Description and profile of the journal

Antropomotoryka. Journal of Kinesiology and Exercise Sciences (JKES) is the official, reviewed, quarterly academic publication of the International Association of Sport Kinesiology (IASK), issued by the University of Physical Education in Krakow since 1989, and from 2010, in cooperation with the University School of Physical Education in Wroclaw. The journal has received academic patronage from the Rehabilitation, Physical Education and Social Integration Committee of the Polish Academy of Sciences and can be found in the IC Journal Master List international indexing database. Since 2014, the journal is published in the original electronic version in English. On subscribers’ request, the journal may be issued in English and Polish in book format.

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Aim

In Antropomotoryka. Journal of Kinesiology and Exercise Sciences (JKES) the results of innovative experiments and observations on human locomotive activities conducted under natural and laboratory conditions by researchers of human motor skills (anthropomotorics) or related fields and disciplines, such as: physiology, psychology, physical anthropology, biomechanics, medicine, computer sciences, economics, genetics, pedagogy, sports education are presented. This allows to acquaint oneself with the essence of human physical activities, their structure, skills, motor functions and aptitudes, learning of these motor functions, their monitoring and control, and the health and sports effects of the broadly understood human notion of physical activity.

In accordance with the aim of the journal, the subject of the article should fall under one of the four thematic categories:

I. Theoretical and applied aspects of kinesiology (Fundamental and Applied Kinesiology).
II. Scientific basis of motor function training in sports and recreation (Sport Sciences).
III. Teaching, controlling and monitoring motor functions. Scientific basis, formation and evaluation of activity and physical fitness (Exercise Sciences).
IV. Reviews, debates and discussions, historical elaborations, conference announcements, reports from conferences and congresses of the IASK and brief summaries of papers printed in foreign journals, book reviews on the theory of human motor skills and also, assessment of the current state and prospects for the development in anthropomotoric research achievements (Varia).

Papers of high scientific value previously qualified for publication in another foreign journal may also be submitted, provided that the author obtains written consent to reprint the article from the foreign journal in which the text has been or will be published.

Requirements for submission

Submitting the paper should be done via the Index Copernicus Publishers Panel – the electronic system for management of the editing process. For this purpose, it is necessary to register on the following website: http://970.indexcopernicus.com/.

Manuscript registration takes place in accordance with the instructions for authors: http://970.index-copernicus.com/icc_publishers_panel_instrukcja_obslugi_dla_autorow.pdf

- Once registered on the IC Publishers Panel platform, authors should contact the editorial office via the IC Publishers Panel e-mail or the editorial office directly via e-mail: antropomotoryka@awf.krakow.pl.
- The author responsible for correspondence with the publisher concerning the article receives notification confirming submission of the article, and information about stages of its publication.
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- The lead author is required to determine the contribution of the co-authors in creation of the article in accordance with the requirements of the IC Publishers Panel – electronic system for managing the editorial process.

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Texts submitted for publication should be written in English or Polish in accordance with the following editorial requirements:

- The volume of empirical work including the summary, figures and tables should not exceed 22 pages, and the reviews – 30 pages standard A4 size (up to 1,800 characters including spaces per page);
• Texts should be prepared using only Microsoft Office Word text editor, pages should be numbered, font: Times New Roman; size: 12 points; spacing: 1.5; justified text; title written in bold typeface; centred.

• Tables and figures labelled using Arabic numerals and headers, explanations and descriptions of illustrations below the figures and the results above the tables should be placed on separate pages in the English and Polish versions. Headers, explanations and descriptions below the figures and above the tables should be in English and Polish.

Example:
Tablica 1., Ryc. 1., Objaśnienia, Chłopcy
Table 1., Fig. 1., Commentary, Boys

• Figures and tables should be placed on separate pages (See: Illustrative material);

Abstract and key words (English and Polish versions on separate pages – if article is meant for publication in both English and Polish) containing the full title of the paper and its short title (up to 40 characters including spaces) to be placed in the running head, names of author(s), affiliation of the author(s) presented according to the following scheme: faculty, university, country, contribution of the co-authors in the creation of the article using symbols in the case of collective works (pattern of symbols according to the instructions in IC Publishers Panel); mailing address of the lead author (author’s full name, address, e-mail address and phone number).

The main body of the text (in English and Polish)

The main body of the text should include the following parts:

Introduction. Introduction acquaints the reader with the subject of the article and places it against the background of existing research (literature review).

At the end of the introduction, the aim, research problems and hypotheses should be clearly stated.

Material and methods. An accurate description of the research subject (material) should be presented in the methodological part. The number of subjects, their age, sex and other characteristics of the participants should be indicated. Additionally, information regarding the conditions of testing, time and methods, techniques and research instruments, with particular emphasis on the description of the used apparatus should be given. The name and address of its producer should be given. If an original method or technique of research was used, it should be described precisely by presenting its validity and reliability (reproducibility). In the case of modifying already recognized methods, the applied changes must be described and the need for these changes must be justified. Statistical methods should be explained so that it can be easily determined whether they are properly suited for the purpose of research. The author of the review or meta-analysis should provide methods of searching for materials, methods of selection, etc.

Results. Presentation of the results should be logical and cohesive, and closely linked to the data in the tables and figures. Referencing results presented in the tables or figures, the abbreviated name of the table and figures (Table 1, Fig. 2) should be placed in parentheses and on the margins of the work, suggesting their location in the comments. In the main body of the paper, the same results in tables and figures cannot be repeated.

Discussion. The author should relate the results to data from literature (other than described in the introduction), highlighting the innovative and significant aspects of his/her work. The adopted hypotheses should be verified or falsified.

Conclusions. Presenting cognitive and applicative findings, the posed hypotheses should be considered and vague statements not supported by the results of the research should be avoided.

Acknowledgements. A list of persons or institution(s) contributing to the preparation of the article, financially or technically supporting the research process or article publication may be given. It is particularly desirable to provide the study grant number.

References. The bibliographic list contains only items which are referenced in the body of the text. Bibliographic descriptions, enumerated using Arabic numerals and listed in the order of citation (not in alphabetical order) should be printed on a separate page. Each referenced item should start with a new line. The sequenced number of the bibliographical item, given in square brackets, must correspond to the order of reference to the publication in the body of the text.

Bibliographic description of the article should include: the name of the author(s), initial(s), surname(s), title of the article, name of the journal in functioning abbreviated form, year of publication, issue, volume number, pages, DOI number (if the publication has one). Bibliographic description should end with a full stop.

The Vancouver Referencing Style, also known as the author-number system of citation, recommended for medical sciences should be used in the publication (https://www.library.uq.edu.au/training/citation/vancouv.pdf). Enumeration of the referenced texts and principles of citation are defined by the so called Vancouver Convention drawn up by the ICMJE (International Committee of Medical Journal Editors). According to it, referencing material from the source in the body of the text should end in the bibliographic item number in square brackets, e.g. [1]. In the case that reference is made to the authors, the reference is placed immediately after the author’s surname (without first name initial) (e.g.: “According to Aronson et al. [23] this study is ...”).

Repetition of the reference to the same publication is done by its earlier established number. References of attachments are organized according to the order of their citation in the body of the text. Citing two or more publications should be included in square brackets in chronological order of their publication. Explanatory notes or supplementary text should be numbered using the Oxford Referencing System, maintaining consistency throughout the article.
Examples

Monograph by no more than six authors:

Monograph by more than six authors. After the sixth author, the following abbreviation is placed: et al.

Subsequent editions of the monograph (Edition number is placed after the title)

Conference reports (papers)

Articles in journals published in electronic version, with digital DOI

Articles in journals published in electronic version without DOI (digital object identifier)

Articles in journals published in electronic version, found in the PubMed database.

Important information for authors of articles submitted for publication
In view of the fact that since 2014 onwards, the quarterly journal will be published in the original electronic version in English, please translate into English: titles of articles in the bibliographic listing published in a language other than English, providing the language of the original in square brackets after the English title. The title of the journal must remain in full version or in functioning abbreviated form. Example:

The National Library of Medicine recommends placing the English translation of the title in square brackets, and information regarding the language of the article after the page

Example:


Illustrative material

- **Technical requirements**
  
  **Figures** – should follow a consistent background colour scheme; do not use grid lines or shading.
  
  **Tables** – standardized format, reducing grid lines to a minimum.

**Example:**

<table>
<thead>
<tr>
<th>Group</th>
<th>Variable</th>
<th>A</th>
<th>SD</th>
<th>B</th>
<th>SD</th>
<th>d</th>
<th>Significance level p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age [years]</td>
<td>21.5</td>
<td>3.2</td>
<td>22.0</td>
<td>1.5</td>
<td>-0.5</td>
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<tr>
<td>Body height [cm]</td>
<td>176.2</td>
<td>3.3</td>
<td>178.0</td>
<td>4.1</td>
<td>-1.8</td>
<td>0.005 *</td>
<td></td>
</tr>
<tr>
<td>Body mass [kg]</td>
<td>68.3</td>
<td>2.7</td>
<td>79.4</td>
<td>3.5</td>
<td>-11.1</td>
<td>0.006 *</td>
<td></td>
</tr>
<tr>
<td>BMI [kg/m²]</td>
<td>22.3</td>
<td>2.2</td>
<td>25.7</td>
<td>2.8</td>
<td>-3.4</td>
<td>0.006 *</td>
<td></td>
</tr>
</tbody>
</table>

NS – statistically non-significant difference

* – p<0.05; ** p<0.01; ***p<0.001

**Scanning.** The resolution of scanned illustrations must be at least 300 dpi. Black and white illustrations (lines of the art.) should be in TIFF format, or colour and images (grey) in TIFF or JPEG format (low degree of compression, up to 10%). All files can be compressed using RAR or ZIP; **Symbols,** for example: arrows, asterisks or the abbreviations used in tables or figures should be clearly explained in the legend.

**Equations** must be written legibly, especially indices and exponents in powers.

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**Appropriate Procedures of Reviewing in the Sciences:**

**Veracity in Scientific Research and Respect for Intellectual Property:**
http://bbn.uksw.edu.pl/node/76

**Ethical Principles of a Scientific Researcher:**

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- Articles not prepared in accordance with the requirements of the “Article publication requirements” will be returned to the author for improvement. The publisher reserves the right to remove linguistic defects or apply abbreviations.
- The publisher reserves the right to make improvements related to terminology standardization.
- The publisher decides whether the article will be released for publication based on the reviewers’ opinions and the responses of the authors or lead author to the reviewers’ comments.
- After translated, proofread and edited, the article is sent to the author(s) for approval. The publisher sets a one-week deadline for submission of further modifications by the author.
- Before publication, the author responsible for correspondence with the publishing office will receive the article by e-mail (in PDF format), edited in accordance with the journal’s style template, to obtain consent for its publication. At this stage of publishing, only minor, final modifications may be made. Delay in re-submission/consent may cause the article to be moved to the next issue.

**Concluding remarks**

- **Publication of articles in Antropomotoryka. Journal of Kinesiology and Exercise Sciences (JKES) is free of charge.** The author responsible for correspondence concerning the article receives a free PDF file with the issue of the quarterly journal, in which his/her paper is published.
- **Abstracts and full texts in English and Polish are posted on the following websites:** http://www.antropomotoryka.pl/ and http://970.indexcopernicus.com/
- **Subscription to issues of the journal published in book format can be ordered for a fee at:** joanna.stepien@awf.krakow.pl.
- **Distribution and sales of current and archival issues of “Antropomotoryka. Journal of Kinesiology and Exercise Science” can be found at:**
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The New Year of 2015 is coming fast. We feel the breath of the old year of 2014. The laws of nature are relentless. Eternal metamorphosis. We hope for a better tomorrow and look forward to the further development of our journal with optimism. I think that the leaven for a new perspective of its development may be the content of this year’s final, 68th issue.

Undoubtedly, this is due to close cooperation of our editorial office with representatives of medical biology, often wrongly put into the shadow of other basic sciences in the interpretation of human movement. The fact that this is not a proper positioning is ascertained by the search of objective indicators of fatigue following prolonged exercise in a marathon, which was the topic of one of the articles published in issue No. 66 of our journal. In issue No. 68, as many as three publications can be found in which the subject of changes in blood rheology and hematology under the influence of various physical stressors is discussed.

In the article *Effects of winter swimming and taking a sauna on biochemical properties of the blood in “Walruses”* focus was placed on people who enjoy swimming in cold water, regardless of the season. This brings to mind the question of the cause and source of this natural phenomenon. In quest of the answer, a group of 20 participants engaging in open water swimming in winter (November-March) was examined. In the study, levels of immunoglobulin (IgG, IgA, IgM), contents of thyroid hormones (FT3, FT4, TSH), and cortisol were determined for the participants. The experiment consisted in introducing an additional procedure involving the use of a short-term (10 min) sauna before the 10 participants bathed in cold water. The results were surprising. Only in the group who took a sauna and cold bath were there statistically significant elevated levels of cortisol in the first series of tests (November) and elevated IgM serum at the end of the observation period (March).

