozvonochnika [Achieving harmony in 3D correction of spinal deformity]. *Khirurgiia Pozvonochnika*, 2018, Vol. 15, no. 1, pp. 101-109. (in Russian) DOI: 10.14531/ss2018.1.101-109.
19. Tsukanov A.N., Charnashtan D.V., Valetko A.A., Grakovich R.I., Bronskaia K.V., Chechetin D.A. Diagnostika staticheskikh deformatsii pozvonochnika metodom topograficheskoi fotometrii v dinamike do i posle reabilitatsionnykh meropriiatii u detei shkolnogo vozrasta [Diagnosis of static spinal deformities by topographic photometry in dynamics before and after rehabilitation measures in school-age children]. *Problemy Zdorovia i Ekologii*, 2016, no. 3 (49), pp. 44-47. (in Russian)
20. Sernadskii V.N. Tsifrovaia meditsina dlia detskoi ortopedii [Digital Medicine for Pediatric Orthopedics]. *Glavnyi Vrach Iuga Rossii*, 2018, no. 4 (63), pp. 64-65. (in Russian)
21. Sernadskii V.N. Tsifrovaia meditsina dlia detskoi ortopedii [Digital Medicine for Pediatric Orthopedics]. *Glavnyi Vrach Iuga Rossii*, 2021, no. 1 (76), pp. 46. (in Russian)
22. Kravtsova E.Iu., Muravev S.V., Firsova M.B. Sostoianie kortikospinalnykh traktov pri iunosheskom idiopaticheskom skolioze (rezultaty diagnosticheskoi transkranialnoi magnitnoi stimuliatsii) [The state of the corticospinal tracts in juvenile idiopathic scoliosis (results of diagnostic transcranial magnetic stimulation)]. *Meditsinskii Almanakh*, 2014, no. 3 (33), pp. 98-101. (in Russian)
23. Antropov E.S., Cherkasova V.G., Muravev S.V., Pecherskii V.I. Kineziologicheskoe teipirovanie v korrektsii deformatsii pozvonochnika u detei na doklinicheskoi stadii iunosheskogo idiopaticheskogo skolioza [Kinesiology taping in the correction of spinal deformity in children at the preclinical stage of juvenile idiopathic scoliosis]. *Sportivnaia Meditsina: Nauka i Praktika*, 2016, vol. 6, no. 3 (24), pp. 54-64. (in Russian) DOI: 10.17238/ISSN2223-2524.2016.3.54.
24. Kravtsova E.Iu., Muravev S.V., Kravtsov Iu.I. Sanatorno-kurortnoe lechenie bolevogo sindroma v spine u podrostkov s iunosheskim idiopaticheskim skoliozom [Sanatorium-resort treatment of the back pain syndrome in adolescents with juvenile idiopathic scoliosis]. *Voprosy Kurortologii, Fizioterapii i Lechebnoi Fizicheskoi Kultury*, 2017, vol. 94, no. 1, pp. 41-45. (in Russian) DOI: 10.17116/kurort201794141-45.
25. Belokrylov N.M., Pecherskii V.I., Likhacheva L.V., Dudin M.G., Sharova L.V. Osobennosti formirovaniia pozvonochnika pri nachalnykh proiavleniiakh skolioticheskoi deformatsii [Features of the spine formation in the initial manifestations of scoliotic deformity]. *Pedagogiko-psikhologicheskie i Mediko-biologicheskie Problemy Fizicheskoi Kultury i Sporta*, 2012, vol. 7, no. 3, pp. 6-11. (in Russian)
26. Illés S, Somoskeöy S. The EOSTM imaging system and its uses in daily orthopaedic practice. *Int Orthop*., 2012, vol. 36, no. 7, pp. 1325-1331. DOI: 10.1007/s00264-012-1512-y.
27. Dolganov D.V., Dolganova T.I., Samylov V.V. Evaluation of postural function disorders of the spine in orthostatic stereotypes. *Genij Ortopedii*, 2018, vol. 24, no. 3, pp. 357-364. DOI: 10.18019/1028-4427-2018-24-3-357-364.
