Article

Normative Values of Skeletal Muscle Contractile Parameters and Lateral Symmetry in Artistic and Rhythmic Gymnasts

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Abstract: Introduction: The purpose of this study was to determine the normative values of muscles' contractile properties, lateral symmetry, and the impact of aging on muscle contractility in gymnastics. **Materials and Methods:** A survey of 81 athletes from different disciplines was undertaken: MAG (n = 26), WAG (n = 28), and RG (n = 27). The athletes' average age was 15.41 ± 5.03 years. We try to establish the normative values for contraction time (muscle pairs) in gymnastics for Slovenian athletes for ten skeletal muscles. **Results:** Athletes' age affects contractility in a negative way. Differences between the duration of contractility and age were found in all disciplines: m. BF (r = 0.48, p < 0.001), m. TB (r = 0.37, p < 0.013), m. ES (r = 0.17, p < 0.025), m. VL (r = 0.36, p < 0.00) and m. VM (r = 0.40, p < 0.000) at a statistical significance of p < 0.05. **Conclusions:** A comparison between the left and right side shows little asymmetry in WAG and that the occurrence of injuries is in the middle range. In RG we see a bigger deviation, which could trigger the emergence of pain or injury in m. BF (13%) and m. GL (14.5%), but in MAG the deviation is greater in m. BB (12%), m. BF (11%) and m. GM (13%).

Keywords: tensiomyography; gymnastics; contraction time; asymmetry

1. Introduction

Scientific results in sports have led to changes in both the concept of the athlete's preparation and sports theory. Selection and an orientation to systematic training started almost 20 years ago in almost every sport [1]. This is why experts created diagnostic models for use in selection, and diagnostic models for monitoring changes or, better put, the body's response to physical activity among young, middle-aged and older athletes.

One can find many studies that talk about young athletes' guidance in different sports, the effect of exercise on body composition, as well as the development of functional and locomotor skills and qualities. In contrast, not a lot of information is available about the type and composition of skeletal muscle, especially in adolescents [2]. We found one longitudinal study which discussed changes in skeletal muscle fibres in growing-up children [3]. We conclude that, due to the invasiveness of the muscle biopsy method and correlated ethical questions, research of skeletal muscles is rarely undertaken in sports — in gymnastics practically never. With development of the TMG method, which is scientifically proven, objective and reliable [4-7], we have gained more knowledge about the structure and properties of the muscles [8-10].

The tensiomyography (TMG) method monitors radial muscle belly displacement under isometric conditions. A twitch type of electrical stimulus induces the concentric

contraction of the muscle. Due to the maintenance of the muscle volume the muscle thickens, causing the sensor to move and send the signal [11,12].

The basic parameters of TMG are: Tc – contraction time, Dm – maximal displacement, Ts – sustain time, Td – delay time, Tr – relaxation time (Figure 1). Contraction time (Tc) and maximal displacement (Dm) are the most researched parameters of the TMG method in different sports [2,6,11,13-15].
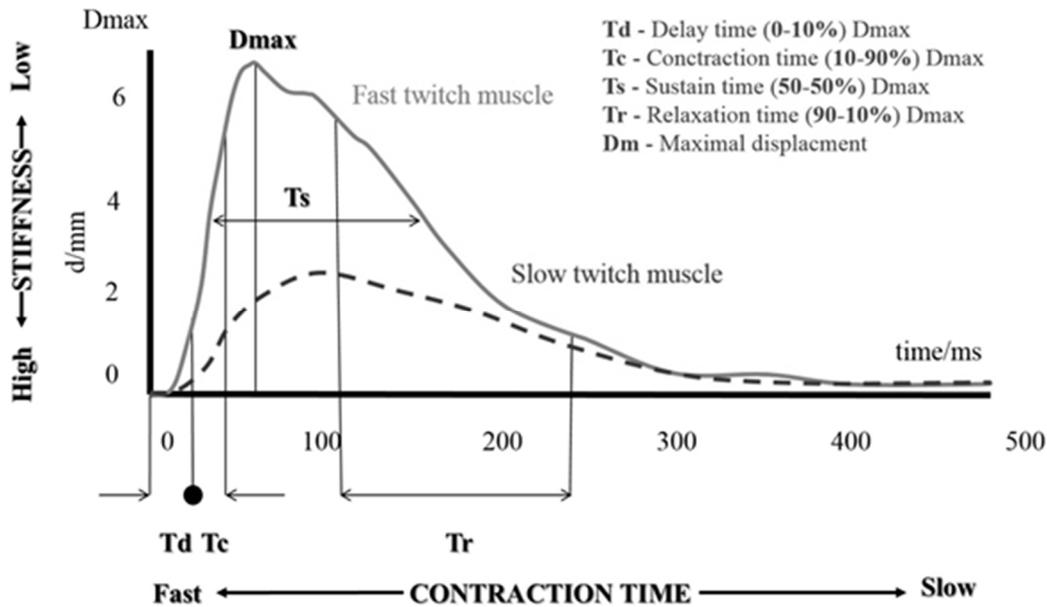

