Original article
https://doi.org/10.18019/1028-4427-2025-31-4-424-432

Validation of video-assisted computer vision goniometry to measure shoulder abduction motor function

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Abstract

Introduction Goniometry is used to measure shoulder abduction range of motion aiding in diagnosis, rehabilitation planning and monitoring progress in rehabilitation evaluating a patient's shoulder function. Computer vision technology holds promising potential for the assessment of movement by unifying and objectifying goniometric studies of different somatometric parameters.

The **objective** was to validate a video-assisted computer vision goniometry of the motor function of shoulder abduction using the potential of neural networks.

Material and methods The study involved 33 volunteers, males and females aged 18 to 56 years, with the weight of 53 to 108 kg and the height of 155 to 195 cm. Measurements of related samples were compared to validate the author's method of goniometric examination of shoulder abduction. Classical goniometry was used for patients of group 1. Changes in the shoulder position were radiologically explored in group 2 and video-assisted goniometry computer vision was employed for examinations in group 3. The study was performed using hardware and software "Arthro-Pro" system. Statistical processing was produced using the Statgraphics software package.

Results The average difference in the abduction was insignificant in groups 1 and 2 measuring (0.62 ± 0.63)° from a minimum of 5.2° to a maximum of 1° with confidence interval of $p = 0.95$. The difference in the abduction angle ranged from -11.8° to 22.7° in groups 1 and 3 with the average difference of 6° and confidence interval of $p = 0.95$.

Discussion The minor difference in the abduction angles obtained with computer vision technologies and classical goniometry indicated the comparability of the two methods facilitating the possibility of introducing artificial intelligence for assessing musculoskeletal function in clinical practice.

Conclusion The video-assisted computer vision goniometry is practical for measurements of shoulder abduction in clinical practice.

Keywords: shoulder joint, motion capture, computer vision, radiography, goniometry

For citation: Demkin SA, Malyakina AA, Akhramovich SA, Kaplunov OA, Obramenko IE, Simonova IE. Validation of video-assisted computer vision goniometry to measure shoulder abduction motor function *Genij Ortopedii*. 2025;31(4):424-432. doi: 10.18019/1028-4427-2025-31-4-424-432.

INTRODUCTION

Goniometry is used to measure shoulder abduction range of motion aiding in diagnosis, rehabilitation planning and monitoring progress in rehabilitation evaluating a patient's shoulder function [1]. The method was first described by Hippocrates, Celsus Cornelius, Galen and other ancient scientists. Modern goniometry recommendations were reported by V.A. Gamburtsev [1] to diagnose musculoskeletal diseases, were included in the algorithms of trauma and orthopedic services, medical rehabilitation departments, military medical boards, medical and social expert boards and other units.

With a long history of goniometry, there is no unification in studies of somatometric features. There are no adequate techniques for measuring movements in the joint including the shoulder. The lack of standardization of goniometric studies of shoulder movements can be explained by the fact that are produced in a specific manner by researchers with a difficulty of identically positioning a hand-held goniometer even in one patient [2].

The shoulder as the most human mobile joint, is characterized by the maximum degrees of freedom, complexity and multi-component movements making the assessment problematic with the use of manual goniometry and modern motion capture technologies [3]. For decades, various technological solutions have been sought to objectify the method and improve the accuracy. The is The contactless motion capture technology using marker video recording of human movements is a breakthrough in the objectification of goniometric studies. The disadvantages of the technology include high cost of equipment, the complexity and labor intensity of implementing the method that hinder the mass introduction of the technique into clinical practice. Such factors as lighting, sensor positioning can shift and overlap each other on the human body during movements affect the accuracy of the measurements [4–8].

Computer vision based on the potential of a neural network, which is related to optical markerless and contactless motion capture technology is promising for unification and objectification of goniometric studies of somatometric features. Achievements in training neural networks allow for most accurate recognition of human movements and formation of a projection kinematic model of the human body to produce measurements [9–16]. However, the technique of performing diagnostic movements, lighting and other factors that can interfere with the indicators have a significant impact on the method. Similarly, interpreting the findings and the role in diagnosing diseases accompanied by musculoskeletal dysfunction remains unresolved [17–21].

The existing rules for conducting goniometric measurements on the shoulder joint have some "pitfalls" that affect the movement indicators, including those obtained with computer vision. This would include the "range of motion" parameter itself, which assumes that the measurement begins from the "zero position" and ends with the maximum abduction. The initial (zero) position can be affected by the body position, during the diagnostic exercise, in particular. Scoliosis can change the trajectory of the upper limb movements. Video filming is performed in a plane, and shoulder abduction does not always occur only in the frontal plane, which can distort the measurements [22–26].