28. Dudin M.G., Pinchuk D.Iu. *Idiopaticheskii skolioz. Neirofiziologiia, Neirokhimiia* [Idiopathic scoliosis. Neurophysiology, neurochemistry]. SPb., 2017, 304 p. (in Russian)

29. Muravev S.V., Cherkasova V.G., Chainikov P.N., Mekhonoshina O.O., Kovalev M.A., Gushchin M.O. Otdelnye neirofiziologicheskie aspekty etiopatogeneza iunosheskogo idiopaticheskogo skolioza [Some neurophysiological aspects of the etiopathogenesis of juvenile idiopathic scoliosis]. *Permskii Meditsinskii Zhurnal*, 2019, vol. XXXV, no. 4, pp. 39-45. (in Russian) DOI: 10.17816/pmj36439%45.
30. Shnaider L.S., Sarnadskii V.N., Pavlov V.V. Luchevoi i opticheskii metody otsenki pozvonochno-tazovykh vzaimootnoshenii u patsientov s vrozhdennym vyvikhom bedra [Radiation and optical methods for assessing spinal-pelvic relationships in patients with congenital hip dislocation. Spinal Surgery]. *Khirurgiia Pozvonochnika*, 2009, vol. 16, no. 1, pp. 63-69. (in Russian)
31. Wolf C., Betz U., Huthwelker J., Konradi J., Westphal R.S., Cerpa M., Lenke L., Drees P. Evaluation of 3D vertebral and pelvic position by surface topography in asymptomatic females: presentation of normative reference data. *J. Orthop. Surg. Res*., 2021, vol. 16, no. 1, pp. 703. DOI: 10.1186/s13018-021-02843-2.
32. Prokopev N.Ia., Barankhin O.V., Borisov S.A. Glubina lordoza na sheinom i poiasnichnom urovne kak pokazatel osanki u malchikov perioda vtorogo detstva na nachalnom etape zaniatii edinoborstvami [The depth of lordosis at the cervical and lumbar levels as an indicator of posture in boys during the second childhood at the initial stage of martial arts]. *Nauka-2020*, 2021, no. 3 (48), pp. 52-58. (in Russian)
33. Ali Makhammad Ali, Prokopev N.Ia., Khristov V.V. Romb Mashkova v otsenke funktsionalnoi nagruzki na pozvonochnyi stolb u iunoshei sbornoi komandy Sirii po shosseinym gonkam [Mashkov's rhombus in assessing the functional load on the spinal column in young men of the Syrian National Road Racing Team]. *Sciences of Europe*, 2021, vol. 2, no. 85, pp. 11-16. (in Russian)
34. Antropov E.S., Cherkasova V.G., Muravev S.V., Krylova I.V. Sravnitelnaia kharakteristika sostoianiia kostno-myshechnoi i vegetativnoi nervnoi sistem skalolazov detskogo i podrostkovogo vozrasta v zavisimosti ot urovnia sportivnogo masterstva [Comparative characteristics of the state of the musculoskeletal and autonomic nervous systems of rock climbers of childhood and adolescence, depending on the level of sportsmanship]. *Pedagogiko-psikhologicheskie i Mediko-biologicheskie Problemy Fizicheskoi Kultury i Sporta*, 2016, vol. 11, no. 4, pp. 195-202. (in Russian) DOI: 10.14526/01_1111_167.
35. Glinkowski W.M., Tomasik P., Walesiak K., Głuszak M., Krawczak K., Michoński J., Czyżewska A., Żukowska A., Sitnik R., Wielgoś M. Posture and low back pain during pregnancy - 3D study. *Ginekol. Pol*., 2016, vol. 87, no. 8, pp. 575-580. DOI: 10.5603/GP.2016.0047.
36. Berenov K.V., Berenova O.F., Karpinskaia E.D. Biomekhanicheskie osobennosti ravnovesiia i parametrov pozvonochno-tazovogo balansa u beremennykh s poiasnichno-tazovoi boliu [Biomechanical features of balance and parameters of spinal-pelvic balance in pregnant women with lumbar-pelvic pain]. *Travma*, 2020, vol. 21, no. 3, pp. 42-47. (in Russian) DOI: 10.22141/1608-1706.3.21.2020.208420.