Figure 1. Parameters of tensiomyography (TMG) method.

TMG is a non-invasive and time and financially undemanding method which can be used to define the structure of skeletal muscle [2,6] and, on the basis of time parameters, data about the muscle function. The latter can be used for different analyses: for measuring muscles' adaptation abilities to specific training or exercise, for diagnosing lateral and functional symmetries, for measuring muscle fatigue, for controlling a rehabilitation programme etc. [2,6,14,16-17].

Studies have shown that muscle asymmetries increase the risk of injuries in different locations [18-22]. Sensitive and accurate measuring devices for discovering muscle asymmetries are an isokinetic device, force plate and TMG [23], except for the trunk where the TMG method is used to discover muscle asymmetries in modern sports diagnostics [12]. Asymmetries of the back muscles (m. Erector Spinae) can lead to different back deformations and injuries [24-25].

In addition to the basic parameters, it is useful to longitudinally monitor and study the correlation of different parameters over longer periods. In prior studies, the influence of age on contraction time was found [15,26].

The purpose of this study was to determine the normative values of muscles' contractile properties, lateral symmetries and the effect of ageing on selected skeletal muscles' contractile properties in MAG, men's artistic gymnastics; WAG, women's artistic gymnastics and RG, rhythmic gymnastics.

2. Materials and Methods

2.1. Measured Muscles

The measurements lasted 30–35 minutes per athlete. We conducted one measurement of the left-side muscles and one measurement of the right-side muscles on a therapeutic desk, which provided comfort and exactly accommodated the athlete in a lying or sitting position. All muscles were relaxed before and after the measurement.

Measurement of m. biceps brachii (m. BB) and m. triceps brachii (m. TB) was carried out in a sitting position. The measured upper extremity was 30º abducted in the shoulder, 90º flexed in the elbow (where 0° means a fully extended elbow), the forearm was pronated. To maintain this position, we used foam pads placed under the elbow [26]. Measurement of m. rectus femoris (m. RF), tibialis anteriror (m. TA), m. vastus lateralis (m. VL), m. vastus medialis (m. VM) were done in a lying position, where flexion of the knee was 30° (where 0° means a fully extended knee). To maintain this position, we used foam pads placed under the knee. The measurement of m. biceps femoris (m. BF), m. erector spinae (m. ES), m. gastrocnemius lateralis (m. GL) and m. gastrocnemius medialis (m. GM) were performed lying on the abdomen, with 5º of knee flexion (where 0° means a fully extended knee). To maintain this position, we used foam pads placed under the ankle [15].

2.2. Electrical Stimulation

Two surface electrodes were placed on the muscle belly in an appropriate position. The electrodes were connected to an electric stimulator, which releases an electric stimulus lasting 1 millisecond with a power supply voltage of 12 V and output intensity from 0 to 110 mA [17]. For all athletes, we gradually increased the output intensity from 5 to 10 mA until the contraction time parameter reached the highest values or until the muscle response no longer increased [16]. A sensor was placed on the muscle belly perpendicularly. The electric stimulus induced the muscle contraction, the muscle belly thickened and pushed the perpendicularly placed sensor away. The sensor measured the maximal displacement, contraction time, sustain time, delay time, relaxation time and sent the measurements for further computer analysis [27-28].

As suggested by Valenčič [9], for each muscle response Dm, Td and Tr were calculated. Dm means maximal displacement of the muscle, Tc is defined as the time between 10% and 90% of the maximal displacement [15]. Athletes were familiar with both the basic principles of the TMG method and the purpose of the measurements. They were also informed not to warm up or perform any strenuous activities before the measurements. The measurement protocol for each muscle was carried out once. The measurements were performed in a gymnastics centre in Slovenia in the first half of the day and lasted for 14 days.

