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Abnormal Scapular Kinematics In Symptomatic Acromioclavicular Arthritis. A Biomechanical Analysis Using Inertial Sensors

Christos K. Yiannakopoulos *, Iakovos Vlastos, Georgios Kallinterakis, Elina Gianzina, Nikolaos Sachinis

School of Physical Education & Sport Science, National & Kapodistrian University of Athens, Greece

***Corresponding Author:** C.K. Yiannakopoulos

Email: C.Yiannakopoulos@phed.uoa.gr; ckyortho@gmail.com

Abstract

Purpose: The purpose of this study was to non-invasively evaluate the scapula kinematics in a group of athletes with Acromioclavicular Joint (ACJ) arthritis using inertial sensors.

Methods: In this study 9 male overhead athletes with a mean age 33 ± 5.9 years were enrolled with symptomatic ACJ osteoarthritis, secondary to Distal Clavicle Osteolysis. The dominant arm was affected in 7 cases. In all patients weight lifting was part of their daily exercise routine. Scapular kinematics was evaluated using an inertial measurement unit (IMU) consisting of a high-resolution accelerometer, gyroscope, and magnetometer. The IMUs were positioned in the upper and lower limbs, the scapula and sternum sensors. The patients were asked to perform shoulder abduction and forward flexion in the scapular axis and the displacement and rotational data of the movement were recorded using a dedicated software.

Results: Scapular motion was measurably affected in the symptomatic shoulder. The translation in abduction, measured in mm, was statistically significantly higher in the shoulder with ACJ osteoarthritis along the laterally directed x axis (23.54 $\pm$7.1 mm vs 19.58 $\pm$6.9 mm) and anteroposteriorly directed z axis (13.97 $\pm$ 2.97mm vs 7.17 $\pm$4.73mm), The same finding was noticed in forward flexion for the z axis (14.03$\pm$2.53 mm vs 9.41$\pm$5.92 mm). The rotation, in rads, was significantly higher in the anteroposteriorly directed z axis (0.50$\pm$0.23 vs 0.37$\pm$0.052).

Conclusion: Scapular kinematics is affected in patients with symptomatic ACJ osteoarthritis as verified with the use of inertial sensors.

Keywords: Acromioclavicular Arthritis ;Distal Clavicle Osteolysis; Inertial Sensors; Scapular Kinematics; Shoulder

Introduction

Acromioclavicular joint (ACJ) osteoarthritis is a common frequent radiological finding not only in middle and old aged but also in younger patients [14]. Although possibly overstated, the prevalence of arthritic ACJ changes on MRI has been reported to be 68% in patients aged 30 years or less and 93% in patients older than 30 years [17]. In 80% of the cases the arthritic changes are characterized as mild and only in 5% as severe, without significant difference between the two sexes [17]. ACJ osteoarthritis often is not symptomatic and even in the presence of a rotator cuff tear does not warrant surgical treatment usually excision [14]. Asymptomatic ACJ osteoarthritis may remain stable for many years. Progression of asymptomatic ACJ osteoarthritis was reported to be 10% in a 7 year follow up especially following heavy arm use and in patients with advanced disease [6].

Scapulohumeral motion in health and disease is very important for the preservation of shoulder function. The scapula plays key role by being mobile enough to place the glenoid in an optimal relation to the humerus. Scapular dyskinesis (SDK) alters this role and is frequently present in glenohumeral instability[10]. The prevalence of SDK is higher (61%) in overhead sports athletes than in non-overhead sports athletes (33%) [3]. It is not clear if SDK is associated with acromioclavicular joint pain or if it is the result of normal movement variability [14]. The definition of normal and abnormal scapular motion in health and disease remains elusive [1].

Evaluation of 3D kinetics and kinematics of the scapula is important to recognize the effect of shoulder pathology on the scapulothoracic joint and vice versa, offering the potential to provide information about the disease severity and the postoperative progress of the rehabilitation program [2, 4]. Several studies investigated scapulothoracic kinematics with the use of wearable inertial sensors in normal subjects, in various pathological conditions, neurological and musculoskeletal and in gait analysis [1, 4, 5, 15].

The purpose of this study was to evaluate the scapular kinematics in a group of patients with symptomatic ACJ osteoarthritis using an inertial sensor system.