The next publication is titled *Impact of systemic cryotherapy on the rheological properties of the blood in healthy young males,* and in it, the authors of the study already following a series of 10 treatments noted: increased average values of erythrocytes, hematocrit, platelets and red blood cell deformability at 0.30 Pa and 0.58 Pa shear stress, and a decrease in aggregation index. Surprising was that after the applied treatments, there was a reduction in blood morphology indicators, such as: hemoglobin, mean hemoglobin concentration, mean corpuscular mass of hemoglobin, mean corpuscular volume of red blood cells.

In the traditional section of *Antropomotoryka: Teaching, steering, control of motor functions (Exercise Sciences)* the following works were included: *Analysis of muscle strength using a dynamometer in women’s professional cycling team,* *The structure of dynamic and kinematic limb motion in a Taekwon-do European
**Champion during turning kicks, and Movement analysis in tandem track cyclists using video analysis.**

The first one presents the results of research concerning the strength of selected muscles in female professional cyclists. The strength of flexor and extensor muscles in the knee and hip joints was measured. Analysis of collected data led to the conclusion that the results of similar studies can be useful for individualization of the sports training process and may contribute to reducing the risk of injury and overloading the musculoskeletal system.

The aim of research presented in the study titled *The structure of dynamic and kinematic limb motion in a Taekwon-do European Champion during turning kicks*, was an attempt at kinetic identification of turning kick factors based on the obtained velocities, pressure on the ground and kicking time in a 17-year-old holder of the 1st Dan degree, winner of the European ITF Taekwon-Do championship. The mean values of parameters, which were used to determine the curve of velocity changes as a function of relative length (performing kick) of the competitor’s lower limb, were obtained with precise motion analysis using the Italian BTS Spa Smart-D system for complex motion analysis. In this manner, the following values were determined: mean maximum foot and hand velocity, relative to axes X, Y and Z, respectively; kick time, maximum pressure of the supporting foot on the ground and pressure force of kicking foot during take-off. Analysis of the results made it possible to note that the speed of the kicking foot correlates with the sweeping movement of the hands ($r = 0.64$ for the right hand and $r = 0.61$ for the left). This may be indicative of the fact that the proper and dynamic hand sweeping movement is dependent on turning kick kinetics. The obtained measurements of pressure force on the ground of the supporting foot show three characteristic peaks. The first manifest themselves immediately after foot take-off. These values are strongly correlated to the speed of the kicking foot ($r = 0.91$), appearing at the moment of obtaining maximum speed of the other foot, and the third informing about returning to initial stance.

In the next paper submitted by scholars from “DynamoLab” Academic Laboratory of Movement and Physical Performance, Medical University of Łódź, Poland, we can find the study results of motion analysis in tandem track cyclists, which was conducted on the basis of a video recording system. The detailed biomechanical analysis of the collected data proposes a number of interesting insights to be used in practice, allowing to correct the sports training process of the participating Polish team representatives.

I am convinced that no one will be disappointed picking up the last 2014 issue of *Antropomotoryka* during their Christmas, winter holiday.

To all the loyal readers of our Krakow-Wroclaw periodical, I wish you satisfaction from finding the content of our journal to be of highest scientific level. I would also like to thank the reviewers from Poland and abroad for the work put into maintaining *Antropomotoryka* at a top-level. A word of thanks towards our brotherly University in Wroclaw and all the members of the Editorial Board along with Mrs. Vice Chancellor of the University of Physical Education in Wroclaw, as well as to the secretarial team of our editorial office, constantly active and extremely conscientiously fulfilling its duties. Certainly everyone knows its selfless help and kindness using the platform of the Index Copernicus this year, both authors and reviewers.

To all our supporters, wishing you a traditional Polish Happy New Year – *Do Siego Roku*!

**Edward Mleczko**
Editor-in-Chief
*Antropomotoryka*
Abstract

**Study aim:** The aim of the study was to examine the effect of winter swimming and taking a sauna on selected biochemical indicators of the blood.

**Study material:** The participating „Walruses” belonged to the Krakow Walrus club – “The Heaters”. The study group consisted of 20 males, aged 30–45, ‘walrusing’ throughout the whole season from November to March. In order to examine the biochemical indicators of the blood, venous blood samples were drawn from the participants and the following were determined: immunoglobulin levels (IgG, IgA, IgM), the contents of thyroid hormones (FT3, FT4, TSH), and cortisol. On the test day, in November and March, one group of the studies “Walruses” (n = 10) took only cold baths bath for 5 minutes, and the second group of participating “Walruses” (n = 10), on the day of the study, went into a sauna for 10 minutes and took a cold bath for 5 minutes.

**Study results:** At the beginning of the winter swimming season in November, a statistically significant increase in cortisol concentration was found in a group that took the sauna as well as cold baths compared to the group that only took cold baths. A significant increase in IgM concentration at the end of the season in March was also noted for this group. No statistically significant changes in the level of TSH, FT3, FT4 or cortisol were noticed.

**Conclusions:** This study is the first combining the effects of winter swimming and taking a sauna on the level of immunoglobulin (IgG, IgA, IgM), thyroid hormones (FT3, FT4, TSH) and cortisol.

Introduction

Exposure to cold as well as high temperatures cause severe reactions of the organism. Under the influence of cold baths, activity of the sympathetic-adrenal system, adrenal secretion of norepinephrine, epinephrine and cortisol [1, 2] are stimulated. The released catecholamines activate the respiratory and cardiovascular centres in the medulla [3]. As a consequence of the activation of the sympathetic nervous system is-adrenergic receptor stimulation and strong vasoconstriction of the skin, which prevents the transfer of heat from the inside the body to the skin, and its further loss [4]. During cooling of the body, an increase in the secretion of the thyrotropin (TSH) and thyroid hormones can be observed. This results in an increase in metabolism non shivering thermogenesis and heat production [5, 6].

Taking a sauna effects the adrenergic system, endocrine glands, especially the adrenal glands stimulated both by the hypothalamic-pituitary, cerebral-adrenal and the renin-angiotensin-aldosterone system. Under the influence of being in the sauna, activation of the sympa-
thetis nervous system also occurs. An increase in the production of the adrenocorticotropic hormone (ACTH) and cortisol levels along with their metabolites in blood or urine takes place. Another hormone, in which increased secretion is induced by thermal stress, is the growth hormone [7]. Passive heating of the body stimulates the secretion of this hormone to a greater degree than does a temperature increase of the body caused by physical activity [8]. Prolactin and \( \beta \)-endorphin levels also increase as a result of being in the sauna [9].

Sutkowy et al. (2015) confirmed that single exposure to extremely high and low temperatures is likely to cause the formation of reactive oxygen forms in healthy people, which interferes with antioxidant protection. Their research included 25 young males, who were divided into 2 groups. One used a sauna, the second was exposed to the cold (cryogenic chamber) [10]. After analyzing the results, they suggested that both long-term use of the sauna and the impact of cold on the body (cryogenic chamber) allows for gradual adaptation and toughening of the body. However, in “Walruses”, regularly swimming in winter, increased immunity of the organism was found [11, 12, 13].

The aim of the study was to answer the question of impact the sauna and winter swimming has on biochemical indicators of the blood in “Walruses”.

**Study material and methods**

**Characteristics of the study group**

“Walruses” are individuals who swim in the winter when the water temperature ranges from 1°C to 4°C. The participants belonged to the Krakow Walrus club – “The Heaters”. In order to study changes in biochemical properties of the blood, venous blood samples were collected and tested twice for the study participants. The study took place at the Bagry lagoon, at the beginning at the beginning of the season on 18th November, 2013 and at the end of the season on 30th March, 2014. The group consisted of 20 men, aged 30–45, ‘walrusing’ throughout the season from November to March. On the day of the test, in November and March, one research group (n = 10) took only cold baths and the second group of participants (n = 10) took a sauna as well as a cold bath.

Weather conditions on 18th November, 2013 (beginning of ‘walrusing’ season):

- water temperature 7°C
- air temperature 4°C
- humidity 55%
- wind speed 9 km/h

Weather conditions on 30th March, 2014 roku (end of ‘walrusing’ season):

- water temperature 7.5°C
- air temperature 4°C
- humidity 75%
- wind speed 5 km/h

On the day of the study (at the beginning and end of season), the time of a single cold bath in the first only ‘walrusing’ group was 5 min, however, for the second ‘walrusing’ and sauna taking group, the sauna stay lasted 10 min before immersion. Getting from the building with the sauna to the lagoon took about 3 minutes. Blood samples were drawn from the participants in the amount of 3 ml from the vein inside the elbow, on an empty stomach in the morning, after leaving the water. The samples were put into tubes with clot accelerator to obtain serum. Blood was drawn by a qualified nurse, under medical supervision. The study was approved by the Bioethics Committee at the Regional Medical Chamber in Krakow.

**Study of biochemical properties**

After the blood samples were drawn, they were transported to the M. Skłodowska-Curie Centre of Oncology in Krakow. There, the following parameters were marked: immunoglobulin content (IgG, IgA, IgM), the level of thyroid hormones (FT3, FT4, TSH) and cortisol.

**Determining immunoglobulin concentration (IgG, IgA, IgM)**

Marking IgG, IgA, IgM immunoglobulin concentrations was performed using the Siemens BN ProSpec apparatus. The assay required N antisera, i.e. liquid animal sera produced by immunizing rabbits with human immunoglobulin having a high degree of purity. Each of the N antisera was put into separate 2 ml vials. Next, the device automatically prepared serial dilution of the N reference protein and determination was performed. The results were based on the method assumption, by which the proteins present in the serum sample reacted with specific antibodies to form immune complexes. These complexes caused the beam of light rays passing through the sample to split, wherein the intensity of the scattered light was proportional to the concentration of the corresponding protein in the sample. For the marking, the immunosorbent ELISA test was used, which is derived from the RIA radioimmunoassay test.

**FT3 thyroid hormone (free triiodothyronine) concentration assay**

The test was performed using the Roche Diagnostics e411 cobas analyzer. The assay was carried out using the competitive method in the blood serum. The results were read from the calibration curve based on the two-point calibration.

**Cortisol concentration assay**

The test was performed using the Roche Diagnostics e411 cobas analyzer. The total time of serum assay was 18 minutes. The results were read from the calibration curve.
curve based on two-point calibration. For the assay, the immunosorbent ELISA test was used, which is derived from the RIA radioimmunoassay test.

**Statistical analysis**

Data are presented as mean values and standard deviation. Normality of distribution was verified using the Shapiro-Wilk test. Variables with normal distribution were compared using the Student’s t-test for dependent samples, in the case that the given assumptions were not met using the t-test, the Wilcoxon test was used.

Differences between groups were analyzed using the t-test for unpaired variables. In the case that the given assumptions were not met using the t-test, the Mann-Whitney U test was performed. In analyzes, the assumed level of significance was $\alpha = 0.05$. Analyses were performed using the Statistica 10 package (StatSoft®, USA).

**Results**

1. **Analysis of results in group 1 – only winter swimming.**

   Considering changes in IgA [g/L], IgG [g/L], IgM [g/L], TSH [mU/L], FT3 [pmol/L], FT4 [pmol/L] and cortisol [nmol/L] concentrations at the beginning and end of the season, no statistically significant differences were noted (Tab. 1).

2. **Analysis of results in group 2 – sauna and winter swimming.**

   Considering changes in IgA [g/L], IgG [g/L], IgM [g/L], TSH [mU/L], FT3 [pmol/L], FT4 [pmol/L] and cortisol [nmol/L] concentrations at the beginning and end of the season, no statistically significant differences were noted (Tab. 2).

3. **Comparison of groups 1 and 2 at the beginning and end of the winter swimming season (group 1 – only winter swimming and group 2 sauna and winter swimming).**

   Comparing groups 1 and 2, no statistically significant changes in IgA [g/L], IgG [g/L], IgM [g/L], TSH [mU/L], FT3 [pmol/L] and FT4 [pmol/L] concentrations were found at the beginning or end of the winter swimming season (Tab. 3, Tab. 4). The only statistically significant increases observed were in cortisol concentration [nmol/L] at the beginning of the season in November (Tab. 3, Fig. 1), and IgM concentration [g/L] at the end of the season in March (Tab. 4, Fig. 2) for the sauna and winter swimming group.