2.3. Samples

Measurements of n=81 athletes from different disciplines were conducted in this study: men's artistic gymnastics (n=26 athletes), women's artistic gymnastics (n=28 athletes) and rhythmic gymnastics (n=27 athletes). Their average age was 15.41 ± 5.03 years.

Table 1. Average age of the gymnasts included in the study.

Gymnastics Disciplines	MAG n = 26 (32.1%)	WAG n = 28 (34.6%)	RG n = 27 (33.3 %)
Age (years)	18.46 ± 7.18	14.32 ± 3.33	13.59 ± 1.89

2.4. Statistical Analysis

Data processing was done with IBM® SPSS® Statistics 27 and Microsoft Office 2013 – Excel. SPSS 27.0 was used for statistical analysis, which included descriptive statistics (means and standard deviations), correlational analyses, *t*-tests. Paired t-test was performed to determine whether there were any significant differences left and right side of body. The significant level was defined as ($p < 0.05$). Statistical analysis was performed with descriptive statistics (contraction time, laterality) and Pearson's correlation coefficient (the effect of age on the muscle contractility).

3. Results

Skeletal muscles have different contraction times. In (Table 2) shows the lowest value was reached in m. ES (14.00 ± 1.3) in all three events and the highest value was reached in m. BF (WAG 25.19 ± 11.0 and RG 25.05 ± 8.3) and m. BB (MAG 22.83 ± 9.0).

Table 2. Middle values of the contraction time parameter of selected skeletal muscles for all gymnasts together and separated by disciplines WAG, MAG and RG.

Gymnastics Disciplines	MAG		WAG		RG	
Muscles	N	Tc (ms) and SD*	N	Tc (ms) and SD*	N	Tc (ms) and SD*
M. Biceps brachii	26	25.00 ± 3.1	16	21.50 ± 2.4	0	
M. Triceps brachii	26	17.38 ± 1.8	16	15.83 ± 2.2	0	
M. Biceps femoris	51	22.83 ± 9.0	56	25.19 ± 11.0	54	25.05 ± 8.3
M. Erector spinae	51	14.89 ± 1.7	55	14.14 ± 1.4	54	14.00 ± 1.3
M. Gastrocnemius lateralis	15	20.13 ± 12.0	21	20.89 ± 3.1	36	19.48 ± 11.8
M. Gastrocnemius medialis	14	19.45 ± 1.9	21	20.61 ± 4.1	36	19.77 ± 2.3
M. Rectus femoris	51	20.95 ± 3.2	55	20.57 ± 3.1	54	21.99 ± 2.5
M. Tibialis anteriror	18	15.16 ± 2.4	22	15.79 ± 1.1	36	15.77 ± 1.8
M Vastus lateralis	49	18.24 ± 2.2	54	17.30 ± 1.7	54	17.49 ± 2.0
M. Vastus medialis	51	19.37 ± 2.7	56	18.68 ± 2.1	54	18.51 ± 2.2

*Tc (ms) – contraction time in milliseconds

Major differences were found with m. BB, which contracts 14% slower in MAG than in WAG. Another major difference appears in m. BF where values in MAG are lower than in WAG and RG. Compared to MAG, the contraction time of BF is 2.36 ms (10%) slower in WAG and 2.22 ms (9%) slower in RG. A peer-to-peer comparison of all three disciplines shows the smallest differences occur in the contraction time of m. ES and m. TA.

Table 3. Deviations from lateral symmetry in the contraction time parameter of selected skeletal muscles for all gymnasts together and separated by disciplines WAG, MAG and RG.

Gymnastics Disciplines	MAG		WAG		RG	
Muscles	N	Median	N	Median	N	Median
M. Biceps brachii	13	12.0%	8	5.0%		
M. Triceps brachii	13	7.0%	8	3.5%		
M. Biceps femoris	25	11.0%	28	9.5%	27	13.0%
M. Erector spinae	25	5.0%	27	4.0%	27	4.0%
M. Gastrocnemius lateralis	7	5.0%	10	6.0%	18	14.5%
M. Gastrocnemius medialis	6	13.0%	10	10.0%	18	8.0%
M. Rectus femoris	25	7.0%	27	5.0%	27	6.0%
M. Tibialis anteriror	9	7.0%	11	7.0%	18	5.0%
M Vastus lateralis	23	9.0%	27	6.0%	27	8.0%
M. Vastus medialis	25	6.0%	28	6.0%	27	9.0%