Materials and methods

Methods

Sample

In this study 9 athletes with a mean age 32±4.9 years were enrolled. All patients presented for surgical treatment due to unilateral, persistent, symptomatic ACJ osteoarthritis secondary to Distal Clavicle Osteolysis (DCO) and were tested prior to surgery. There was stiffness of the affected shoulder on passive examination nor had any patient significant scapular dyskinesia. All patients underwent limited ACJ excision. The contralateral shoulder was used as a control and no patient reported glenohumeral or scapulothoracic pathology, history of shoulder injury or neck symptomatology. MRI examination of the healthy shoulder was performed in all patients with DCO and the presence of shoulder or ACJ pathology was excluded. All measurements were performed at the Biomechanics Laboratory, School of Physical Education and Sport Science (SPESS) of the National and Kapodistrian University of Athens, Greece. The Institutional Ethics Committee approved the study protocol and a written informed consent was obtained from all participants.

Instrumentation

The Shadow Motion Capture System (Motion Workshop, Seattle, WA, USA) was used for this study. The Shadow system offers 17 precision inertial measurement units which provide low noise, high resolution output data. Each Shadow sensor is an inertial measurement unit (IMU) consisting of a high resolution, low noise accelerometer, gyroscope, and magnetometer with an output data rate of 100, 200, or 400 Hz and a 1000 Hz internal update rate and low latency, 20 ms for wifi applications. The miniature inertial sensors provide 0.5° static accuracy and 2° dynamic accuracy with a size of 33 x 18 x 6 mm. The weight of the whole wearable system is 1.1 kg with an 8-hour independency. The Accelerometer has a resolution of 0.18 mg, the Gyroscope 0.12 °/s and the Magnetometer 0.25 mG. The inertial sensors are positioned in the upper and lower limbs with straps while the scapula and sternum sensors are placed in pockets in a tight fitting lycra shirt (**Figure 1**). The IMUs are connected with the docking station using a Wi-Fi 802.11n protocol. A dedicated software is used to record the inertial sensor recordings.

Figure 1. Placement of the inertial sensors. The scapular inertial sensors (arrow) are placed in a special pocket in the lycra suit, in close contact with the scapular spine. The orientation of the x, y and z axes is also marked. The y axis is oriented perpendicular to the floor, the x axis is directed laterally and the z axis anteriorly. The rotational and translational movement of the sensors are recorded in real time. Additional sensors are placed in the arms, distal to the deltoid insertion (stars) and on the sternum (not shown).

Calibration

Calibration was performed before data acquisition and processing as per the manufacturer's instructions. The calibration process includes elimination of magnetic field interaction from any ferromagnetic material and subsequently orientation calibration of the inertial sensors units using a T pose, with the subject placing his upper limbs in 90° of horizontal abduction. The magnetic calibration corrects for any deviation of to the measured parameters due to the geomagnetic field induced by the proximity to ferromagnetic materials, such as iron and nickel.

Measurement Procedure

All participants were offered a two-minute preparation to be familiar with the equipment and the tasks they had to execute. Each participant was asked to perform two tasks, full shoulder abduction and forward flexion in the scapular axis, 30° from the frontal plane. Each patient performed three successive repetitions with repeated calibration between the tasks. The normal shoulder was examined first and the dysfunctional, painful shoulder later.

Data collection

All data were transmitted through a Wi-Fi dock station of the system directly to a personal computer using the dedicated Shadow software and they were exported in .c3d file format according to the International Biomechanics recognized file type for kinematic analysis. A dedicated bioengineering analysis software, Mokka 3D motion Kinematic and Kinetic Analyzer version 0.6.2, was used to analyze the data.

Outcome measures

The data derived from the scapular sensor provided information regarding the total translation in mm for the three axes, x, y and z as well as the rotational movement in radians for the respective axes.

Data Analysis

All outcome measures were computed using Microsoft Excel and the mean of the three repetitions were used. Statistical analysis was performed with a paired t-test using SPSS (v. 24.0, IBM Corp., Armonk, NY, USA). The level of statistical significance was set at $p=0.05$.