37. Rozanova O.I., Tsyrenzhapova E.K. Relef-topografiia rogovitsy u patsientov s kataraktoi posle ranee vypolnennoi perednei radialnoi keratotomii [Relief topography of the cornea in patients with cataracts after previously performed anterior radial keratotomy]. *Saratovskii Nauchno-meditsinskii Zhurnal*, 2020, vol. 16, no. 1, pp. 261-265. (in Russian)
38. Avdeeva M.V., Kreneva Iu.A., Panov V.P., Filatov V.N., Meltser A.V., L.A. Karasaeva. Faktory riska razvitiia i progressirovaniia degenerativno-distroficheskikh zabolevanii pozvonochnika po rezultatam skriningovogo obsledovaniia zhitelei Sankt-Peterburga [Risk factors for the development and progression of degenerative-dystrophic diseases of the spine according to the results of a screening examination of residents of St. Petersburg]. *Analiz Riska Zdoroviu*, 2019, no. 1, pp. 125-134. (in Russian) DOI: 10.21668/health.risk/2019.1.14.
39. Kolesnikov V.N., Shandybina N.D., Erium S.S. Ekologiia cheloveka: sberezhenie natsii kak strategiia uspeshnogo razvitiia. Upravlencheskoe konsultirovanie [Human Ecology: Saving the Nation as a Strategy for Successful Development. Management Consulting]. *Glavnyi Vrach Iuga Rossii*, 2018, no. 2 (110), pp. 73-79. (in Russian) DOI: 10.22394/1726-1139-2018-2-73-79.
40. Hackenberg L., Hierholzer E., Pötzl W., Götze C., Liljenqvist U. Rasterstereographic back shape analysis in idiopathic scoliosis after anterior correction and fusion. *Clin. Biomech*. (Bristol, Avon), 2003. vol. 18, no. 1, pp. 1-8. DOI: 10.1016/s0268-0033(02)00165-1.
41. Betsch M., Wild M., Große B., Rapp W., Horstmann T. The effect of simulating leg length inequality on spinal posture and pelvic position: a dynamic rasterstereographic analysis. *Eur. Spine J*., 2012, vol. 21, no. 4, pp. 691-697. DOI: 10.1007/s00586-011-1912-5.
42. Lane H.B. Photogrammetry in medicine. *Photogrammetric Engineering & Remote Sensing*, 1983, vol. 49, no. 10, pp. 1453-1456.
43. Astakhova I.S., Zhuravlev A.V. Trekhmernoe modelirovanie kak metod vizualizatsii obektov geologicheskogo naslediia v muzeinom prostranstve [Three-dimensional modeling as a method of visualization of geological heritage objects in the museum space]. *Obshchestvo. Sreda. Razvitie (Terra Humana)*, 2019, no. 4, pp. 31-37. (in Russian)
44. Belinskaia A.Iu., Khomutov S.Iu. *Vozmozhnosti magnitno-ionosfernykh nabliudenii v zadachakh prognoza i diagnostiki prirodnykh i tekhnogennykh ekstremalnykh sobytii* [Possibilities of magnetic-ionospheric observations in the problems of forecasting and diagnosing natural and technogenic extreme events]. Interekspo Geo-Sibir, 2012, vol. 3, pp. 37-45. (in Russian)
45. DeLorenzo L., Vander Linden A., Bergmann P.J., Wagner G.P., Siler C.D., Irschick D.J. Using 3D-digital photogrammetry to examine scaling of the body axis in burrowing skinks. *J. Morphol*., 2020, vol. 281, no. 11, pp. 1382-1390. DOI: 10.1002/jmor.21253.
46. Dixit I., Kennedy S., Piemontesi J., Kennedy B., Krebs C. Which Tool Is Best: 3D Scanning or Photogrammetry – It Depends on the Task. *Adv. Exp. Med. Biol*., 2019, vol. 1120, pp. 107-119. DOI: 10.1007/978-3-030-06070-1_9.
47. Omari R., Hunt C., Coumbaros J., Chapman B. Virtual anthropology? Reliability of three-dimensional photogrammetry as a forensic anthropology measurement and documentation technique. *Int. J. Legal Med*., 2021, vol. 135, no. 3, pp. 939-950. DOI: 10.1007/s00414-020-02473-z.