Lateral symmetry or, better expressed, a comparison of the left and right side is very useful, especially when preparing prevention programmes. In the analysis of all gymnastics disciplines we found that the middle deviations are higher in m. BB (11%) and m. BF (11%). For these muscles, the risk of injuries or pain increases. In WAG, we found that the middle deviations are within limits, indicating little risk of pain or injuries. In RG, we can see a bigger deviation, which increases the risk of injuries or pain in m. BF (13%) and m. GL (14.5%), while in MAG there is a bigger deviation in m. BB (12%), m. BF (11%) and m. GM (13%).

Concerning the correlation of contraction time with ageing, we found that age can extend the contraction time in some muscles (Table 4). In group analysis of athletes from all gymnastics disciplines, we established a statistically significant correlation for m. BB (r = 0.483, p = 0.001), m. TB (r = 0.379, p < 0.013), m. ES (r = 0.178, p < 0.025), m. VL (r = 0.366,

p < 0.00) and m. VM (r = 0.405, p < 0.000) at p < 0.05. Despite the statistical significance, many correlations (r) are weak. A statistically significant correlation $0.40 \leq r \leq 0.70$ [29] was found in m. BB and m. VM.

In MAG, a statistically significant correlation between age and contraction time (slow down) was found for m. VL (r = 0.486, p < 0.027) and m. VM (r = 0.485, p < 0.000) at p < 0.05. In WAG, a statistically significant correlation between age and contraction time (slow down) was found for m. GL (r = 0.543, p < 0.011) at P < 0.05. In RG, a statistically significant correlation between age and contraction time (slow down) was found for m. TA (r = 0.380, p < 0.022) and m VL (r = 0.377, p < 0.005) at p < 0.05.

Table 4. Correlation (r) between age of the athlete and contraction time (Pearson's correlation coefficient).

Gymnastics Disciplines	MAG			WAG			RG		
Muscles	r	p	N	r	p	N	r	p	N
M. Biceps brachii	.331	.099	26	.394	.131	16			
M. Triceps brachii	.240	.238	26	.276	.300	16			
M. Biceps femoris	-.041	.775	51	.060	.659	56	.187	.177	54
M. Erector spinae	.197	.165	51	.012	.929	55	.051	.714	54
M. Gastrocnemius lateralis	-.229	.411	15	.337	.135	21	-.208	.222	36
M. Gastrocnemius medialis	.180	.538	14	.543*	.011	21	.238	.162	36
M. Rectus femoris	.203	.153	51	.227	.095	55	.241	.079	54
M. Tibialis anteriror	-.139	.583	18	-.119	.598	22	.380*	.022	36
M Vastus lateralis	.486**	.000	49	.261	.056	54	.377**	.005	54
M. Vastus medialis	.485**	.000	51	.219	.105	56	.247	.072	54

* Correlation is significant at the 0.05 level (2-tailed), ** Correlation is significant at the 0.01 level (2-tailed).

The results in (Table 5) of t test women's artistic gymnastics between m.VM_Tc_R - m.VM_Tc_L were significant; t test (27) = 2.78, p < .010, Cohen's d = .38, effect size r = .19, indicates that there are significant differences between m.VM_Tc_R (19.37±2.20, n = 28) and the scores at the m.VM_Tc_L (18.55±2.02, n = 28). The effect size, r was small .19. The mean difference is 0.820. The results in Table 5 of independent t test rhythmic gymnastics between m.VM_Tc_R - m.VM_Tc_L were significant; t test (27) = 3.58, p < .001, d = .72, r = .34, indicates that there are significant differences between m.VM_Tc_R (19.35.±2.27, n = 28) and the scores at the m.VM_Tc_L (17.83±1.90, n = 28). The effect size, r was small .34. The mean difference is 1.517.

Table 5. T test differences in contraction time in milliseconds readings of right and left side body.