Results

The results of the study are presented **in Table 1**. The affected shoulder presented significant alteration in the pattern of scapular motion. The total translation in abduction, measured in mm, was statistically significantly higher in the shoulder with ACJ osteoarthritis along the laterally directed x axis (23.54 ±7.1 mm vs 19.58 ±6.9 mm) and anteroposteriorly directed z axis (13.97 ± 2.97mm vs 7.17 ±4.73mm), showing increased translation of the scapula compared to the normal, contralateral side. The same finding was noticed in forward flexion for the z axis (14.03±2.53 mm vs 9.41±5.92 mm). The rotation, in rads, was significantly higher in the anteroposteriorly directed z axis (0.50±0.23 vs 0.37±0.052). The results are presented in **Figures 2 to 6**.

Table 1. The results of the present study. The total translation in mm for threes axes, x, y and z is presented as well as the rotational movement in radians for the respective axes. All values are presented as mean±standard deviation. The level of statistical significance is reported. ACJ OA, Acromioclavicular joint osteoarthritis, n.s, not statistically significant.

		Abduction			**Flexion at 30^{o}**		
	Axis	**Controls**	**ACJ OA**	**p-value**	**Controls**	**ACJ OA**	**p-value**
Total Translation (mm)	X	19.58±6.9	23.54 ±7.1	**p=0.043**	16.13±14.66	17.4 ±17.76	n.s
	Y	3.65±2.91	3.62±4	n.s	2.2687±1.63	2.79 ± 2.61	n.s
	Z	7.17±4.73	13.97± 2.97	**p=0.001**	9.41±5.92	14.03 ±2.53	**p=0.03**
Rotation (rads)	X	0.81±2.14	0.41±0.072	**p=0.01**	0.29 ±0.154	0.45 ± 0.15	**p=0.01**
	Y	0.115±0.078	0.16±0.55	n.s	0.0713±0.0573	0.13 ±0.1365	n.s
	Z	0.37±0.052	0.50±0.23	**p=0.049**	0.327±0.63	0.423 ±0.15	**p=0.05**

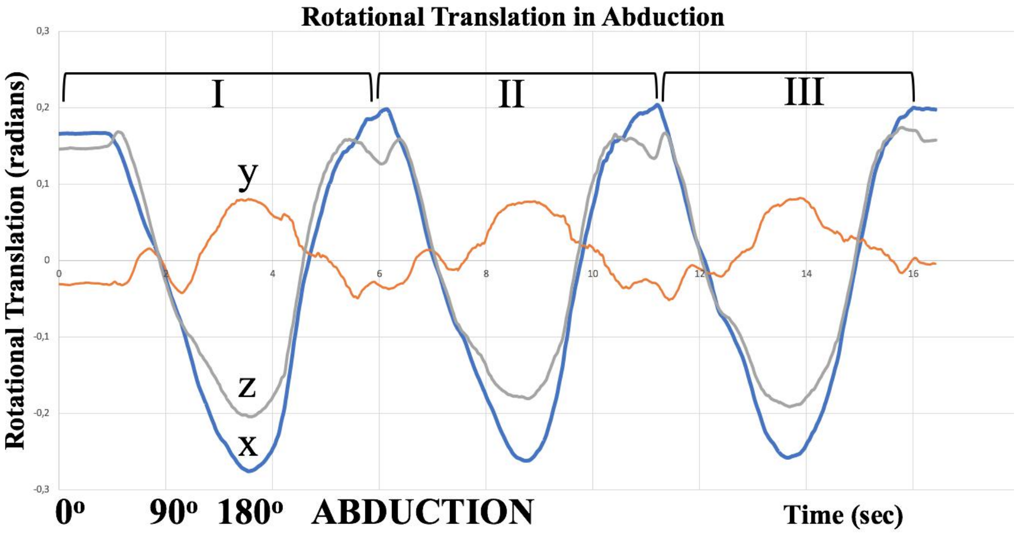

Figure 2. Rotational translation of the shoulder of a healthy athlete in horizontal abduction. The rotation of the scapular inertial sensor in the 3 axes is continuously recorded. The athlete performed three successive movements (I, II, III). The starting point with the arms at the side is not zero because the calibration of the device was performed in a T pose position in 90o of abduction. The respective values in all axes become zero when the shoulder is in the position of calibration (90o of abduction). The pattern of movement is reproducible.