48. Morgan B., Ford A.L.J., Smith M.J. Standard methods for creating digital skeletal models using structure-from-motion photogrammetry. *Am. J. Phys. Anthropol*., 2019, vol. 169, no. 1, pp. 152-160. DOI: 10.1002/ajpa.23803.
49. Wang J.M., Mi J.Y., Hu W.H., Li Z.D., Zou D.H., Chen Y.J. Evaluation of 3D Measuring Methods for Body Surface Damage and Scars. *Fa Yi Xue Za Zhi*, 2020, vol. 36, no. 2, pp. 204-209. (in English, Chinese) DOI: 10.12116/j.issn.1004-5619.2020.02.011.
50. Turchini J., Buckland M.E., Gill A.J., Battye S. Three-Dimensional Pathology Specimen Modeling Using "Structure-From-Motion" Photogrammetry: A Powerful New Tool for Surgical Pathology. *Arch. Pathol. Lab. Med*., 2018, vol. 142, no. 11, pp. 1415-1420. DOI: 10.5858/arpa.2017-0145-OA.
51. Lussu P., Marini E. Ultra close-range digital photogrammetry in skeletal anthropology: A systematic review. *PLoS One*, 2020, vol. 15, no. 4, pp. e0230948. DOI: 10.1371/journal.pone.0230948.
52. Michalik R., Knod M., Siebers H., Gatz M., Dirrichs T., Eschweiler J., Quack V., Betsch M. Introduction and evaluation of a novel multi-camera surface topography system. *Gait Posture*, 2020, vol. 80, pp. 367-373. DOI: 10.1016/j.gaitpost.2020.06.016.
53. Michalik R., Siebers H., Eschweiler J., Quack V., Gatz M., Dirrichs T., Betsch M. Development of a new 360-degree surface topography application. *Gait Posture*, 2019, vol. 73, pp. 39-44. DOI: 10.1016/j.gaitpost.2019.06.025.
54. Pivotto L.R., Navarro I.J.R.L., Candotti C.T. Radiography and photogrammetry-based methods of assessing cervical spine posture in the sagittal plane: A systematic review with meta-analysis. *Gait Posture*, 2021, vol. 84, pp. 357-367. DOI: 10.1016/j.gaitpost.2020.12.033.
55. Maddaluno M.L.M., Ferreira A.P.A., Tavares A.C.L.C., Meziat-Filho N., Ferreira A.S. Craniocervical posture assessed with photogrammetry and the accuracy of palpation methods for locating the seventh cervical spinous process: a cross-sectional study. *J. Manipulative Physiol. Ther*., 2021, vol. 44, no. 3, pp. 196-204. DOI: 10.1016/j.jmpt.2020.07.012.
56. Navarro I.J.R.L., Candotti C.T., do Amaral M.A., Dutra V.H., Gelain G.M., Loss J.F. Validation of the Measurement of the Angle of Trunk Rotation in Photogrammetry. *J. Manipulative Physiol. Ther*., 2020, vol. 43, no. 1, pp. 50-56. DOI: 10.1016/j.jmpt.2019.05.005.
57. Alexandre A.S., Sperandio E.F., Yi L.C., Davidson J., Poletto P.R., Gotfryd A.O., Vidotto M.C. Photogrammetry: a proposal of objective assessment of chest wall in adolescent idiopathic scoliosis. *Rev. Paul. Pediatr*., 2019, vol. 37, no. 2, pp. 225-233. DOI: 10.1590/1984-0462/;2019;37;2;00001.

58. Leal J.S., Aroeira R.M.C., Gressler V., Greco M., Pertence A.E.M., Lamounier J.A. Accuracy of photogrammetry for detecting adolescent idiopathic scoliosis progression. *Spine J*., 2019, vol. 19, no. 2, pp. 321-329. DOI: 10.1016/j.spinee.2018.06.362.
59. Pazos V., Cheriet F., Danserau J., Ronsky J., Zernicke R.F., Labelle H. Reliability of trunk shape measurements based on 3-D surface reconstructions. *Eur. Spine J*., 2007, vol. 16, no. 11, pp. 1882-1891. DOI: 10.1007/s00586-007-0457-0.