### Table 1. Mean values ± standard deviation of indicators assayed in group 1 performing winter swimming

<table>
<thead>
<tr>
<th>Parameter</th>
<th>n</th>
<th>Initial measurement (November) X ± SD</th>
<th>Final measurement (March) X ± SD</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>IgG [g/L]</td>
<td>5</td>
<td>13.26 ± 2.09</td>
<td>14.30 ± 2.77</td>
<td>0.1152</td>
</tr>
<tr>
<td>IgA [g/L]</td>
<td>5</td>
<td>2.92 ± 0.66</td>
<td>2.98 ± 0.90</td>
<td>0.7948</td>
</tr>
<tr>
<td>IgM [g/L]</td>
<td>5</td>
<td>0.80 ± 0.57</td>
<td>0.62 ± 0.28</td>
<td>0.3134</td>
</tr>
<tr>
<td>TSH [mU/L]</td>
<td>5</td>
<td>2.41 ± 1.58</td>
<td>2.69 ± 1.45</td>
<td>0.4343</td>
</tr>
<tr>
<td>FT3 [pmol/L]</td>
<td>5</td>
<td>5.39 ± 0.67</td>
<td>5.11 ± 0.27</td>
<td>0.3089</td>
</tr>
<tr>
<td>FT4 [pmol/L]</td>
<td>5</td>
<td>17.07 ± 3.40</td>
<td>15.11 ± 1.72</td>
<td>0.1430</td>
</tr>
<tr>
<td>cortisol [nmol/L]</td>
<td>5</td>
<td>432.72 ± 166.56</td>
<td>469.58 ± 199.68</td>
<td>0.7660</td>
</tr>
</tbody>
</table>

### Table 2. Mean values ± standard deviation of indicators assayed in group 2 using a sauna and performing winter swimming

<table>
<thead>
<tr>
<th>Parameter</th>
<th>n</th>
<th>Initial measurement (November) X ± SD</th>
<th>Final measurement (March) X ± SD</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>IgG [g/L]</td>
<td>6</td>
<td>11.93 ± 1.81</td>
<td>12.13 ± 1.34</td>
<td>0.5673</td>
</tr>
<tr>
<td>IgA [g/L]</td>
<td>6</td>
<td>2.85 ± 0.92</td>
<td>2.90 ± 0.92</td>
<td>0.7558</td>
</tr>
<tr>
<td>IgM [g/L]</td>
<td>6</td>
<td>1.27 ± 0.51</td>
<td>1.25 ± 0.43</td>
<td>0.9178</td>
</tr>
<tr>
<td>TSH [mU/L]</td>
<td>6</td>
<td>2.70 ± 1.39</td>
<td>2.45 ± 1.32</td>
<td>0.5000</td>
</tr>
<tr>
<td>FT3 [pmol/L]</td>
<td>6</td>
<td>5.54 ± 0.64</td>
<td>5.25 ± 0.59</td>
<td>0.3454</td>
</tr>
<tr>
<td>FT4 [pmol/L]</td>
<td>6</td>
<td>18.00 ± 1.56</td>
<td>16.78 ± 1.22</td>
<td>0.2262</td>
</tr>
<tr>
<td>cortisol [nmol/L]</td>
<td>6</td>
<td>651.13 ± 146.67</td>
<td>536.68 ± 176.94</td>
<td>0.2980</td>
</tr>
</tbody>
</table>
Table 3. Comparison of initial measurements (November) in the only winter swimming group with the sauna + winter swimming group

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Only winter swimming $\bar{x} \pm SD$</th>
<th>Sauna + winter swimming $\bar{x} \pm SD$</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>IgG [g/L]</td>
<td>13.26 ± 2.09</td>
<td>11.93 ± 1.81</td>
<td>0.2882</td>
</tr>
<tr>
<td>IgA [g/L]</td>
<td>2.92 ± 0.66</td>
<td>2.85 ± 0.92</td>
<td>0.8998</td>
</tr>
<tr>
<td>IgM [g/L]</td>
<td>0.80 ± 0.57</td>
<td>1.27 ± 0.51</td>
<td>0.1864</td>
</tr>
<tr>
<td>TSH [mU/L]</td>
<td>2.41 ± 1.58</td>
<td>2.70 ± 1.39</td>
<td>0.7518</td>
</tr>
<tr>
<td>FT3 [pmol/L]</td>
<td>5.39 ± 0.67</td>
<td>5.54 ± 0.64</td>
<td>0.7188</td>
</tr>
<tr>
<td>FT4 [pmol/L]</td>
<td>17.07 ± 3.40</td>
<td>18.00 ± 1.56</td>
<td>0.5652</td>
</tr>
<tr>
<td>cortisol [nmol/L]</td>
<td>432.72 ± 166.56</td>
<td>651.13 ± 146.67</td>
<td>0.0459</td>
</tr>
</tbody>
</table>

Figure 1. Changes of the average cortisol concentrations [mmol/L] between the beginning and the end of the season in the ‘winter swimming + sauna group’ and ‘winter swimming only’ group

Table 4. Comparison of initial measurements (March) in the only winter swimming group with the sauna + winter swimming group

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Only winter swimming $\bar{x} \pm SD$</th>
<th>Sauna + winter swimming $\bar{x} \pm SD$</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>IgG [g/L]</td>
<td>14.30 ± 2.77</td>
<td>12.13 ± 1.34</td>
<td>0.1209</td>
</tr>
<tr>
<td>IgA [g/L]</td>
<td>2.98 ± 0.90</td>
<td>2.90 ± 0.92</td>
<td>0.8877</td>
</tr>
<tr>
<td>IgM [g/L]</td>
<td>0.62 ± 0.28</td>
<td>1.25 ± 0.43</td>
<td>0.0207</td>
</tr>
<tr>
<td>TSH [mU/L]</td>
<td>2.69 ± 1.45</td>
<td>2.45 ± 1.32</td>
<td>0.7771</td>
</tr>
<tr>
<td>FT3 [pmol/L]</td>
<td>5.11 ± 0.27</td>
<td>5.25 ± 0.59</td>
<td>0.6538</td>
</tr>
<tr>
<td>FT4 [pmol/L]</td>
<td>15.11 ± 1.72</td>
<td>16.78 ± 1.22</td>
<td>0.0936</td>
</tr>
<tr>
<td>cortisol [nmol/L]</td>
<td>469.58 ± 199.68</td>
<td>536.68 ± 176.94</td>
<td>0.5688</td>
</tr>
</tbody>
</table>
Discussion

The tests within the framework of this study were performed in order to answer the question - what is the impact of taking a sauna and winter swimming on the biochemical indicators of the blood in “Walruses”? Although there are reports on the impact of being in a sauna or winter swimming on the human body, there are no studies which simultaneously combine exposure to low and high temperatures in “Walruses”.

In conditions of severe heat loss, an increase occurs in the secretion of hormones stimulating metabolism. Hermanussen et al. (1995) conducted a study in a group of 11 healthy students. The participants went for winter swims at least once a week for 2 to 10 minutes for 2.5 months. After analyzing the results of TSH in both groups (both untraining and training in the cold), the levels increased by about 48%, and the level of cortisol by approximately 34% [14]. In a review paper, Teległów et al. (2008) described how cortisol secreted by the adrenal cortex modulates many physiological responses in reaction to cold. It elevates resting energy consumption, inhibits vasodilatation, increases the availability of free fatty acids and affects the operation of the sympathetic nervous system. Cortisol secretion is regulated by the adrenocorticotropic hormone (ACTH). The increase in cortisol levels during exercise in cold water seems to depend on changes in the internal temperature of the body [4]. As reported by Plich et al. (2013), Vescovi (2000) and Ježová et al. (1994) changes in cortisol concentration levels under the influence of being in a sauna are similar [15, 16, 17]. Plich et al. (2013) conducted an experiment to investigate the effects of taking a sauna on cortisol concentration in 9 runners and 9 men not related to sports. Both groups participated in 15-minute sessions in a sauna with a 2 minute break for a cold shower at a temperature of 19–20°C. After analyzing the results, a statistically significant increase in cortisol concentration levels were noted in both groups, but higher in untrained men [15]. Ježov et al. (1994) performed studies in 8 men and 8 women, who spent 20 minutes in a sauna at a temperature of 80°C. The study showed a biphasic response of cortisol concentration in the plasma. Its level decreased during the initial phase (15 minutes), however, it later increased, the highest value recorded 15 minutes after leaving the sauna. Hyperthermia caused stronger activation of the neuroendocrine system in women compared to men [16]. Kauppinen et al. (1989) carried out a study in which 9 men participated. They took a sauna and were subjected to low temperatures (immersion in freezing water and showers at 15°C). An increase in cortisol levels was observed. The authors suggested that the tendency to secrete ACTH, cortisol and an increase in activity of the sympathetic nervous system caused by a stay in the sauna and cold baths, can cause elevation of the pain threshold and develop tolerance to cold [17]. Debt and Leppanem (2000) conducted a study which involved 11 women,

Figure 2. Changes of the average IgM concentrations [g/L] between the beginning and the end of the season in the ‘winter swimming + sauna group’ and ‘winter swimming only’ group
aged 25–52 and 9 men, aged 19–64. The experiment took place in Finland. The volunteers spent 15 minutes in a sauna heated to 95°C, with a humidity of 30-50%, and then walked to the lake (about a minute), which was located 50 m away. The air temperature was between −3.5°C to −15°C. The subjects swam in the freezing water for about half a minute. After getting out of the lake, they returned to the building with the sauna. The study was conducted four times during late winter. After testing, a significant increase in the cortisol level was noted, i.e. 61%. Also, an increase in the concentration of interleukin-6 (IL-6) was observed, which is indicative of adaptation of the immune system.

In our study, only at the beginning of the season in November did we observe a statistically significant increase in cortisol in the sauna and winter swimming group compared with the only winter swimming group. This demonstrates that the combination of high and low temperatures was a stronger stimulus at the beginning of the winter swimming season compared with the impact of only the low temperature of the water.

Maintaining the thyroid at a resting, constant level depends on the cooperation of the TSH and TRH thyroid hormone feedback loops. Adaptation to changing environmental conditions, mediated by TRH, is expressed by an increase in thyroid hormone secretion due to cold [19, 20, 21, 22] and a reduction in their synthesis when exposed to heat [23, 24]. Štrbák et al. (1987) performed a study to investigate the impact of taking a sauna on thyroid function parameters. The participating males, aged 20–25, spent 30 minutes in the sauna. There was an increase in TSH level in the plasma [25]. Leppäläuto et al. (1986) conducted a study which involved 10 healthy men and 7 women. They used the sauna at a temperature of 80°C. The session lasted for one hour, twice a day for seven days. The level of cortisol, TSH and thyroid hormones was assayed only for men. There were no significant changes in the concentration of the thyroid hormone serum or TSH, however, cortisol levels decreased [26]. Plich et al. (2007) conducted a study involving 10 healthy female students, aged 19–21. The volunteers spent 40 minutes in the sauna, with a 5 minute break for a 2 minute cold shower at the temperature of 20–22°C, and a 3 minute rest in a lying position. The average temperature in the sauna, measured 1.5 m above the floor level, was 80°C and the humidity equalled 5–27%. Blood tests were performed on first and fourteenth day of the experiment. A statistically significant decrease in cortisol concentration was noted, while the concentration of the thyroid hormones (FT3, FT4, TSH) did not change [8].

In this study, there was no statistically significant changes in the levels of TSH, FT3 or FT4, which confirm the results of the study conducted by Plich et al. (2007) [8].

The reduced incidence of various diseases in people toughened by exposure to cold water is connected to higher levels of IgA in the plasma [12, 27]. Banafi et al. (2009) studied the effects of systemic cold (cryogenic chamber), inter alia, the immunological parameters of athletes (IgM, IgG, IgA). The obtained results showed no change compared with the baseline measurements [28]. Based on the results of our research, similarly, no statistically significant changes in the levels of IgG and IgA immunoglobulin were found. Only at the beginning of the season in March, a statistically significant increase in IgM concentration in the sauna and winter swimming group could be found. IgM is a gamma-globulin produced by plasma cells constituting 5% of the immunoglobulin fraction. Due to the reason that an increase in IgM levels can be observed in inflammation states, the combination of cold and heat factors may have resulted in a strong reaction in “Walruses” after the whole season.

Although studies have already been conducted regarding the impact of cold and taking a sauna on biochemical indicators, so far, this study is the first combining the effects of ‘walrusing’ and a sauna on the levels of immunoglobulin (IgG, IgA, IgM), thyroid hormones (FT3, FT4, TSH) and cortisol.

References

Effect of Winter Swimming and Taking in a Sauna on the Biochemical Properties of Young Women


Word count: 4,022

Tables: 4
Figures: 2
References: 28

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RHEOLOGICAL PROPERTIES IN MARATHON RUNNERS

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1 Department of Clinical Rehabilitation, University of Physical Education in Krakow; 2 Faculty of Physical Education and Sport, University of Physical Education in Krakow; 3 Faculty of Physical Education and Sport – doctoral studies, University of Physical Education in Krakow, 4 Jagiellonian University Medical College; Faculty of Pharmacy, Department of Medicinal Chemistry.

Keywords: blood rheology indicators, men over the age of 40, marathon running, adaptive changes, exercise-induced stress

Abstract

Study objectives. 1. Understanding the adaptive changes in blood flow in the circulatory system under the influence of long-term amateur marathon running in older males. 2. Determination of the continuous effects of a single long-term exercise in a marathon on blood rheology profile indicators in men over the age of 40.