Gymnastics Disciplines	MAG			WAG			RG		
A combination of muscle	t	df	p	t	df	p	t	df	p
m.BB_Tc_R - m.BB_Tc_L	941	12	.365	-.118	7	.909			
m.TB_Tc_R - m.TB_Tc_L	1.183	12	227	.685	7	.515			
m.BF_Tc_R - m.BF_Tc_L	-.284	24	.779	-.294	27	.771	1.214	26	.236
m.ES_Tc_R - m.ES_Tc_L	1.311	24	.202	.869	26	.393	.594	26	.557
m.GL_Tc_R - m.GL_Tc_L	1.024	6	.345	-1.710	9	.121	.043	17	.966
m.GM_Tc_R - m.GM_Tc_L	-.457	5	.667	.202	9	.844	.490	17	.630
m.RF_Tc_R - m.RF_Tc_L	-.167	24	.869	-1.315	26	.200	-.335	26	.740
m.TA_Tc_R - m.TA_Tc_L	-1.569	8	.155	.577	10	.577	1.142	17	.269
m.VL_Tc_R - m.VL_Tc_L	-2.052	22	.052	-.535	26	.597	.178	26	.860
m.VM_Tc_R - m.VM_Tc_L	-.395	24	.696	2.783	27	.010*	3.589	26	.001*

Abbreviations: N, Number of Participants; M, Mean; SD, Standard deviation; t = t test value, df = Degrees of Freedom, *p, indicates a statistically significant difference at p<0.05; MAG, men's artistic gymnastic; WAG, women's artistic gymnastics; RG, Rhythmic gymnastics.

4. Discussion

The sample of athletes in our study is representative for Slovenia and represents almost the whole population of MAG, WAG and RG gymnasts who take part in competitive sports. A characteristic of gymnastics is quick and explosive movements [1,30-31]. Estimating skeletal muscle fibres' contraction time values among MAG, WAG and RG gymnasts is therefore important. Contraction time is mainly correlated with the percentage of slow (type I) and fast (type II) muscle fibres and their metabolic, morphological and biomechanical features [32-34]. We conclude that with lengthening of the contraction time the percentage of slow muscle fibres increases and, consequently, the muscle becomes slower [26]. In artistic and rhythmic gymnastics this means that the performance of an athlete is becoming worse.

Considering the analysis of the results (Table 2), we suggest the normative values of the contraction time parameter for MAG, WAG and RG. We compared our results with the results for other athletes from different sports. In a study of eight top dancers (average age 19-1 ± 3.6 years) it was found that the contraction time (m. BF: 34.2 ± 7.7, m. ES: 18.3 ± 2.2, m. GM 23.5 ± 2) was slower than the contraction times for the same muscles in gymnastics [35]. Šimunič and Samardžija [36] established that gymnasts have on average quicker m. BB and m. TB muscles compared to footballers and volleyball players, a quicker m. BF muscle compared to footballers and volleyball players, and longer contraction times of m. BF compared to athletes [36]. Longer contraction times (m RF 45.9 ± 16.2 and m BF 28.2 ± 5.2) were also found in professional bikers (Vuelta race) aged 27.5 ± 5.5 years [37].

Among gymnasts, the main difference was found between MAG and WAG in elbow flexors (m. BB), which are 3.5 ms or 14% slower in men (Table 2). The difference is likely seen because of the larger muscle mass of arms and shoulders in MAG gymnasts compared to WAG gymnasts. On the other side, in RG (9%) and WAG (10%) m. BF is slower compared to MAG. In the literature no data about similar measurements from other countries were found. Our study is likely the first large study to use the TMG measurement system in gymnastics. One case study of a top gymnast from Croatia was found. He was injured and with the use of TMG he obtained additional diagnostics. Based on the results, a corrective programme was made, which he successfully completed allowing him to continue his basic training. He also obtained the best score for a floor event at the European championship in 2015. Values of contraction time after the rehabilitation (when the gymnast was ready for 100% loading) were similar to the values of Slovenian gymnasts, except for m. GM which was slower in the Croatian athlete (43%) in comparison to Slovenian MAG gymnasts [31].