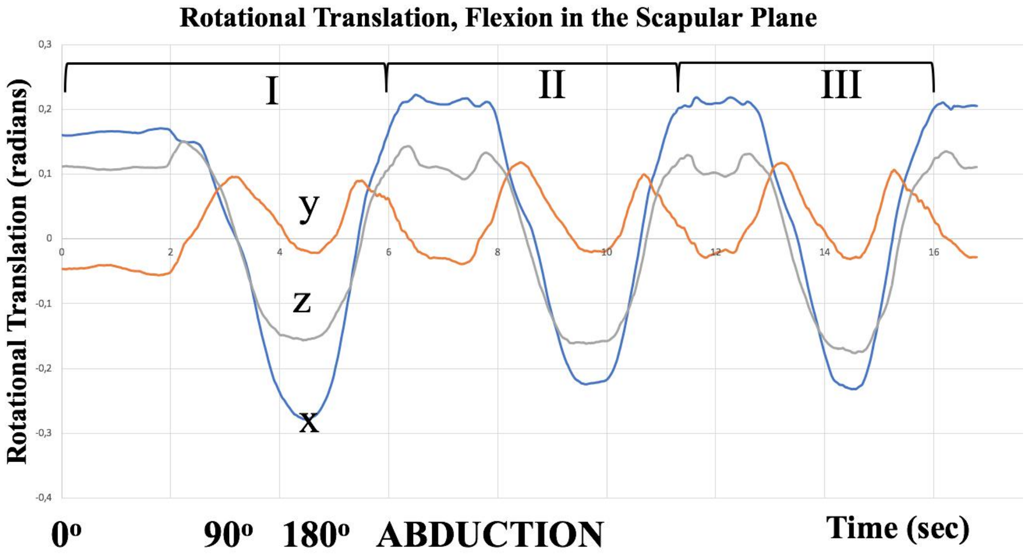

Figure 3. Rotational translation of the shoulder of a healthy athlete in 30 degrees of forward flexion in the scapular plane. The rotation of the scapular inertial sensor in the 3 axes is continuously recorded. The athlete performed three successive movements (I, II, III). The starting point with the arms at the side is not zero because the calibration of the device was performed in a T pose position in 90o of abduction. The respective values in all axes become zero when the shoulder is in the position of calibration (90o of abduction).

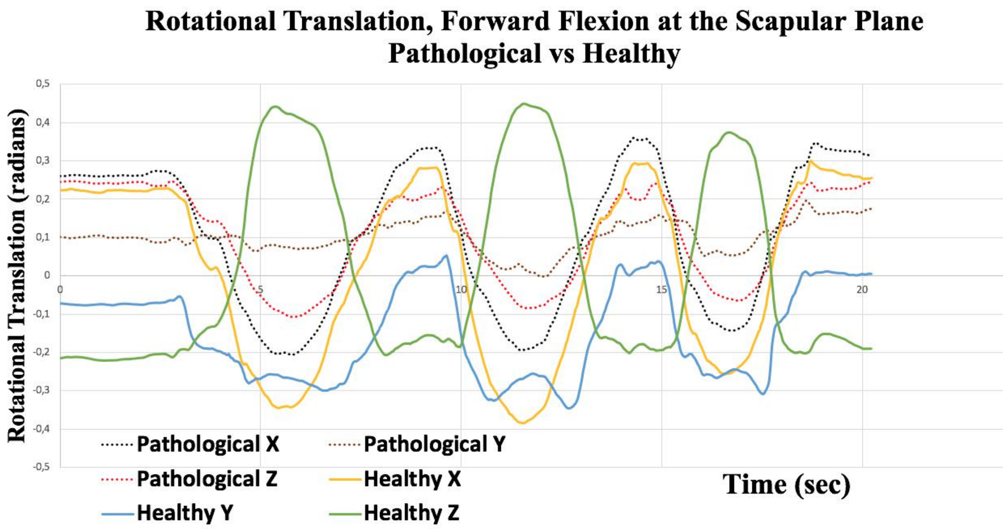

Figure 4. Comparison of the rotational translation of the pathological with the contralateral healthy shoulder in 30 degrees of forward flexion in the scapular plane. The scapular motion in the three axes is presented. The athlete performed three successive movements (I, II, III). The pathological shoulder is presented with dashed lines and the normal with solid lines. The healthy shoulder yields negative values and the pathological positive values because of the calibration method. Only the absolute values of motion were taken into consideration.