Thus, the accuracy of measurements produced with computer vision technologies is determined by the peculiarities of the study of changes in the position of the recognized segments of the shoulder during motion and by the performance of a diagnostic exercise. Considering the current problems, we have developed the "Arthro-Pro" hardware and software system based on computer vision technology (certificate of state registration of the computer program No. 2023667718 dated 08/17/2023). The hardware and software complex allows for video capture and evaluation of human movements using a specially created algorithm for taking measurements on a projection kinematic model obtained with artificial intelligence and by performing specially developed diagnostic exercises. It is essential to validate the technology with existing goniometric research methods.

The **objective** was to validate a video-assisted computer vision goniometry of the motor function of shoulder abduction using the potential of neural networks.

MATERIAL AND METHODS

The study was conducted at the departments of medical rehabilitation and sports medicine, normal physiology of the Volgograd State Medical University. Volunteers of both genders who met the inclusion criteria (*n* = 33), underwent a medical examination with trauma and orthopedic surgeon, rehabilitation specialist and signed informed consent to participate in a clinical trial approved by Volgograd State Medical University (protocol dated 10.21.2022 No. 2022/149).

Results of related samples obtained during a series of examinations were compared to validate the author's method of goniometric study of shoulder abduction:

— Group 1 included examination with goniometry “Classical goniometry” (CG);

— Group 2 included radiological examination of changes in the position of the bone structures of the shoulder "X-ray" (R);

— Group 3 included examination using the video-assisted goniometry technique "Computer Vision" (CV).

Inclusion criteria for clinical trial:

— clinically healthy men and women with normosthenic body type;

— age from 18 to 60 years;

— normal shoulder functioning according to clinical examination.

Non-inclusion criteria:

— identified shoulder dysfunctions;

— injury to the internal and periarticular structures of the shoulder joint, identified with X-ray, MRI, ultrasound;

— psychomotor, psychoorganic and neurological disorders;

— connective tissue dysplasia syndrome;

— systemic connective tissue diseases.

The study involved men and women aged 18 to 56 years, with a body weight of 53 to 108 kg and a height of 155 to 195 cm.

CG of the shoulder was performed using a hand goniometer. The subject was placed in the basic stance, the movement performed in the frontal plane. The goniometer was applied to the joint from behind at the point where the hinge coincides with the humeral head. One of the branches was placed vertically along the axis of the spine, the other along the axis of the shoulder. The initial position was considered as zero (Fig. 1a) [6]. The result of the examination was the maximum amplitude of the shoulder abduction after three repetitions. Deviation from the anatomical position was described by a positive number of degrees ranging from 0 to 180°. Measurements of the range of motion were performed on the right (Fig. 1b).

Fig. 1 Measuring the amplitude of shoulder abduction using a hand-held goniometer: (a) zero position; (b) maximum abduction

Considering the significant variability of the goniometric values using a hand-held goniometer [6], the shoulder abduction was recorded using radiography (series 2). The analysis of the radiographic image suggested use of the following anatomical landmarks (lines, arrows) assessed in the initial position (Fig. 2a) and at maximum abduction (Fig. 2b).

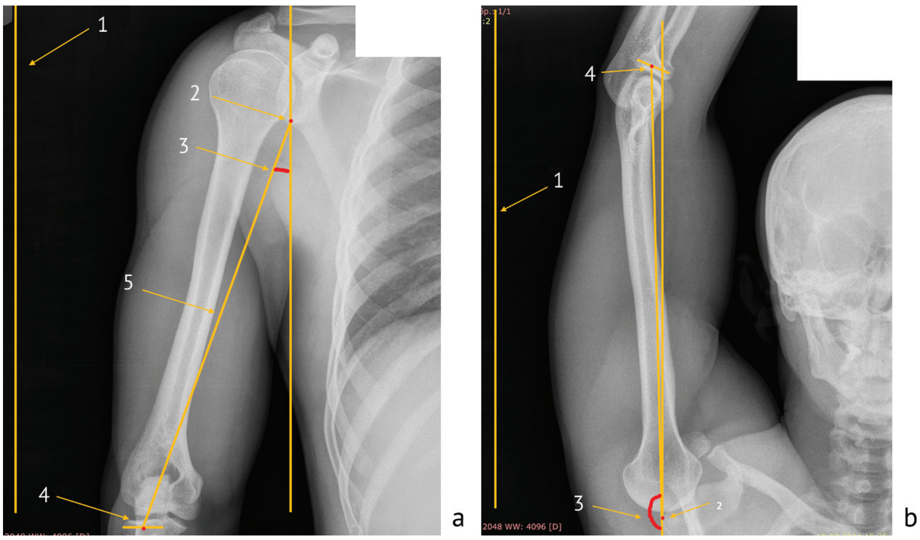

Fig. 2 Radiographs showing the shoulder abduction at: (a) zero position; (b) maximum abduction (1: vertical (template); 2: lower pole of the glenoid, through which the vertical (template) to be drawn; 3: abduction angle; 4: center of the radial head; 5: the line drawn through the lower pole of the glenoid and the center of the radial head)