Study design and methods. The type of conducted research was case-control studies (CCS). A group of 10 runners over the age of 40, practicing amateur running in the AZS AWF “Masters” Sports Club for at least three years (min 3 - max 15 years) was qualified for observation. In accordance with the principles of the case study method, individual and average results of marathoners before and after the run, at the distance of 42,195 m, with a finishing time above three hours – were referred to the reference and average standards, and the dispersion of identical measurements in the control group. The group was comprised of honorary, healthy blood donors, volunteers of the same age, from Krakow’s blood donor centre, performing only habitual physical activity.

Research techniques and tools. Blood samples were drawn from the marathoners twice: on an empty stomach the day before the marathon, and 15 minutes after the end of the marathon. Blood was drawn once on an empty stomach from the volunteers. To examine plasma viscosity, deformability of erythrocytes (rbc) (elongation index EI and aggregation rbc index AI) we used an apparatus having an international certificate (LORCA analyzer, Myrenne Roetgen D-52159 viscometer, Chrom - 7 coagulometer) and all procedures applicable in blood rheology research methodology were carried out.

Results. The results of our study suggest that in some indicators of blood rheology, only in part of male subjects with long-term training experience or earlier competitive sports training, there were positive adaptive changes. After finishing the marathon, smaller shifts caused by the body’s reaction to stress fatigue were found in their rheological profile indicators.

Conclusions: Long-term exposure to endurance sports and competition in marathons of persons over the age of 40 may cause micro-traumas and intensification of undesirable involution changes, particularly in the circulatory system. There is a need to control sport preparation and medical qualification of older people who engage in marathon running. Rheological studies should be routine in controlling the effects of training in older persons engaged in amateur marathon running.
Introduction

Rheological blood tests include four basic properties: blood viscosity, plasma viscosity the deformability of erythrocytes (elongation index rbc) and aggregation (aggregation index rbc).

Several research results have confirmed the occurrence of not only an increase in the number and size of cell aggregates, but also an increase in the bonding strength of erythrocytes in ill-patients (represented by AI and Amp) [1]. As is known, an increase in such a force causes commitment to disrupt aggregates at higher shear rates. Increasing the bond strength of erythrocytes also increases the speed of the aggregation process itself (represented by T½). An increase in the number and size of erythrocyte aggregates means an increase in blood viscosity and hence, an increase in blood flow resistance – particularly in sections of diseased vessels. This leads to restriction or even stagnation of blood flow [2]. The proper ability of erythrocytes to deform is necessary for the efficient transportation of oxygen and carbon dioxide, and consequently, normal tissue perfusion. Reducing the capacity of erythrocyte deformability - identified in ill-patients – does not only lead to a decrease in tissue oxygenation [3], but also shortens the lifetime of red blood cells [4]. Adverse changes in the rheological properties of the blood can be observed in various disease states. They are, inter alia, an element of increased risk of cardiovascular diseases, which are one of the main causes of death in people of all ages in industrialized countries. Currently, this group includes marathon runners [5].

It should be emphasized that the development of measurement techniques in a number of worldwide research centres in the late 20th century has allowed not only to explore the phenomenon of rheological blood properties, but has also increased the accuracy and reliability of diagnostic tests. It is thanks to them that rheological changes in the properties of blood in various diseases have been determined. The most frequently assessed indicators are: blood and plasma viscosity, aggregation of blood cells and red blood cell deformability [6-8].

It is known that due to interaction between these factors, increased viscosity may not be the cause but the effect of flow disturbances and anoxia in a number of diseases. Due to the fact that rheological changes in the blood can be the result of disease, they can also be a factor in the formation of various pathological processes in the. Increased blood viscosity can be found in polycythemia, hyperproteinemia, dehydration, before menstruation, after exercise, postpartum, in leukaemia with high leukocytosis, hepatis, pneumonia, cyanosis, acidosis, diabetes, hypocalcaemia and hyperglycaemia [9]. In turn, the decrease in blood viscosity could be observed in late pregnancy, over-hydration, heart failure, liver swelling and after transfusions of plasma and liquid [10-11,8].

A number of studies show that increasing the viscosity of plasma and red blood cell aggregation and the reduction of their deformability underlies both stable and unstable angina, myocardial infarction, arteriosclerosis of the lower extremities [12-15], as well as neurological complications of atherosclerosis [16,17] and pathological states facilitating atherogenesis, which are diabetes, visceral obesity, hypertension syndrome, hypercholes- terolemia and renal failure [18-23].

Increased blood viscosity is the most important factor, apart from flow rate, determining the size of shear stress, which is a necessary force in the normal functioning of endothelial cells, maintaining flow and actions, as well as the structure of the vessel wall [24,25].

Numerous studies have devoted much attention to the phenomenon of shear mechanical stress on changes in endothelial function, and other complex processes in the arterial wall [26,27], among others, inhibiting endothelin gene expression and transformation of the vascular phenotypic to the so-called anti-atherosclerosis [28]. It turned out that too low values of shear stress cause endothelial dysfunction and morphological changes: remodelling vessels, thickening of the intima-media membrane complex (IMT, intima-media thickness) and formation of atherosclerotic plaques in the vascular areas subjected to low values of shear stress (bifurcations) [17].

At low values of shear stress, Turchetti et al. [29] showed a higher viscosity in both plasma and whole blood of patients with hypertension in comparison to the control group. The main factor responsible for this state was elevated fibrinogen levels, and the severity of rheological disorders corresponded with the advancement of hypertension and the occurrence of cerebral and cardiac complications of hypertension. Fibrinogen, in addition to having a direct effect on plasma viscosity, plays a significant role in erythrocyte aggregation, which is positively correlated with the severity of hypertension [30]. Consistent with the LIFE study (Losartan Intervention for End Point Reduction in Hypertension Study), blood viscosity does not only affect the value of blood pressure, but also its organ complications in patients with hypertension. In multivariate analysis, haemoglobin and hematocrit determined left ventricular hypertrophy, as well as its systolic and diastolic activity the strongest [31].

According to Raizer et al. [32], such an observation may confirm the earlier results obtained by Devereux’a et al. [33], regarding the relationship between blood viscosity and left ventricular hypertrophy. All patients with
an increased value of left ventricular mass index (LVMI) in the LIFE Study also had higher blood viscosity, whereas among the patients without cardiac hypertrophy, blood viscosity was comparable to the control group. In the Edinburgh Artery Study [34], it was demonstrated that blood viscosity is associated with the risk of cardiovascular events and thickness of the IMT complex of the carotid arteries. For the male participants of this study, a significant correlation was found between the thickness of the IMT complex and whole blood viscosity, viscosity corrected for hematocrit and plasma viscosity.

Viscosity compounds of the whole blood and their most important determinant of increased risk of cardiovascular events inspired researchers of the North Glasgow MONICA Study and the Scottish Heart Health Study to attempt assessment of the impact of these parameters on mortality [35]. Thirteen years of observing 1,238 patients provided irrefutable evidence regarding the adverse effects of increased viscosity of the whole blood, plasma, hematocrit values and fibrinogen concentration on total mortality. The value of the mortality risk rate for elevated whole blood viscosity values after adjustment to age and sex was 1.55, and for plasma viscosity – 1.23, the highest value – 1.78 – reached for elevated levels of fibrinogen.

Based on the presented review of studies, it may be assumed that control of blood rheology indicators could be valuable for athletes performing extreme physical exercise. At the same time, rheological test can be used to detect certain irregularities which may explain or eliminate failure in sport achievements. Up to date, international studies engaging amateur marathon runners over the age of 40 are rare [36].

From the few observations of changes in the profile of blood rheology indicators in people of various ages practicing amateur sport (carried out at different times and using non-comparable research tools) - a number of interesting observations were obtained, documenting the occurrence of many of unfavourable adaptive and post-exercise changes, often irreversible, in healthy, sport practicing people [36]. The published reports also show that, to a large extent, the scope and direction of adaptive and post-exercise changes varied between individuals, hence the interpretation of the athletes’ test results is not easy. Solving the signalled problem, using methods adequate to the given predicament, used in case-control studies, results were obtained justifying the conclusion that the results of blood rheology measurements may be the first sign of adverse post-exercise health reactions, as well as adverse adaptive changes developing over time, which may even sometimes be pathological. Among the more recent studies, it is indicated that such phenomena occur more frequently in people who run marathons [37-40].

According to the statistics of the International Statistical Classification of Diseases, 10th Revision, codes I00-I99, during the first decade of the 21st century, a total of 526 deaths, including 376 (71.5%) associated with cardiovascular disease, occurred. Many heart attack survivors, however, were convinced of the health effects of training running [41].

There are divided opinions among physicians regarding the participation of those convalescent after heart attacks or those who underwent cardiac surgery in sports or marathon competitions [36]. The stance of the American College of Sports Medicine, beginning with the high-profile polemic among American cardiologists [42], with pseudoscientific theories [43] and training views [44], is indisputable, and can be brought down to the maxim present in the most recent meta-analysis of the advantages and disadvantages of practicing various disciplines of endurance sports at an older age, primarily including ischemic heart disease: Exercise and the Heart - the Harm of Too Little and Too Much. [40]. This stance is confirmed by the results of cardiac observations carried out in various academic centres [45-51].

Consequently, the following problem may be put forward: to what extent can training marathon running stimulate ischemic heart development in physically active people? In the light of modern knowledge, it is mainly due to coronary atherosclerosis [52-55].

According to well-reasoned views, arteriosclerosis is treated as a chronic response to blood vessel wall inflammation, initiated by endothelial damage [56]. This phenomenon occurs during training and marathon running. These are micro-traumas, the accumulation of which can lead to different conditions of atherosclerosis development over time.

There is already some evidence that the degree of the rheological disorder determines the weight of the hemorheological parameter of the atherosclerosis risk. The more blood exhibits non-Newtonian properties, which should be understood as a high viscosity at low shear rates (the blood viscosity at low shear rates is a function of fibrinogen concentration, hematocrit values, plasma viscosity and the rheological properties of red blood cells), the longer the dwelling time of atherogenic particles in areas of secondary flow formation (vascular bifurcations, side branch exits, curvature of the inner vessel) in which there is a significant deceleration of blood flow [57]. This type of mechanism accelerates the atherosclerosis process, becoming its specific catalyst. Hemorheological disorders seem to be an important link in the process of atherogenesis. Another reason, which is also a classical risk factor in “paving the way” to artery damage, is the generalized dysfunction of the endothelium which accompanies it.

The rheological properties of blood are therefore a common “platform” on which many independent, clas-
sic risk factors of atherosclerosis may be put. Due to this, it should be assumed that the determination of fibrinogen, hematocrit and plasma viscosity values should be among routine tests used in risk factor assessment of cardiovascular disease development in patients engaged in marathon running at an older age [5].

For this purpose, diagnosis of health risks posed by those training exclusively full distance (42,195 m) marathon running within a few hours were conducted, using objective methods. The observations in our study are ground-breaking for our country.

So far, no rheological studies used for the diagnosis of pathological changes in people practicing amateur marathon running at an older age have been conducted. Filling the gap becomes a necessity. According to official reports, in the last decade only during marathons (not including half marathons and training activities) 590 people have died, mostly due to cardiac reasons. Contrary to popular belief, it should be assumed that amateur running sports training leads to adverse adaptive changes, and participation in a marathon can generate high stress causing harmful changes in blood rheology indicators. In order to verify this hypothesis, blood tests were conducted before and after the marathon in men over the age of 40. The collected results will be stored in the International Committee for Standardization in Haematology (Expert Panel on Blood Rheology) [58] online database, in order to develop reference standards for haematological and rheological indicators in people of all ages performing extreme exercise and sport at different competitive levels.

Study objectives

1. Determination based on blood rheology indicators of the effects of adaptation on physical stress, implemented in the long-term training of people who engage in amateur marathon running at an older age.

2. Assessment of the extent and direction of changes in blood rheology indicators under the influence of a single, few-hour-long continuous exercise leading to full exhaustion.

Research questions:

1. In male amateur marathon runners over the age of 40, can cases of non-beneficial adaptive changes to ensure the growth of tissue oxygenation by increasing the capacity for erythrocyte deformation, and reducing blood viscosity by optimizing plasma viscosity, aggregation speed and erythrocyte bond strength and fibrinogen concentration be found in the profile of blood rheology indicators?

2. To what extent can a single, long-term exercise in a marathon run cause, from the health point of view, undesirable stress in the body, in the direction of an increase in blood viscosity, fibrinogen concentration, aggregation index and reduction in aggregation amplitude and erythrocyte regeneration speed?

Study design

The study involved 10 healthy men, age 40-60, who participated in marathon runs. They were randomly selected from among amateur runners training in the clubs: "Association of Visegrad Marathon" in Rytro and "Masters AZS AWF" in Krakow. Their training experience in amateur sport was similar and averaged 5 years (min 3-max 10 years). Only two of them previously took part in medium level runs at a championship level.

Each year, the runners participated in several marathon races (an average of 6 times). Apart from this, in the meantime, they participated in cross country and street races over long distances. Prior to the test, the participants performed individual training programs as recommended by the trainers conducting classes on so-called “running paths”. Most of the sports activities were carried out in a group under the supervision of trainers, 4-6 times a week. The annual distance in training of participants did not exceed 3,000 km.