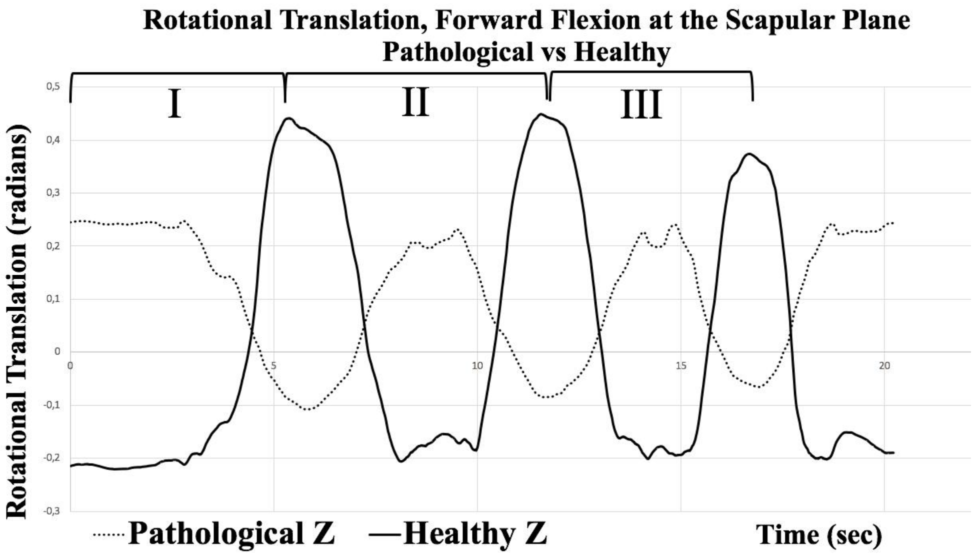

Figure 5. Rotational translation in the y axis (perpendicular to the floor) of the pathological with the contralateral healthy shoulder in 30 degrees of forward flexion in the scapular plane. There is significant reduction the translation of the pathological shoulder.

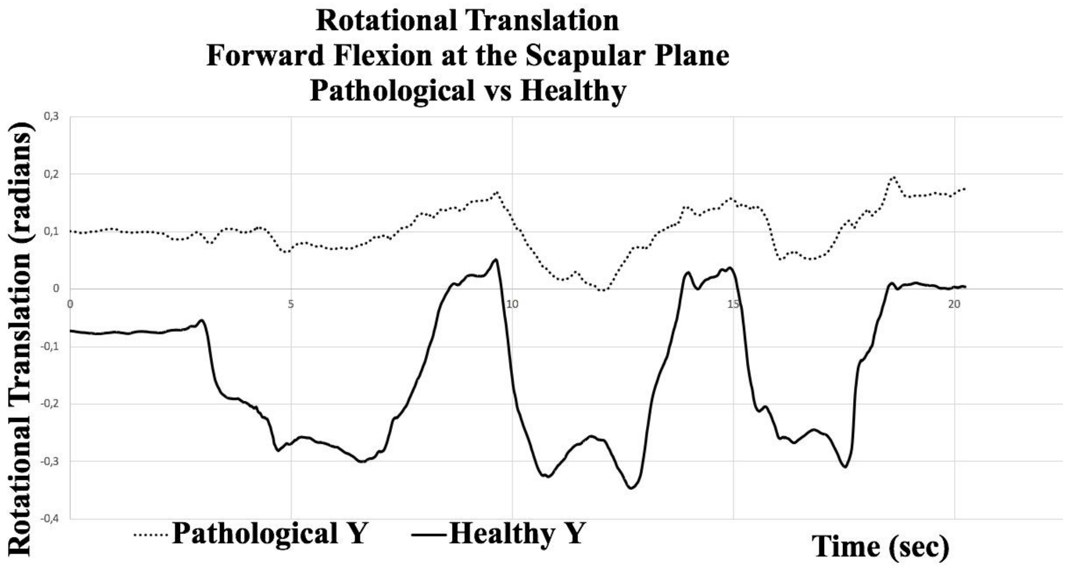

Figure 6. Rotational translation in the z axis (anteroposterior) of the pathological with the contralateral healthy shoulder in 30 degrees of forward flexion in the scapular plane. Significant reduction the translation of the pathological shoulder in this axis can be noted as well.

Discussion

The present study showed that isolated ACJ osteoarthritis in the athletic shoulder is causing alteration in the kinematic pattern of the scapula compared to the contralateral, healthy side.