60. Bliss D.P. Jr., Vaughan N.A., Walk R.M., Naiditch J.A., Kane A.A., Hallac R.R. Non-Radiographic Severity Measurement of Pectus Excavatum. *J. Surg. Res*., 2019, vol. 233, pp. 376-380. DOI: 10.1016/j.jss.2018.08.017.
61. Paula de Moraes Jorge A., Monteiro E.R., Hoogenboom B.J., Oliveira A., Palassi Quintela M.V. Computer photogrammetry as a postural assessment in Schwartz-Jampel syndrome: A case report. *J. Bodyw. Mov. Ther*., 2021, vol. 26, pp. 72-76. DOI: 10.1016/j.jbmt.2020.12.017.
62. Cullen S., Mackay R., Mohagheghi A., Du X. The Use of Smartphone Photogrammetry to Digitize Transtibial Sockets: Optimization of Method and Quantitative Evaluation of Suitability. *Sensors* (Basel), 2021, vol. 21, no. 24, pp. 8405. DOI: 10.3390/s21248405.
63. Porto A.B, Okazaki V.H.A. Thoracic Kyphosis and Lumbar Lordosis Assessment by Radiography and Photogrammetry: A Review of Normative Values and Reliability. *J. Manipulative Physiol. Ther*., 2018, vol. 41, no. 8, pp. 712-723. DOI: 10.1016/j.jmpt.2018.03.003.
64. Guidi G., Malik U.S., Micoli L.L. Optimal Lateral Displacement in Automatic Close-Range Photogrammetry. *Sensors* (Basel), 2020, vol. 20, no. 21, pp. 6280. DOI: 10.3390/s20216280.
65. Agustsson A., Gislason M.K., Ingvarsson P., Rodby-Bousquet E., Sveinsson T. Validity and reliability of an iPad with a three-dimensional camera for posture imaging. *Gait Posture*, 2019, vol. 68, pp. 357-362. DOI: 10.1016/j.gaitpost.2018.12.018.
66. Petriceks A.H., Peterson A.S., Angeles M., Brown W.P., Srivastava S. Photogrammetry of Human Specimens: An Innovation in Anatomy Education. *J. Med. Educ. Curric. Dev*., 2018, vol. 5, 2382120518799356. DOI: 10.1177/2382120518799356.
67. Hernandez A., Lemaire E. A smartphone photogrammetry method for digitizing prosthetic socket interiors. *Prosthet. Orthot. Int*., 2017, vol. 41, no. 2, pp. 210-214. DOI: 10.1177/0309364616664150.
68. Chandler J.H., Buckley S. *Structure from motion (SFM) photogrammetry vs terrestrial laser scanning. Geoscience Handbook 2016: AGI Data Sheets*. 5th Ed. Alexandria, VA, American Geosciences Institute. Section 20.1. 2016.
69. Villa C., Flies M.J., Jacobsen C. Forensic 3D documentation of bodies: Simple and fast procedure for combining CT scanning with external photogrammetry data. *Journal of Forensic Radiology and Imaging*, 2017, vol. 10, pp. 47-51. DOI: 10.1016/J.JOFRI.2017.11.003.
70. Saad K.R., Colombo A.S., Ribeiro A.P., João S.M. Reliability of photogrammetry in the evaluation of the postural aspects of individuals with structural scoliosis. *J. Bodyw. Mov. Ther*., 2012, vol. 16, no. 2, pp. 210-216. DOI: 10.1016/j.jbmt.2011.03.005.
71. Evin A., Souter T., Hulme-Beaman A., Ameen C., Allen R., Viacava P., Larson G., Cucchi T., Dobney K. The use of close-range photogrammetry in zooarchaeology: Creating accurate 3D models of wolf crania to study dog domestication. *Journal of Archaeological Science: Reports*, 2016, vol. 9, pp. 87-93. DOI: 10.1016/j.jasrep.2016.06.028.
72. Shitoev I.D., Nikitin V.N. *Svidetelstvo o gosudarstvennoi registratsii dlia EVM* [Certificate of state registration for computers]. Author's license no. 2020661234 RF, 2020. (in Russian)

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