Study programme

The research program obtained the consent of the Bioethics Committee, at the Local Medical Chamber in Krakow. According to the adopted project, runners began the first series of tests on an empty stomach in the morning, the day before the start of the “10th Cracovia Marathon”. Blood collection and its analysis was conducted by the laboratory personnel at the Locomotor Pathology Laboratory of the Department of Clinical Rehabilitation, Academy of Physical Education in Krakow. The second series of tests was carried out during the first minutes after finishing the marathon at specially designed measuring stations, organized in a tent at the finish line. The collected blood was immediately transported to the laboratory of Physical Education in Krakow, in order to perform analysis of the collected samples using the same method as before the marathon.

Methods

Determination of aggregation indices (AI, Amp, T½)

The blood sample was subjected to oxygenation by saturation with carbogen for 15 minutes. Then, 1 ml of blood was introduced into the cylinder of the LORCA analyzer, which was set into rotation. After 10 seconds, the cylinder stopped and aggregation of blood cells began. The measurement was taken at 37°C. The method of aggregation kinetics measurement was based on the phenomenon of scattering laser light through red blood cells, the intensity of which depended on the degree of
erythrocyte aggregation. Thanks to computer analysis, the curve showed the dependency of scattered light intensity over a constant period of time, i.e. selectogram [59].

Aggregation indices were calculated using the following formula:

- **AI** – Aggregation index [%]
  \[ AI = \frac{A}{A+B} \times 100 \%
  \]
  where: \(A\) – area above the selectogram curve, \(B\) – area below the selectogram curve.

- **Amp** – Amplitude of aggregation [au]
  \[ \text{Amp} = I_{\text{max}} - I_{\text{min}} \]
  where: \(I_{\text{max}}\) – the maximum intensity of scattered light at maximum disaggregation,
  \(I_{\text{min}}\) – the minimum intensity of scattered light at maximum aggregation.

- **T\(\frac{1}{2}\)** - Half time kinetics of aggregation [s]
  \[ T_{\frac{1}{2}} = I_{\text{min}} + \frac{1}{2} \text{AMP} \]

**Determination of elongation index (EI)**

For the determination of the elongation index of red blood cells, 25 ml of blood mixed with 5 ml of 0.14 mM solution of Polyvinylpyrrolidone (PVP) in buffered saline (PBS) was used. The solution of this buffer had well-defined physico-chemical properties, i.e.: a pH of 7.4, osmotic pressure of 300 mOsm/kg and viscosity of 30 ± 2 mPa · s. Measurement temperature was stabilized at 37°C. The blood sample was placed in the LORCA analyzer similar as in the case of the aggregation test. The diffraction pattern in the projection image was acquired with the deflection of the laser light passing through the thin layer of red blood cells in the rotating cylinder [60]. With the increase of the shear stress, the diffraction image of blood shifted from a circular to elliptic shape. The value of the long axis to the short axis of erythrocytes was recorded as well as the elongation index (EI), which is the measurement of the degree of red blood cell deformation during their movement in the analyzer. This was calculated from the following formula:

\[ EI = \frac{A-B}{A+B} \]

where: \(A\) – red blood cell long axis length, \(B\) – erythrocyte short axis length.

**Determination of blood plasma viscosity (BPV)**

Blood plasma viscosity was measured using the D-52159 Roetgen Myrenne viscometer, Germany. After centrifugation of the cellular blood components, 0.5 ml of plasma was put into the viscometer measurement capillary. At constant temperature and pressure, the flow time was measured, and the result was given in mPa·s.

**Results**

**Rheological indicators**

In accordance with the objectives of the research, it was assumed that the level of rheological indicators examined before the marathon run will be characterized by the level of adjustive changes resulting from a long training process. In turn, the differences between the level of indicators identified before the marathon run (measurement 1) and the second measurement (2) after completing several hours of exercise during the 42,195 m run, can attest to the scope and direction of changes brought about under the influence of prolonged physical exertion. In contrast to previously used methods of solving this type of research problem, analysis of the results of our own research was primarily based on individual observations, and not only (as is generally conducted in scientific studies) measurements of average values. Because it was assumed that the process of adaptation to physical exercise (trainability) in sports is conditioned by many factors, and its evocation in the desired direction, similarly as in the case of disease treatment in medicine, it differs between individuals. Failing to recognize such an issue and relying only on average results (very often calculated without random sampling) in the interpretation of such phenomena associated with the discussed process is, to say the least, arguable and could lead to far-reaching adverse practical consequences.

In Table 1, the results of the considered rheological indicator measurements in the men tested before and after the marathon are presented, at the same time, noting the direction of diversification with an arrow and its range as a percentage (%).

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Before</th>
<th>After</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>AI</td>
<td>12%</td>
<td>15%</td>
<td>+3%</td>
</tr>
<tr>
<td>Amp</td>
<td>10 au</td>
<td>9 au</td>
<td>-1 au</td>
</tr>
<tr>
<td>T(\frac{1}{2})</td>
<td>5 s</td>
<td>4.5 s</td>
<td>-0.5 s</td>
</tr>
</tbody>
</table>

Tab. 2 contains arithmetic means of the dispersion measurement and the extent of differences between the first and second test compared to average values and dispersion of the considered rheological indicator measurements in the comparative group.

For comparative purposes, the collected research material is graphically illustrated in bar graphs 1-3, 5-8. In each figure, for the selected parameter, values of mea-
Table 1. Aggregation indices in males before (1) and after (2) the marathon run.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Measurement</th>
<th>T½ [s]</th>
<th>AMP [au]</th>
<th>AI [%]</th>
<th>BPV [mPa s]</th>
<th>FIB [g/l]</th>
</tr>
</thead>
<tbody>
<tr>
<td>M.M.</td>
<td>1</td>
<td>3.34</td>
<td>21.18</td>
<td>53.24</td>
<td>1.18</td>
<td>4.57</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1.83 -45%</td>
<td>12.24 -42%</td>
<td>65.98 -24%</td>
<td>1.32 -2%</td>
<td>4.31 -6%</td>
</tr>
<tr>
<td>J.Ś.</td>
<td>1</td>
<td>3.04</td>
<td>21.81</td>
<td>55.84</td>
<td>1.25</td>
<td>3.89</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1.80 -41%</td>
<td>11.92 -46%</td>
<td>66.33 -19%</td>
<td>1.34 -11%</td>
<td>3.81 -2%</td>
</tr>
<tr>
<td>A.P.</td>
<td>1</td>
<td>3.30</td>
<td>14.03</td>
<td>54.23</td>
<td>1.18</td>
<td>2.45</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>4.28 -30%</td>
<td>15.83 -13%</td>
<td>46.92 -13%</td>
<td>1.21 -2%</td>
<td>2.50 -2%</td>
</tr>
<tr>
<td>G.P.</td>
<td>1</td>
<td>3.54</td>
<td>20.16</td>
<td>52.06</td>
<td>1.22</td>
<td>4.69</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>3.91 -10%</td>
<td>18.17 -10%</td>
<td>49.88 -4%</td>
<td>1.24 -2%</td>
<td>3.87 -17%</td>
</tr>
<tr>
<td>T.M.</td>
<td>1</td>
<td>4.67</td>
<td>19.71</td>
<td>45.72</td>
<td>1.15</td>
<td>3.81</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>3.10 -34%</td>
<td>17.03 -14%</td>
<td>55.34 -21%</td>
<td>1.94 -68%</td>
<td>3.75 -2%</td>
</tr>
<tr>
<td>S.Z.</td>
<td>1</td>
<td>2.49</td>
<td>19.16</td>
<td>60.37</td>
<td>1.18</td>
<td>5.01</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>2.64 -16%</td>
<td>18.78 -2%</td>
<td>58.66 -3%</td>
<td>1.76 -49%</td>
<td>4.90 -2%</td>
</tr>
<tr>
<td>K.C.</td>
<td>1</td>
<td>2.94</td>
<td>18.79</td>
<td>56.37</td>
<td>1.11</td>
<td>4.59</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>3.53 -30%</td>
<td>19.60 -14%</td>
<td>51.87 -8%</td>
<td>1.27 -14%</td>
<td>3.96 -14%</td>
</tr>
<tr>
<td>R.P.</td>
<td>1</td>
<td>3.31</td>
<td>17.95</td>
<td>53.66</td>
<td>1.16</td>
<td>4.19</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>3.14 -15%</td>
<td>18.41 -3%</td>
<td>54.96 -2%</td>
<td>1.25 -18%</td>
<td>3.47 -17%</td>
</tr>
<tr>
<td>J.A.</td>
<td>1</td>
<td>3.17</td>
<td>17.73</td>
<td>54.87</td>
<td>1.19</td>
<td>3.30</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>2.88 -9%</td>
<td>16.43 -7%</td>
<td>56.86 -4%</td>
<td>1.32 -11%</td>
<td>3.33 -11%</td>
</tr>
<tr>
<td>W.M.</td>
<td>1</td>
<td>2.99</td>
<td>23.02</td>
<td>55.91</td>
<td>1.20</td>
<td>3.97</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>4.46 -49%</td>
<td>25.45 -11%</td>
<td>46.99 -16%</td>
<td>1.25 -14%</td>
<td>3.54 -11%</td>
</tr>
</tbody>
</table>

Table 2. Mean values and standard deviations of rheological indicators determined before and after the run in marathon runners and the extent of the difference (d) between them. Taking into account the average values and standard deviations of the control group.

<table>
<thead>
<tr>
<th>indicator</th>
<th>unit</th>
<th>before run (x ± SD)</th>
<th>after run (x ± SD)</th>
<th>control group (x ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T½</td>
<td>[s]</td>
<td>3.28 ± 0.60 ††</td>
<td>3.16 ± 0.92 ††</td>
<td>1.72 ± 0.61</td>
</tr>
<tr>
<td>AMP</td>
<td>[au]</td>
<td>19.4 ± 2.5 ††</td>
<td>17.4 ± 3.8</td>
<td>14.3 ± 2.8</td>
</tr>
<tr>
<td>AI</td>
<td>[%]</td>
<td>54.2 ± 4.0 ††</td>
<td>55.4 ± 6.9 ††</td>
<td>67.3 ± 6.6</td>
</tr>
<tr>
<td>BPV</td>
<td>[mPa · s]</td>
<td>1.18 ± 0.04</td>
<td>1.33 ± 0.17 ††</td>
<td>1.15 ± 0.12</td>
</tr>
<tr>
<td>FIB</td>
<td>[g/l]</td>
<td>4.05 ± 0.76</td>
<td>3.74 ± 0.63 *</td>
<td>3.63 ± 0.71</td>
</tr>
<tr>
<td>El 0.3Pa</td>
<td>[u]</td>
<td>0.073 ± 0.028 †</td>
<td>0.080 ± 0.027 †</td>
<td>0.040 ± 0.018</td>
</tr>
<tr>
<td>El 59.97 Pa</td>
<td>[u]</td>
<td>0.612 ± 0.017</td>
<td>0.611 ± 0.030</td>
<td>0.624 ± 0.009</td>
</tr>
</tbody>
</table>

* statistically significant difference (p < 0.05) relative to measurement before run
† statistically significant difference (p < 0.01) relative to control group
†† statistically significant difference (p ≤ 0.001) relative to control group

Half-life of red blood cell aggregate regeneration (T½)

Half-life of red blood cell aggregate regeneration (T½) required for the regeneration of red blood cell aggregates in the blood drawn from the runners the day before participation in the sports competition and measurements taken in 10 runners and the arithmetic mean as well of standard deviation of the control group are compared. Table 2, in addition to the scope of the difference (d) between the first (1) and second (2) measurement, and the values of the tested indicator in the control group, the level of significance (p) is given.
in the 15th minute following the end of the race, after a few hours of physical exercise in the marathon. Their values of the 1st and 2nd measurements were referred to the arithmetic means and dispersion of measurements of the control group (male donors at the blood donation centre). As is clear from the data presented in Figure 1, in all relationships between measurements before and after the marathon, increased values of half-life T½ were observed in athletes with a greater range of differences in the first measurement. This scope and direction of diversification is clearly reflected in their average values, listed in Table 2, and in statistical significance of differences at the level of: p ≤ 0.001 (before the race) and p ≤ 0.01 (after the marathon).

From analysis of the change dynamics in the T½ indicator between the first and second series of measurements, it becomes apparent (Table 1) that in individual cases, it is difficult to determine the dominant direction of differentiation (Fig. 1), when the tendency for decrease in this rheological indicator during the second series of measurements is more evident (in 6 cases) (5-45%) than its growth (6-49%). In the mean values extent, this situation resulted in the difference between the 1st and 2nd series of measurements to be small and thus, statistically insignificant (Tab. 2). It seems that considering the scope of diversity in individual cases, on the one hand, with the index decreased by 45%, and on the other, its increase by as much as 49%, it would be difficult to resist the interpretation of test results only on the basis of average values, and the inference that a few hours of exercise in a marathon did not have impact on the decrease in the red blood cell aggregation indicator in competitors who have been training for a shorter period of time.