The results also allow us to define lateral symmetries, which represent a great problem in gymnastics. In addition to studies dealing with risks of injuries and rehabilitation programmes [38-39], one more specific analysis of Code of points of MAG and WAG was found, which warned about systematic asymmetries in gymnastics [40], and an in-depth analysis of balance beam events where the trend of asymmetry in 60% of elements was found [41]. Our research shows that in WAG the asymmetry does not exceed 10% (Table 3) and, according to the range of risks [38-39,42], we can define this as a low-risk injury factor (low: up to 10%, middle: 10–20%, high: 20% and more). Higher asymmetry, which also means a bigger risk of injury, was found in RG in m. BF (13%) and m. GL (14.5%) and in MAG in m. BB (12%), m. BF (11%) and m. GM (13%). The risk of injury is increased primarily because of movement biomechanics, where the loading is greater on one extremity [43], especially upon landing [44]. Marshal et al. [45] found that the majority of injuries in gymnastics happen on landing, and so it is clear why larger asymmetries increase the risk of injury. Bračič [19] found that when one leg produces greater force on the ground during jumping, the body rotates in the frontal plane in the direction of the leg which produces less force, which has a negative impact on the effectiveness of the movement. Asymmetrical force production also affects the landing, where the leg which

produced less force when jumping is overloaded [19]. Asymmetric jumps increase the risk of injuries on different body parts [18,22,46].

Age has a negative influence on muscles' contractile properties in all observed disciplines. Dahmane [26] made similar findings in elderly people as did Šimunič et al. [15] among 9- to 13-year-old children. With analysis of the results, we found the influence of age on the contraction time in all three gymnastics disciplines in m. BB (r = 0.483, p < 0.001), m. VL (r = 0.366, p < 0.000) and in m. VM (r = 0.405, p < 0.000) at p < 0.05. Analysis of each gymnastics discipline shows there is a statistically significant correlation of slower contraction time and age among MAG in m. VM and m. VL, among RG in m. TA and m. VL and among WAG in m. GM (Table 4).

We assume that this could be correlated with the previously mentioned imperfections of the Code of points, where a strong and systematic focus on asymmetries was found [40]. Still, the finding is that ageing negatively affects the contraction time of muscles. This finding opens new possibilities for using the TMG method in the training of gymnasts and suggests the choice of exercise method which would aim at slowing down the negative effect of ageing on muscles' contraction times. For MAG, WAG and RG this would have a positive effect on both gymnasts' performances and the safety of the training.

This study is the first larger study to use the TMG method and in which top athletes from artistic and rhythmic gymnastics participated. We defined normative values. Considering the findings, it would be reasonable to use TMG as a method of analysis for comprehensively evaluating artistic and rhythmic gymnasts. It would add value to the synthetic (force plate) and partly analytic (isokinetic) measurement systems, which are already systematically used in artistic and rhythmic gymnastics. With use of TMG, we could improve the evaluation of gymnasts' condition and gain better insights into their risk of injury. We recommend that further studies define the normative values regarding the speciality of a gymnast because different movement structures and varying loadings on the body could impact on the results. We defined the framework of asymmetry considering the existing measurement systems. It would be reasonable to define the extent of the injury risk considering the established asymmetries and to adjust the ranges of risk to the TMG system.

5. Conclusions

Muscle asymmetries in gymnasts are common and can lead to injury. Good balance and strength, body asymmetries are an important risk factor for injuries and may be associated with decreased performance. In artistic and rhythmic gymnastics, explosive power and strength endurance predominate. Jumps and landings are a basic part of daily training are often researched, typically using the force plate. In the future, TMG as an analytic method will hold an important place in sport diagnostics in gymnastics. With TMG, we can assess the discipline's demands and help improve gymnasts' performances along with the safety of training.

Author Contributions: Study Design, Mitija Samardžija Pavletić [1], Almir Atiković [2] **Data Collection,** Mitija Samardžija Pavletić [1], Almir Atiković [2*], Ekrem Čolakhodžić [3], Selma Sijerčić [4], Emilija Petković [5] and Amra Nožinović Mujanović [6]; **Statistical Analysis,** Ekrem Čolakhodžić [3], Selma Sijerčić [4], Emilija Petković [5] and Amra Nožinović Mujanović [6]; **Data Interpretation,** Ekrem Čolakhodžić [3], Selma Sijerčić [4], Emilija Petković [5] and Amra Nožinović Mujanović [6]; **Manuscript Preparation,** Mitija Samardžija Pavletić [1], Almir Atiković [2*], Ekrem Čolakhodžić [3], Selma Sijerčić [4], Emilija Petković [5] and Amra Nožinović Mujanović [6]; **Literature Search, Ekrem** Čolakhodžić [3], Selma Sijerčić [4], Emilija Petković [5] and Amra Nožinović Mujanović [6]; **Funding Acquisition,** - . All authors have read and agreed to the published version of the manuscript.

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