Measurement of the shoulder movements primarily involves determining the axis of rotation passing through the center of the humeral head and the lateral epicondyle. However, the specified landmarks cannot be accurately compared in the zero position and at maximum abduction of the upper limb due to the bi-planar radiographic image. Anatomical points have been found to be clearly traced both in the zero position and at maximum abduction. These points are located as close as possible to the generally accepted ones (Fig. 2): the lower pole of the glenoid and the center of the radial head, through which a line is drawn. To ensure unification of measurements, the vertical (1) drawn through the lower pole of the glenoid is taken as the second reference point to measure the abduction angle (3) inbetween (Fig. 2).

The amplitude of active shoulder abduction in the 3rd series was assessed using the author's goniometry method of the CV using the hardware and software complex "ArthroPro" including an HD video camera, a tripod and a computer with a preset program. The subject was positioned frontally in relation to the video camera with his shoulder blades pressed against the vertical support. The video camera was placed at a distance of 1.5 m from the subject at a height of 1.5 m from the floor. The position of the arms lowered downwards with the first finger pointing forward was taken as the zero position. Then the subject moved his arms upwards in an arc to the maximum position.

Human movements were recognized using a pre-trained MediaPipe neural network, which processed video images, formed projection points at the shoulder, elbow, wrist, hip, knee and ankle joints, connecting them with lines. The authors introduced a vertical through a point in the shoulder joint to unify measurements. As a result, an abduction angle (arrow) was formed and measurements were recorded by the program (Fig. 3).

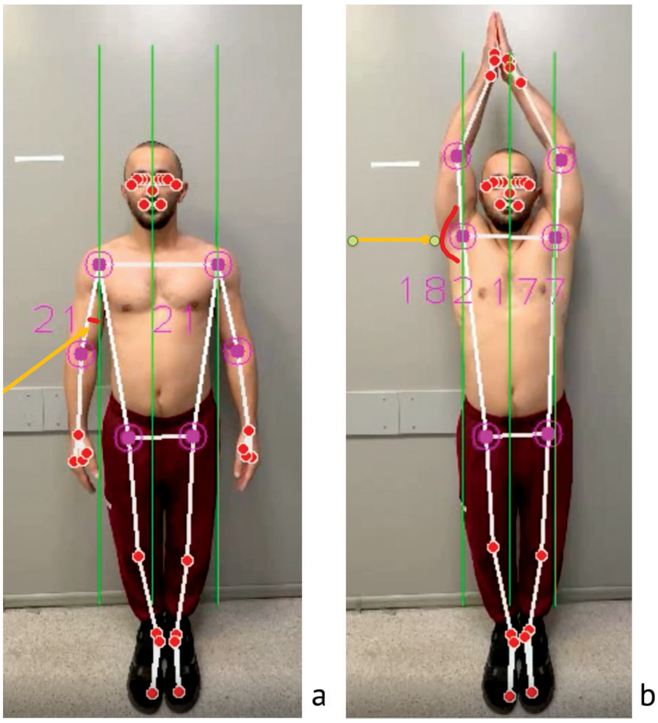

Fig. 3 Shoulder abduction amplitude measured with video-assisted goniometry: (a) zero position; (b) maximum abduction

Confirmation of the compliance of the video-assisted computer vision-based technique with the intended use was obtained using statistical processing of the initial data by analyzing the rank sign criterion, Student's t-criterion, and plotting the Bland-Altman plot in the program. The statistically significant level was set at $p \leqslant 0.05$.

RESULTS

The average amplitude of abduction in the series of measurements of the CV using Arthro-Pro was (178.90 ± 0.63)° (confidence interval of reliability $p = 0.95$), and (179.5 ± 0.1)° (confidence interval of reliability $p = 0.95$) in the KG series.

The observations were paired (Paired Samples with two measurements for each patient), the difference in measurements was analyzed exploring the differences between the two samples. The average difference between the CV and KG amplitude of abduction in the two measurement groups was insignificant, amounting to (–0.62 ± 0.63)° (confidence interval $p = 0.95$) from a minimum of –5.2° to a maximum of 1°, with the only observation with a difference in readings of 5.2° (greater than 5°) being “sharply outstanding” (Fig. 4a).