In relation to comparative material from studies in ill-patients and a comparative group of the Upper Silesia Polish population, it can be said that for all analyzed cases in our study, a similar direction of differentiation occurred between the sports and comparative groups, as in the comparative analysis between groups of ill and healthy individuals.

**Amplitude of total erythrocyte aggregation (AMP)**

In Figure 2 and Table 1, the amplitude of total aggregation (AMP – amplitude, total extent of aggregation) of the red blood cells are presented for values before and after the marathon compared to the mean value and standard deviation of the control group. Before the exercise, the level of the indicator in all marathoners – except for one case – exceed the range of the arithmetic mean variation of the control group. In this measurement, similarly as in the second, the range of variation in the averages of the sports and control group was statistically significant at the level of 0.001 p ≤ before and p ≤ 0.01 after the marathon (Tab. 2).

Referring the pre-exercise AMP values to those detected in the second blood collection, it should be noted that the differences in average values showed a statisti-
cally insignificant decline in the index of total aggregation of erythrocytes (Tab. 2). When analyzing its individual variability in the tested competitors (Tab. 1, Fig. 2), it turns out that there is a clear, dichotomous direction of the volatility indicator. In 60% of the analyzed cases, there was a tendency for its value to decrease in the case of high dispersion of results: 2-45%. A clear AMP decreasing tendency occurred in the group of competitors with less and shorter sports training experience. In 40% of marathoners, performing sports at a high level, there was a slight increase in this indicator (3-13%).

For this reason (similarly as in the case of $T_{1/2}$), it would be difficult to ignore individual differences in direction and extent of post-exercise changes in the interpretation of statistically non-significant variation of the arithmetic means of the mentioned aggregation index. Apart from this, assessing the extent of inter-group differentiation, attention should be paid to the very low range of total aggregation amplitude (AMP) in the control group ($ua = 14.3 \pm 2.8!$). In comparison to similar studies conducted in the Silesian Medical Academy in Katowice, (about 20 ua), it was more than 30% lower [1].

Compared to our research results, it turns out that only in one competitor with much training experience, the results of the first and second measurement surpass the level of the comparative group (Tab. 1). In the remaining cases, the level of AMP not only in the comparative group, but above all, the state of post-exercise changes in the weakest marathon runners was lower than observed in obese individuals, heart attack survivors, or person ill with diabetes or ASA. However, it should be noted that in this case, the noticed difference may have been affected by the method of indicator marking.

**The degree of erythrocyte aggregation in the group of Krakow marathoners in contrast to the comparative group (AI)**

Figure 3 and Tables 1 and 2 show the values of the aggregation index (AI), which is characterized not only by the speed of erythrocyte reproduction, but also by measurements of intensity of their three-dimensional structures which are presented in Fig. 3 and Tab. 1 and 2.

The phenomenon of spontaneous aggregation of red blood cells in whole blood plays a significant role in blood flow at low shear rates and significantly affects the increase of blood viscosity. From our research, it may be concurred that the rate of AI in the study group (apart from two cases of measurements after completing the marathon in the weakest competitors) was at a lower level in the first and second series of measurements than the arithmetic mean in the Krakow comparative group (similar to the rate in the Silesian study) [1]. The occurrence of this slow aggregation tendency of red blood cells in training individuals, before and after the marathon, is documented by clearly statistically significant differences in arithmetic means between the control and sports group: in the first series of measurements: $p \leq 0.001$, and in the second – $p \leq 0.01$. On this basis, it
can be assumed that the desired adaptive process took place in the majority of competitors (Tab. 2).

What is interesting is that long-term, several-hour-long physical exercise caused multidirectional quantitative changes (Tab. 1). In 50% of subjects, a slight increase in the red blood cell aggregation index (2-24%) was found. In the group with the same number of subjects, a slight decrease also occurred in the slightly low aggregation index (3-16%).

Erythrocyte elongation kinetics in the group of competitors in contrast to the comparative group (EI)

In our study, we paid special attention to the process of erythrocyte kinetic deformability formation (EI – elongation index) in the blood of competitors before the marathon and after its completion. We adopted the hypothetical assumption (similarly as in the previously characterized hemorheological indicators) that the level of the indicator, recorded in the first measurement (1), is the effect of the adaptive training process regarding the ability of red blood cell deformation in the athlete’s blood (the ratio of the long axis to short axis of erythrocyte) in the long-term period of the body’s adaptation to this endurance type of exercise.

In turn, with the second measurement (2), we aimed to examine the scope and direction of erythrocyte elongation variation in the runners under the influence of a single, few-hour-long physical effort, performed to complete exhaustion by constant running.

As is clear from the data in Tab. 3, the shape of the diffraction image depended on the shear stress acting on the blood cell during the rotation of the cylinder. Apart from one refraction in the development rate during the third measurement, the change in the dynamic system specified by the index of elongation parameter, its nature was of exponential development (Fig. 4). In this manner, the variation image with the value of erythrocyte deformation depending on the time of scattered light intensity (for a given shear rate) was formed. As it may be concluded from the analysis of data presented in Tab. 2 and 3 and Fig. 4 and 5, only for lower values of shear stress (0.3 Pa) was a higher dispersion of the results noted (usually, authors adopt a negative attitude to data obtained at this level of shear stress, due to the fact that values are always widely scattered) before and after the marathon, and greater ability for erythrocyte deformation in marathoners, especially with longer training experience and at a higher level of sports competition.

In Table 3, the variation of individual elongation indices [EI] is presented. This is a measurement of the amount of red blood cell deformation during their movement in the LORCA analyzer.

In figures: 5 and 6, the effect of extreme values of the applied shear stress (min 0.3 Pa – max 59.97 Pa) on individual values of the red blood cell elongation index in runners before and after the marathon is presented in respect to the arithmetic mean and standard deviation.
Table 3. Variation of elongation index (EI) of red blood cells as a function of time at various levels of shear stress in the blood of the men before (1) and after (2) the marathon run

<table>
<thead>
<tr>
<th>Subject</th>
<th>Measurement</th>
<th>EI</th>
<th>EI</th>
<th>EI</th>
<th>EI</th>
<th>EI</th>
<th>EI</th>
<th>EI</th>
<th>EI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.3Pa</td>
<td>0.58Pa</td>
<td>1.13Pa</td>
<td>2.19Pa</td>
<td>4.24Pa</td>
<td>8.23Pa</td>
<td>15.96Pa</td>
<td>31.04Pa</td>
<td>59.97Pa</td>
</tr>
<tr>
<td>M.M.</td>
<td>1 0.061 0.103 0.208 0.300 0.398 0.483 0.544 0.588 0.619</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 0.062 0.106 0.201 0.297 0.389 0.474 0.535 0.583 0.626</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>J.Š.</td>
<td>1 0.041 0.075 0.179 0.319 0.418 0.502 0.560 0.603 0.626</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 0.055 0.082 0.198 0.339 0.422 0.519 0.579 0.619 0.642</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A.P.</td>
<td>1 0.100 0.144 0.235 0.314 0.407 0.483 0.534 0.577 0.603</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 0.087 0.138 0.239 0.317 0.402 0.477 0.526 0.566 0.598</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G.P.</td>
<td>1 0.047 0.088 0.139 0.287 0.398 0.487 0.552 0.601 0.627</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 0.086 0.100 0.206 0.317 0.418 0.507 0.575 0.619 0.640</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T.M.</td>
<td>1 0.089 0.147 0.213 0.283 0.372 0.446 0.496 0.535 0.579</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 0.084 0.153 0.195 0.248 0.339 0.419 0.465 0.494 0.541</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S.Z.</td>
<td>1 0.075 0.112 0.216 0.326 0.416 0.490 0.549 0.594 0.625</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 0.071 0.117 0.201 0.300 0.392 0.451 0.530 0.576 0.616</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>K.C.</td>
<td>1 0.084 0.142 0.182 0.258 0.380 0.451 0.507 0.557 0.594</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 0.207 0.272 0.287 0.412 0.468 0.537 0.589 0.618</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R.P.</td>
<td>1 0.050 0.092 0.160 0.307 0.412 0.496 0.556 0.601 0.629</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 0.057 0.094 0.160 0.300 0.403 0.490 0.553 0.601 0.631</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>J.A.</td>
<td>1 0.055 0.107 0.179 0.300 0.398 0.480 0.538 0.586 0.619</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 0.076 0.112 0.209 0.300 0.389 0.471 0.531 0.581 0.614</td>
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Figure 4. Curve presenting the dependency of erythrocyte elongation index (EI) on shear stress [Pa] in marathoners and men in the comparative group.
Rheological properties in marathon runners

of the control group. As is apparent from the presented data (Fig. 5), at low shear stress (0.3 Pa) the EI rates for only 50% of marathon runners (presenting a high level of sports) were in the range of or exceeded (two cases) the reference standard (0.053 - 0.093). It should be noted that the arithmetic mean and the measurement of the dispersion of the control group did not fall within this scope. Therefore, it was not considered a good bench-

Figure 5. Elongation index indicators at 0.3 Pa tangential stress (EI 0.3Pa) found in the blood of athletes tested before and after the marathon compared to the average and standard deviation (X ± SD) of the individuals in the control group.

Figure 6. Indicators of elongation index at 59.97 Pa tangential stress (EI 59.97Pa) found in the blood of competitors before and after the marathon compared to the average and standard deviation (X ± SD) in the control group.
mark to evaluate the ability of erythrocyte elongation in athletes, and comparative analysis was limited to taking only the physiological reference standard into consideration.

An analysis of the dynamics of changes in the elongation index applying the shear stress in question (0.3 Pa) shows that in the second series of measurements, in 70% of the studied athletes, there was a slight increase in the elongation index. In the smaller group, there was a tendency for the erythrocyte deformability (elongation) index to decrease. The tendency for weak directional dynamics of EI change by applying the lowest shear stress is confirmed by the statistically insignificant variation range of the averages in the first and second series of measurements (Tab. 3, Fig. 5).

As it can be concluded from the data presented in Fig. 6, in the case of applying the highest shear stress (59.97 Pa), slight differences in erythrocyte deformation index occurred in runners before the start of the marathon. In half of the cases, the values recorded for the runners were lower than the average and standard deviation in the control group. However, comparison of the mean values for these groups did not show any statistically significant differences. As is clear from the analysis above, it would be difficult to state the occurrence of the desired direction of the adaptation process under the influence of long-term training in the marathoners. Also of no influence were the several hours of physical exercise in the marathon on the change in volatility formation of the erythrocyte elongation index. In all the competitors, almost identical results in the first and second series of measurements were noted. In such a case, the differences of the averages, calculated from poorly differentiated individual values, did not show any statistically significant differences. This proves that a few hours of continuous exercise during the run did not affect the deformability kinetics (elongation) of erythrocytes in the blood of marathon runners at the moment of taking measurements with the apparatus at high intensity shear stress (Tab. 2).

Blood plasma viscosity (BPV)

As is clear from analysis of individual plasma viscosity (BPV) measurements in the tested athletes before the marathon, presented in Fig. 7, their level is in the range of the dispersion of the arithmetic mean measurements of the control group. In the first and second measurement, there were no statistically significant differences between the arithmetic average of the BPV indicator of the sports or control group. Due to the fact that the plasma viscosity index value in the control group was below the reference standard (1.4-1.8 mPa · s), it is difficult for it to be considered as a good reference point for assessing the impact of long-term sports training on the adaptive processes of rheological indicators. It should, however, be emphasized that a different method for measuring the viscosity indicator was used in the development of reference standards, as pointed out earlier. In such a case,
the reference standard range of variation was considered as more reliable in the evaluation process. This allows to accept the hypothesis suggesting the existence of positive trends in post-training adaptation of the plasma viscosity indicator. This trend also confirms reference to the indicator of the comparative group.

A comparison of the individual dynamics of the volatility of this indicator after completing the run shows that there was a tendency for increase in blood viscosity due to long hours of physical exertion in all participants, in a very large range of variation: $d = 2-68\%$. Undoubtedly, such tendencies in the dynamics of blood viscosity variation affected the value of the averages in the second measurement and the range of difference between measurements before and after the marathon (Tab. 2), which reached the level of statistical significance at $p \leq 0.05$.

**Fibrinogen**

In Figure 8, and Tables 1 and 2, the concentration of fibrinogen in the blood plasma of the tested competitors before and after the marathon compared to the average in the control group is presented. All determinations gave a result within the physiological norm (2-5 g/l), but in four cases before exercise, the measurements of fibrinogen were above the range of variation of the control group averages, and a lower level of the fibrinogen indicator was found in one person. The scope of difference between the arithmetic mean of fibrinogen, found in the marathon runners before and after several hours of running and the control group, was not statistically significant (Tab. 2).

It should be noted that in the second test, in addition to small increments in two cases (1%), lower fibrinogen values (2-17%) were observed in the remaining measurements. Such a characteristic direction of decrease in fibrinogen due to prolonged physical exertion documents the statistical significance of the difference of the arithmetic mean very clearly (Tab. 2), which was calculated from its individual measurements before and after the marathon ($p \leq 0.05$).