There is increased translation of the scapula in two of the three axes in order to compensate for the lack of ACJ movement due to pain or depletion of the range of motion.

Abnormal scapular movement can be the cause or the outcome of certain shoulder degenerative or traumatic diseases [13]. In patients with subacromial impingement without a rotator cuff tear, kinematic analysis has shown the presence of superior humeral translation which reduces the effective subacromial space [13]. In patients with a symptomatic rotator cuff tear, despite lack of significant kinematic differences, the posterior tilt of the scapular was higher compared to asymptomatic patients (3.1°±1.8° vs 10.4°±0.8°) [11]. In different patterns of scapular dyskinesis there are specific alterations of scapular muscular activation and abnormal scapular kinematics [8].

Gumina et al. [7] demonstrated that chronic, type III, acromioclavicular dislocation causes scapular dyskinesis in 70.6% of patients. Another study investigated individuals with anterior glenohumeral joint instability and compared them with individuals with healthy shoulders. Planar shoulder movement and a functional three-dimensional (3D) reaching task were evaluated finding anterior instability has little impact on scapular kinematics during upper limb movements in a chronic condition without pain, muscle weakness or limited range of motion [9]. In our series the patients did not display visually significant scapula dyskinesis although it was present.

Wearable inertial sensors have been used in the past to study shoulder and scapulothoracic kinematics in a variety of normal and pathological conditions [1, 4, 16]. Significant variation in the methodology used in the various studies is noted [4]. The use of inertial sensors is favored by patients due their versatility, ease of application and ability to be used outside of the laboratory setting. Inertial sensors are attached on the body segment of interest and its movement represents the movement of the tracked body segment [1, 4]. In our study, the sensor was embedded in a specifically designed stretchable shirt, at a predetermined location, over the scapular spine, in order to reduce or minimize the confounding effect of soft tissue, skin and muscle movement. We performed both shoulder abduction and flexion 3 times in order to minimize the soft tissue artifact [20]. The effect of ACJ osteoarthritis, isolated or in conjunction with a rotator cuff tear, on the shoulder motion has been studied using an electromagnetic tracking system [18]. They found that patients with isolated ACJ osteoarthritis have greater internal rotation than controls [18]. Furthermore patients with ACJ osteoarthritis with or without a rotator cuff tear show significant alteration in the activity of the shoulder muscles [19]. Difference is present in shoulder kinematics between symptomatic and asymptomatic patients although the magnitude of those differences is small and their clinical implications are not always clear [12].

The present study has several limitations and strengths. The group of patients was quite homogenous, including male athletes with significant pain and dysfunction due to secondary ACJ osteoarthritis. The contralateral normal shoulder was used as control to avoid possible selection bias. We used inertial sensor technology which allows non-invasive and reliable recording of scapular motion in real time. There is no spatial limitation of this technology since it can be employed even on the athletic field without resorting to more elaborate optoelectronic or electromagnetic registration systems used in laboratory settings. Additionally, inertial sensor usually do not require extensive training or significant expertise. As regards the limitations, first, we evaluated only young athletes with secondary ACJ osteoarthritis with significant localized pain and restriction of overhead activities. It is possible that the impact of non-symptomatic ACJ osteoarthritis in the scapular motion is limited, but this remains to be elucidated. The number of patients is limited due to the rarity of DCO. The kinematic results of surgical ACJ excision have not been evaluated but this study is ongoing.

Conclusions

Our study showed that symptomatic ACJ arthritis in young athletes affects normal scapular kinematics. Inertial sensors have to potential to provide objective data on scapular kinematics in normal and pathological shoulder joints. Placement of the sensors, calibration methods and repeatability of the results have to be ensured in order to make the method a reliable clinical tool.

Abbreviations

ACJ Acromioclavicular Joint

SDK Scapular dyskinesis

DCO Distal Clavicle Osteolysis

Author contributions

CKY conceived the paper, supervised the experiment, and wrote the manuscript, IV and EG executed all measurements and performed data analysis, NS and GK participated in the design of the study and helped draft the manuscript. All authors read and approved the final manuscript.

Ethical approval

Prior to the start of the study, approval was obtained from the Institutional Review Board in accordance with the ethical standards of the Declaration of Helsinki (1964) and its later amendments (PRO15060142).

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