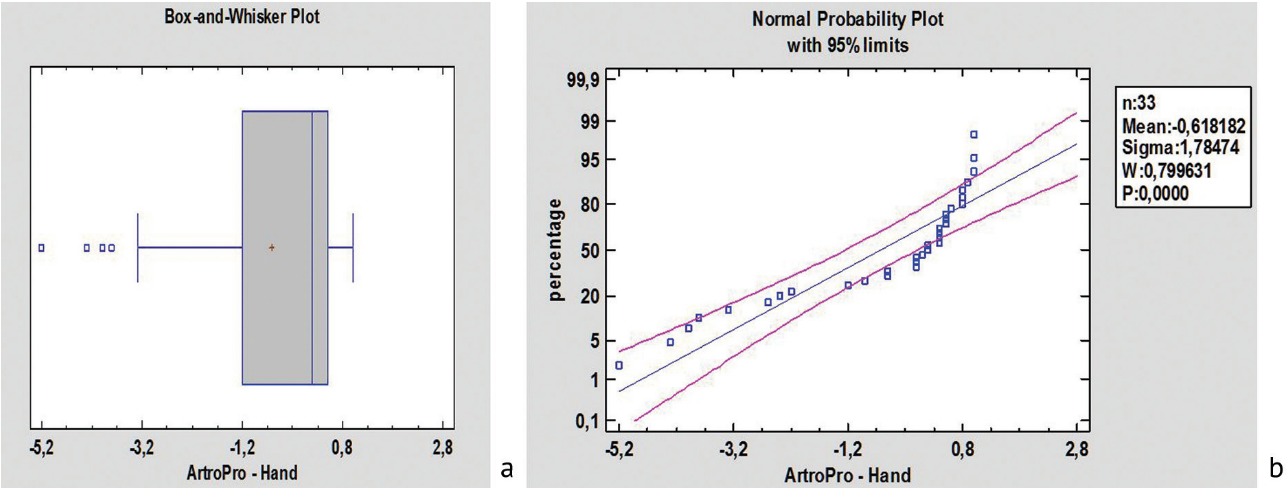

Fig. 4 Graphical analysis of the difference in the amplitude of the shoulder abduction in the clinical-goniometric series and the series using computer vision: (a) "box and whiskers" (Box-and-Whisker Plot); (b) graph on the normal probability paper

The difference in the indicators was not distributed according to the normal law (Fig. 4b) and two criteria were used for comparisons: the rank sign criterion to test the hypothesis that the medians of the two samples were equal, and the Student's t-test (for paired observations) to test the hypothesis that the average difference in the measurements of the abduction angles was zero. Both criteria showed that the hypotheses were true at a significance level of 0.05 (5 %), i.e. the difference in the medians and in the differences in the means of the two samples was insignificant. The average value of the difference was the assumed systematic error.

Thus, the measurements with the CV method contained no systematic error. The Bland–Altman plot is a powerful graphical tool for comparing two measurement methods and assessing the agreement between two sets of data [27]. Also known as difference plots, they are a visual representation of the difference between two measurements on the Y-axis and the average of the two measurements on the X-axis. Figure 5 shows the Bland-Altman chart plotted in Excel.

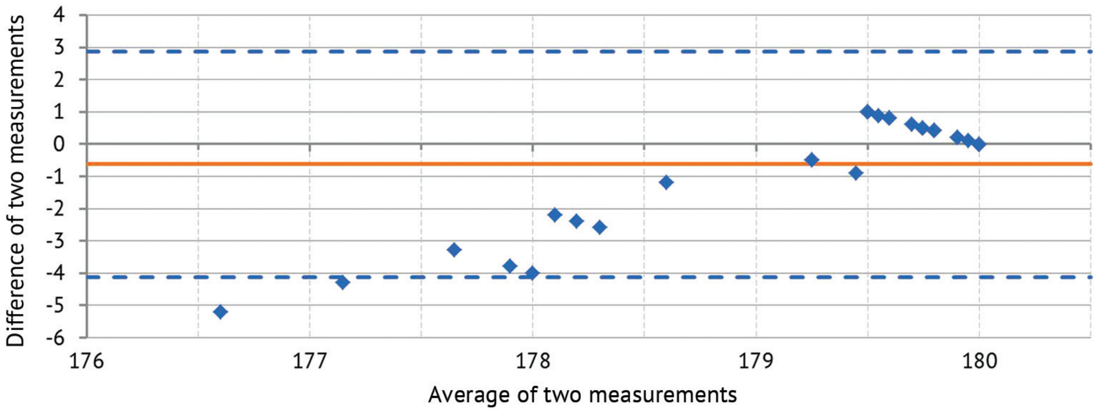

Fig. 5 The Bland–Altman plot

The Y axis shows the difference between the measurements of the CV and KG, and the X axis shows the half-sum of 0.5 × (CV + KG). The horizontal line in the middle Y = –0.62 is slightly shifted relative to zero and shows that the average difference in the indicators is insignificant. The dotted lines represent the 95 % limits of agreement (mean difference ± 1.96 standard deviations of the difference), which show how much the measurements obtained by the two methods can differ in the majority