**Discussion**

The erythrocyte – red blood cell (rbc), is the most popular, most numerous and most exchangeable cell in our system. It is quite specific because it lacks a nucleus. The erythrocyte is a link between the lungs and the rest of our body — providing oxygen, receiving CO$_2$. It would seem that would be the extent of these cells’ role on physiological processes. Aside from the elution of NO from rbc, they are “harnessed” to carry medicine and anti-cancerous substances by flattening nanoparticles incorporated into their membrane or by way of adhesion to their surface [61].

Anthony van Leeuwenhoek may be considered the first discoverer of these cells. A. Leeuwenhoek (1632-1723) was a Dutch canvas trader (cloth merchant) who built the first microscope, by no means for testing blood, but for testing fibres and the quality of fabrics.
1743, in London, Henry Baker, in his work titled “The microscope made easy” wrote the following about this discovery: “An observation of Mr Leeuwenhoek is very well worth regarding; he took notice, that when he was greatly disordered, the Globule of his Blood appeared hard and rigid, but grew softer and more pliable as his Health returned”. This description draws attention to the characteristics of “squeezing and flowing” of rbc through the vascular system, characteristics of which – precisely apply to the rheology of these cells. The double layer of their cell membrane, gradually, within 120 days of circulation, lose one of its important features – flexibility. The cell membrane is surrounded by cytosol, whose main component is hemoglobin. In cytosol, already almost 70 enzymes having the most diverse functions have been detected. The number of these cells – different for both sexes, varies between 4-6 million in 1 ml of blood. This number and the rheological properties, although to a small degree vary seasonally, and rarely take this factor into account in scientific studies [62,63]. In whole blood, there are $25 \times 10^{12}$ of them. A normal erythrocyte equals 110 μm², has a volume of 82-92 fl, is 1.7-2.5 μm thick and has a diameter of 6-8 μm. After fulfilling its role, each erythrocyte must be replaced by a new one, so that a daily portion of 208 trillion of these cells must transfer from the bone marrow into the bloodstream at a rate of 24 million cells per second. Their substantial rheological properties ensure that they overcome 400 km a day without causing intravascular congestion. They maintain this property even in blood preserved for 42 days at blood donation stations.

The subject of our research is the rheological properties of rbc in various states, both physiological and pathophysiological, with special emphasis on physical exercise, sport efforts or varied training.

Particular analysis of erythrocyte membranes of marathoners, as well as the surface of these cells, was conducted by Jordan et al. [64]. Investigating the membrane of these cells, they found no significant difference in its structure. After the marathon, only an increase in the density of the membrane was found. Moreover, in these runners, a reduction in haptoglobin serum was found, and simultaneously, the authors noticed the correlation – when the surface of rbc is reduced there is an increase in the levels of this protein. These relatively minor changes in the erythrocyte membrane in marathon runners after the race, may be the explanation for the low numerical changes in the rbc composition, which is consistent with the findings of Mleczko, et al. [5]. Nonetheless, the authors point out that “Observed structural changes in rbc membrane skeletons as shown by SEM after marathon run may be related to increased susceptibility to chemical stress. Increased susceptibility of rbc to chemical and physical stress may contribute to hemolysis in endurance exercise. Considering the high sensitivity of membrane proteins such as spectrin and protein band 3 to oxidative stress, the observed changes add some additional information to possible mechanism of endurance exercise related hemolysis”. It is regrettable that the authors [64] did not conduct a parallel rheological observation in these individuals.

One of the first studies on the effects of regular physical activity on the rheological properties of blood was the research conducted by Ernst [65]. It was carried using blood samples from 14 individuals who trained intensively, compared to 12 sedentary male controls. The author studied plasma viscosity and changes in red blood cell shape – precisely, their degree of deformability. For the training individuals, plasma viscosity reduction and improvement in rbc deformability were found. The sedentary group subjected to 3 months of training showed a similar rheological response to the group of athletes. The author puts forward three (quite practical) conclusions: 1 – “better than normal” blood rheology in athletes may contribute to enhanced blood flow in the working musculature which increases work output, 2 – the data supports the theory of a link between blood rheology and artheriogenesis, 3 – regular exercise might be a way of therapeutically increasing blood flow in ischemic vascular diseases.

Benhaddad et al. [66] investigated the rheological properties of blood in 36 men playing football, volleyball and doing karate, in the age group 17-33. Athletes were subject to homogeneous training – submaximal exercise pression on a cycloergometer for over 25 min. In addition to testing the flexibility of rbc and their aggregation, many other biochemical markers of the blood were assessed. The work is devoted to the effects of over-training, which adversely alter a number of indicators of blood. As a result of research, after bringing (in vitro) the hematocrit to a stable value of 45%, a slight increase in plasma was found – viscosity in the range of hundredths of the normal value, decrease in elongation index, while an increase in rbc aggregation was noted. According to the authors’ conclusion: “Nevertheless, experimental studies suggest that even moderate rise in plasma viscosity may induce a linear increase of rbc resistance to flow”. The authors, citing other authors, state a significant reduction in ferritin – as well known, a basic protein, a medium for iron transport from the liver to the bone marrow, which is necessary for the erythrocyte synthesis of hemoglobin. A similar argument is confirmed by the study of Hunding et al. [67].

The authors believe that the rheological changes in rbc, their aggregation and plasma viscosity in overtraining individuals are modifiable – observing that they return to normal during a break after a period of intense exercise.
This was one of the first studies [68] on the deformability of rbc using tank tread-like motion involving the rotation of a rbc suspension (the idea was close to the structure of modern rheological laser devices), in which Heinz body was experimentally induced — allowing to track the behaviour of these cells inside cytosol, with simultaneous marking of latex particles as external membrane markers. The authors of this study draw an important conclusion from their research — during rbc deformation at the shear rate of ~ 500 sec⁻¹, with unchanged volume, cytocols move and change their shape (“to whetstoneidal forms”), without loss from the cytosol cell interior. This first rheological rbc experiment, ex vivo, pointed to the considerable flexibility of the rbc membrane.

The most recent studies conducted by researchers from the University of Montpellier [69] regarding the highlighted problem are worth noticing. For the verification of studies from the view of exercise training of blood rheology, the results of the review of literature using the meta-analysis method were given.

In other studies of athletes, careful attention was paid to electrolyte disturbances very often occurring after intense exercise (dehydration, increased loss while sweating), leading to an increase in hematocrit values, thereby increasing blood viscosity and consequently causing disorders in rbc cytosol composition, impairing their rheological properties [70-75, 65].

Particular attention is paid to explaining the issues of shear stress and nitric oxide (NO) in blood viscosity changes, and above all, its transportation in the blood vessels during physical exercise [76-83].

Intriguing and also difficult to explain is the fact that, in our research, the greatest deviation of RBC deformability occurred at low shear stress (0.30-0.58 Pa). It can be assumed that at low stress, a faster change in shape occurs — in a sense, to improve rbc deformability, but of the ones that are “aged” (100-120 days), which are no longer present at a higher shear stress because they were destroyed. There may be many reasons for this phenomenon, but a irrefutable fact is impairment of the so-called Gárdos channel, in which destruction of rbc membrane proteins occurs with age, impairing the transmission of Ca²⁺ and K⁺, leading to the suite of all erythrocyte death called eryptosis [84]. It is known that the better the rbc deformability, the more efficient the blood flow through the vascular system, even in cases of elevated hematocrit levels. This fact is particularly true for the capillary system, so richly diffused in the muscles, which is simultaneously strictly connected to total blood viscosity reduction. Training, intensive sports exercise is are always accompanied by hemo-concentration and dehydration, but as confirmed by the studies of Eï-Sayd [85], when resting, during a mid-training break, a quick return to normal occurs. In addition, based on other works dating from 1950-2010, it has been shown that regular exercise reduces hematocrit, rbc, aggregation, fibrinogen level (f), and thus plasma viscosity [85].

Brun et al. [86] prove that an increase in lactate, exceeding the threshold of 4 mmol/L, affects the flexibility of rbc. Another factor adversely affecting the cells is the elevated value of free radicals (always to some extent accompanied by intense exercise), coming from mitochondria and leukocytes — mostly PMNG. The commonly known physiological pathway is activated in this process: intensive oxygen consumption, mainly by muscles → intensive pulmonary respiration → increase of free radicals → an MDA decrease occurs in rbc membranes, leading to the oxidation of lipids (the bulk composition of the rbc membrane) → rheological impairment of the cell properties. This state of impairment is deepened by loss of water.

Considering the relatively small changes in our research regarding El — elongation index and aggregation (terminology according to Baskurt and Meiseman) [87], the increasing resistance of penicilli which takes place during physical exercise may be taken into consideration, eliminating the “old” 110-120 day old rbc, and ipso facto, this effect with increased (on the way of exercise hypoxy) erythropoietin causes the ejection of a supernormative pool of “young” rbc from the bone marrow — more flexible, more able to transport O2-CO2, replacing these “old” rbc — already disintegrated at a low shear stress force. As long as 70 years ago, Quemada [88] and Dintenfass [89] defined the interdependent characteristics of blood viscosity (ηᵣ), based on physiological characteristics of plasma viscosity (ηᵢ), hematocrit (Ø) and structural parameters of rbc (k), mainly concerning their aggregability at low shear stress and their degree of flexibility at high shear stress. Many authors emphasize that during moderate exercise ηᵣ and Ø increase, while k does not undergo change (as we remember this was confirmed by Fisher et al. using a different method) [68], — rbcs are stable in terms of elongation index and aggregability — this fact is confirmed by our research as well — no significant rbc deformability took place after the marathon run. The increase in hematocrit Ø values is significant, but noticeably goes back to normal during resting state [90].

One direction of rheological blood tests accompanied by physical exertion (with different profiles of competitive sports) is associated with observation of the impact of nutrition, with special emphasis on the nutritional discipline involving carbohydrates, polyunsaturated fatty acid and proper hydration [91]. The dominant achievements of Prof. Brun and his school, over the years 2000–2013, are devoted to this issue. This type of study [92] is a kind of summary of the works of their school, emphasizing -
nutritional and metabolic determinants of blood rheology differ between trained and sedentary individuals!

Important reasons for any moderate activity are recommended by the school of Prof. Brun from Université Montpellier in France, highlighting “When sedentary subjects become obese – the most obvious characteristic is an increase in rbc aggregation correlated to the size of fat stores”. Brun states: “It is clear that 3 months of low intensity are not a perfect model of healthy ‘primitive style’”. According to Brun et al. (1998) [86], rheological blood tests must take account of the triphase effects of exercise on blood rheology: short, mid and long term. The authors, examining the blood rheological properties of these three periods, came to the conclusion that the most beneficial rheological changes for the system are the first and the second type of exercise.

The function of microrheological factors (erythrocyte aggregation and their deformability) in improving the endurance of athletes and their adaptive changes following physical exercise were discussed widely in the review works of Szyguly [93], Toth et al. [94], Mairbäurla [95], Baskurt et al. [96] and Connes et al. [36]. Their review allows for the assumption that there are still many unresolved problems related to blood rheology in athletes and its measure of positive and negative adaptive changes of the human body under the influence of physical exercise. Differences in test results may also be the outcome of applying different research methods, apparatus and, of course, different sports disciplines, thus varying degrees of physical exertion.

Summarizing the whole discussion based on world literature, the results of the effect of physical exercise, with particular focus on over-training in elite athletes, as well as hemorheologic fitness and taking the changes rbc aggregation and elongation into consideration, they may be divided into three ratings: effecting rheological properties, to a greater or lesser extent, with particular focus on over-training in elite athletes, as well as hemorheologic fitness and taking the changes rbc aggregation and elongation into consideration, they may be divided into three ratings: effecting rheological properties, to a greater or lesser extent, with particular emphasis on the decrease in elongation index [97-101, 91], an increase in viscosity [102]; no rheological changes – [103] and a significant increase in rbc deformability [104,105].

In light of analysis of the research acquis and knowledge of the needs of the sports practice, the highly urgent task of future works should be solving the issue of “the alleged anemia of sports”. The limited capacity of our study did not allow to examine the level of both haptoglobin and hemoglobin plasma, but in our further rheological research, these two indicators will be obligatorily implemented – proverbially “dotting the i” in solving the signalled issue (and subject of numerous debates), which is the professed “sports anemia”. This type of study cannot be conducted on homogeneous, so-called whole blood, but must include rbc distributed to a pool of older (80-120 day old) and younger rbc (1-80 day old). This type of fractional separation would bring us closer to solving the reasons for this anemia.

Summarizing the results of our own study on rheological blood indicators (considered as positive health indicators), the need to take individual susceptibility to long- and short-term training exercise into account for their interpretation should be emphasized. Such a problem is pointed out in the earlier characterized works by researchers of the Prof. Brun school [90]. Therefore, the search of regularities in development of the indicators of blood flow in the circulatory system under the influence of physical activity, may be discussion relying only on the results of statistical inference, which is characteristic for the currently dominant testing, i.e. nomothetic, and ignoring the idiographic approach (ipsative) on which the used case study method is based. Focus should not be placed on statistical data (populative), averaged on the basis of a large number of competitors, but on the individual data (noted for 1 competitor) and then used to e.g. track the rheological data during training session or competitions.