(95 %) of people. In our case, the standard deviation SD = 1.78 and the limits of agreement (−0.62 ± 1.96)° × SD define the range (−4.11°; 2.87°). The difference within the limits not exceeding 5° has no clinical significance, so the two methods of CV and CG can be used interchangeably.

Measurements the shoulder abduction in the groups were compared using manual (classical) goniometry (CG) and radiology (R). The statistical analysis showed the significant difference. The difference in abduction measured by the two methods ranged from −11.8 to 22.7°, with a mean difference of 6° [confidence interval $p = 0.95$ for it (6 ± 2.8)°]. Therefore, the radiographic method provides on average significantly underestimated values of the abduction angle (on average 6° less). Individual values were both underestimated by 22.7° and overestimated by 11.8°.

A comparison of the shoulder abduction angle measured with computer vision and the X-ray was not performed.

DISCUSSION

Accuracy is an important aspect in measuring shoulder abduction. The shoulder is the most mobile joint and movements are characterized by multicomponentity. A.I. Kapandzhi reported motion occurring primarily at the scapulohumeral joint in the early phase (0–60°), although stressing thearm may increase the scapular contribution involving acromioclavicular and sternoclavicular joints. Measurements in the zero position can be affected by the soft tissues of the upper limb, the trunk and scoliosis, which can change the abduction pattern. In classical goniometry, one branch is applied parallel to the spine, which can presumably distort the measurement depending on the axis. The vertical line entered into the Arthro-Pro program through the projection point in the shoulder joint is automatically tied to the template in the background, leveling out scoliotic distortions. This aspect affects the compatibility of the indicators of the compared methods (CG – CV) [28–32].

There are differences in the projection points for the goniometer branches and the verticals of the CV. Projections differ, causing differences in abduction angle. The significant differences in the projections of the points were the reason for the occurrence of cases where the values were outside the confidence interval. The small spread of the mean difference fits into the generally accepted criteria for conducting measurements [1–3, 33–35].

Evaluation of the results of radiographic measurements of the shoulder abduction allowed us to identify a larger interquartile spread of the mean difference in relation to the data obtained with the CV and CG methods. This is largely due to the system of radiographic measurements.

The primary objective is to determine the axis of the shoulder rotation with the line drawn through the center of the humerus head and the lateral epicondyle of the humerus. However, rotation of the humerus during abduction and the biplanar format of radiographic images do not allow for accurate comparison of the rotation axes in the initial position and during maximum abduction of the upper limb. Therefore, there was a need for new landmarks that would be localized precisely and simultaneously in two positions (initial — maximum).

These were the lower pole of the glenoid and the center of the radial head. It is worth noting several other reasons that determine the differences in the parameter measured in series 1, 2 and 3. One of the reasons includes the smaller amplitude of the abduction in the radiological format in comparison with the other two series. Radiography required fixing the arm in the initial and abducted positions for a short period of time, which could cause some lowering of the upper limb in the second position, in particular. The greatest deviations were found with comparison of the shoulder abduction angles (series 1, 2, 3) in subjects with a larger shoulder circumference.

CONCLUSION

The average difference in abduction angles in the CV and KG series does not exceed the generally accepted differences of 5°. Radiological assessment of bone position is associated with the selection of projection points for measurements, which can affect the abduction angle parameters. The findings showed that measuring the amplitude of the shoulder abduction angle using computer vision is a valid method that can be used for goniometric examinations in clinical practice.

Conflicting Interests *The authors declared no potential conflicts of interest with respect to the authorship and/or publication of this article.*

Funding *The authors received no financial support for the research and/or authorship of this article.*

Ethical standards *The study was approved by the local ethics committee of the Federal State Budgetary Educational Institution of Higher Education "Volgograd State Medical University" of the Ministry of Health of the Russian Federation (protocol No. 2022/149 dated October 21, 2022).*

Informed Consent *All patients participating in the study signed a voluntary informed consent to participate in a clinical trial.*

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The article was submitted 24.03.2025; approved after reviewing 11.04.2025; accepted for publication 05.06.2025.

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