With the usage of this method, evaluated the individually generalized measurement results of rheological indicators in 10 marathoners compared to the reference (populative) standard were assessed and a reference point, which was the arithmetic mean of the group of physically inactive people was created. In such proceedings, in accordance with the ipsative approach, the adaptive result of long-term sport performance was evaluated – taking into account the level of rheological indicators before the marathon and the fatigue effect – considering the body’s response to stress induced by several hours of exercise to extreme fatigue after completing the race in a time of above 3 hours.

Our results confirmed the occurrence of adverse adaptive changes as a result of many years of marathon running in a part of the participants, as well as large adverse changes in fatigue following the continuous run lasting over 3 hours. Based on a review of rheological study results in ill people, existing knowledge on the physiological reactions occurring under the influence of long-term exercise and our own observations of posttraining and post-exercise changes in men running marathons over the age of 40, it should be assumed that long-term exercise in sports and participation in running marathons cause micro-traumas, which in some cases, may result intensification of undesirable involutional changes, especially in the cardiovascular system. Among the factors determining the occurrence of the specified events, in our study we noticed them to be less frequent in the study group with greater training experience or professionally performing sports in the past.

It follows, that study of blood rheology indicators has been found useful in confirming the possibility of unde-
sirable adaptive and post-exercise changes occurring in marathon runners. Rheological studies should be part of routine qualification for sports training and monitoring the training effects of older people engaged in amateur marathon running.

**Conclusions**

Based on the presented analysis of the findings of our study and the discussion, the following general conclusions may be formulated:

1. In the approach to researching the issue of adaptive changes in blood flow in the circulatory system due to many years of practicing amateur marathon running by older men, and as a result the body’s response to stress caused by a single, several-hour-long physical effort to complete exhaustion – methods of case study and an idiografical approach (causistic) to develop research results can be used with great success.

2. Long-term performance of endurance exercises during sports efforts and exercise loads in a marathon can cause micro-traumas in the body of amateur runners over the age of 40 and intensify undesirable involution changes, particularly in the circulatory system.

3. In the diagnosis of current and permanent adaptive effects in sporting activity, rheological methods of testing erythrocytes both in terms of elongation index and degree of aggregation proved to be useful, and should be routinely used in monitoring the adverse effects (which may appear in the distant future) of this exercise in older marathon runners, and during the performance of extreme exercise by individuals with pathological changes in the cardiovascular system or cardiac procedures, including leading to death.

4. In the light of the results of our own studies, it must be assumed that in older persons, the process of adverse adaptive changes in blood rheology indicators over the course of many years of practicing sport, as well as the level of stress caused by a single exercise to total exhaustion during a few-hour-long marathon, can be impacted by: training experience, sports level and state of physical health.

**References**


Rheological properties in marathon runners


Abstract

Study aim: The aim of the study was to examine the influence of systemic cryotherapy on the rheological properties of the blood.

Study material: The study groups consisted of 10 healthy males, aged 23-24 (23.4 +/- 0.52), who underwent systemic cryotherapy treatments (3 min treatment time, -120°C chamber temperature). In order to analyze the rheological parameters of the blood, venous blood samples were drawn from the study participants three times. The first analysis took place two months before cryotherapy, the second on the day of beginning treatments, and the third was performed after a series of 10 treatments.

Results: In the study group, the mean values of RBC and HCT following the series of 10 treatments were significantly higher after cryotherapy in comparison to the measurements taken two months before as well as on the day of beginning treatments. However, comparing the group two months before cryotherapy with the group on the day of its commencement, a decrease in HCT and MCV levels was found. Analyzing the mean concentrations of HGB, MCHC, MCH, MCV in the young males, statistically significant reduction after the series of 10 treatments was found compared to the values obtained two months before testing and on the day of beginning treatment. However, comparing the group two months before and on the day of beginning cryotherapy treatments, an increase in the MCHC index was found. The average values of WBC and PLT after a series of 10 treatments were higher compared with the values obtained two months before the study. Increased levels of WBC were found comparing the group two months before to the group on the day of beginning cryotherapy treatments. PLT values were higher after a series of 10 treatments compared with the values obtained on the day of beginning treatments. Analyzing the number of EI at shear stress from 0.30 to 59.97 [Pa], a decrease in SS1/2, EImax and SS1/2/EImax values was found before and after systemic cryotherapy treatment. The lower the values of SS1/2, EImax and SS1/2/EImax, the greater the deformability of erythrocytes.

Conclusions: Systemic cryotherapy does not cause any side effects in healthy young males and its regular usage positively affects the rheological properties of the blood.

Introduction

Systemic cryotherapy is used to induce physiological, organ and systemic defensive reactions, which are beneficial and effective in maintaining or restoring homeostasis of the human body [1]. This method is used to alleviate pain and inflammation in degenerative diseases as well as neurological and rheumatoid disorders. The recommended therapy consists of combining cold with exercise, which creates favourable conditions for the im-
The occurrence of erythrocyte deformability plays an important role in the flow of blood cells through the capillaries having a diameter up to two times smaller than the cells themselves. Normal erythrocytes are capable of deformation under stress primarily due to the fact that they have no nucleus, the cytoplasm has a relatively low viscosity, the cell membrane has advantageous visco-elastic properties, and their appropriate shape provides a high ratio of free surface to volume [6, 7]. Changes in the shape of the cell depend on the quality of the spectrin-actin network in conjunction with calcium ions and ATP [8, 9]. The reason for the decline of this capacity is mainly their age, mechanical damage and disease factors.

Changes in shape do not cause changes in volume or surface, and once transferred into larger vessels, the blood cell returns to its previous shape within a short period of time. This does not affect the structure or function of the erythrocyte [10]. The cells during the flow through the vessels may take various forms: twisted, folded in half, similar to a parachute or torpedo [11].

The rheological phenomenon is that even with a hematocrit higher than 80%, the blood remains fluid in contrast to the suspension of rigid molecules, which take the form of a solid consistency at a concentration of about 65%. This is caused by the liquidity of blood cells which can be treated as liquid droplets surrounded by a membrane [12, 13]. The phenomenon of spontaneous aggregation of red blood cells in whole blood, namely the formation of three dimensional erythrocyte structure, is a reversible physiological phenomenon that plays a significant role in blood flow at low shear rates and significantly affects the increase in blood viscosity [14, 15].

The aim of this study was to assess the effects of systemic cryotherapy on the rheological parameters of the blood in young healthy males.

**Study material and methods**

The study group consisted of 10 healthy males, aged 23–24 (23.4+/-0.52), who underwent systemic cryotherapy treatments. In order to analyze morphological and rheological parameters of the blood, venous blood samples were drawn from the participants of the study three times. The first study was held on 6th March, 2014 (two months before cryotherapy), the second on the day of beginning treatments on 5th May, 2014 and the third test was conducted after a series of 10 treatments on 19th May, 2014.

The parameters obtained in the cryo-chamber:
- aerial temperature: −60°C
- chamber temperature: −120°C

The time of a single treatment for the group of males was 1.5 min (1st treatment), 3 min (2–10th treatments). 3 ml of blood were drawn from the vein inside the elbow from the participants on an empty stomach in the morning, into EDTA tubes. Blood samples were drawn by a qualified nurse under medical supervision, in accordance with applicable standards of the Pathology of Locomotion Laboratory at the University School of Physical Education in Krakow, where rheological and morphological parameters of the blood were determined. The study was approved by the Bioethics Committee at the Regional Medical Chamber in Krakow.

**Determination of elongation index**

Erythrocyte deformability was tested using the LORCA analyzer (Laser-assisted Optical Rotational Cell Analyser RR Mechatronics, The Netherlands). The results were obtained as the index of elongation and aggregation according to the Hardeman method [16, 17]. Tests using the above apparatus were conducted within 30 minutes after blood collection, at 37 °C and according to standard protocol.

Blood for the determination of the elongation index was collected in an amount of 25µl to 5 ml 0.14 mM PVP (polyvinylpyrrolidone, M = 360,000, Sigma, viscosity at 37°C above 31mPa) and dissolved in phosphate buffered saline (PBS). The test sample was placed in a measuring chamber between two rotating concentric cylinders. The laser light passing through the thin layer of red blood cells suspended in PBS underwent deflection, giving a diffraction pattern on the projection screen. The diffraction pattern was recorded with a video camera and then transferred to a computer and is dependent on the value of shear stress acting on the blood cell during the rotation of the cylinder. However, as the tension rises, the shape of the diffraction pattern shifts from a circle to an ellipse with an increasing ratio of the long axis “a” to the short “b”. The index was calculated by:

\[
EI = \frac{a - b}{a + b}
\]
The results of the elongation index (EI) were given in the range of 0.30 to 59.97 of the shear stress measured in Pascals. The elongation index is a measure of the amount of deformation of red blood cells during their movement in the measuring chamber [16, 17].

**Determination of aggregation index**

Before the actual test, the blood sample was subjected to oxygenation by incubation and mixing with carbogen within 15 minutes of collection. Blood in the amount of 1.5 ml was put into the measuring chamber of the LORCA analyzer. The computer-controlled cylinder was rotated within 120 sec, and the shear stress was > 400 s⁻¹. After 10 seconds, rotation of the cylinder was stopped and aggregation of erythrocytes began, which was measured by change in the intensity of the laser beam passing through (backscattering), until the highest value was reached (between 0.5 and 2.0 s). From this time on (fragment between 2.0 sec and 1 min or longer), the device subjected the aggregates of the red blood cells to various rates of shear stress from 6 to 700 s⁻¹. The result of computer analysis is the curve presenting the relationship of the scattered light intensity with time (for a given shear rate), i.e. selectogram [24, 25].

The following parameters determining erythrocyte aggregation kinetics were assessed:
- Al [%] – aggregation index
  - A – area above selectogram curve
  - B – area below selectogram curve
  
  \[ Al = \frac{A}{A+B} \times 100\% \]

Also analyzed were:
- AMP [au] – total extent of aggregation
- T½ [s] – half time kinetics of aggregation

**Morphological blood test**

Measurements were taken using the ABX MICRO60 (USA) haematology analyzer. The study used 10 ml of whole blood drawn into K3EDTA.

Determined parameters:
1. Red blood cell count – RBC [10⁹/L]
2. Hematocrit – Hct [L/L]
3. Haemoglobin – Hgb [g/L]
4. Mean corpuscular hemoglobin index – MCH [fmol]
5. Mean corpuscular volume index – MCV [fL]
6. Mean corpuscular hemoglobin concentration – MCHC [mmol/L]
7. White blood cell count – WBC [10⁹/L]
8. Platelet count: PLT [10⁹/L]

**Measurement of plasma viscosity**

After centrifugation of cellular blood components, the obtained 0.5 ml of plasma was put into the measurement capillary of the viscometer. The viscosity of the blood plasma was determined in the viscometer (type D-52159 Roetgen, Myrenne Co., Germany).

**Determination of plasma fibrinogen**

50 µl of plasma was used for the study. Determination was performed using the Bio-Ksel, Chrom – 7 camera.

**Statistical analysis**

Data was presented by the mean values and standard deviation (X ± SD). Normality of distribution was verified using the Shapiro-Wilk test. The differences between the resulting measurements were analyzed by one-dimensional analysis of variance (ANOVA) for systems with reproducible measurements. Sphericity was assessed using the Mauchly’s test. In the case that the sphericity assumption was not met, the multidimensional test was used (Wilks’ lambda). When the ANOVA parametric assumptions were not met, differences between the measurements were calculated using the Friedman ANOVA test. Appropriate post-hoc tests were applied to evaluate the differences between particular measurements.

SS_max and EI_max values were calculated by matching elongation curves with the Lineweaver-Burke model (1), using the non-linear matching algorithm in the GraphPad Prism 6.05 program (GraphPad Software Inc., La Jolla, CA). The method has been described in detail by Baskurt et al. [18, 19, 20]. The quality of matching the curves was evaluated by the R² coefficient of determination.

\[
\frac{1}{\text{EI}} = \frac{\text{SS}_{\text{SS}_2}}{\text{EI}_{\text{max}}} \times \frac{1}{\text{SS}} + \frac{1}{\text{EI}_{\text{max}}} \tag{1}
\]

In analyzes, the following level of significance \( \alpha = 0.005 \) was assumed. Analyses were performed using Statistica 10 (StatSoft®®, USA).

**Results**

The mean values of RBC and HCT after a series of 10 treatments were significantly higher following systemic cryotherapy in relation to the measurements taken two months before and on the day of beginning treatment. In contrast, comparing the group two months before the date of beginning the treatments, a decrease in the levels of HCT and MCV can be found (Tab. 1).
Analyzing the mean concentrations of HGB, MCHC, MCH, MCV in the young males, statistically significant reduction after the series of 10 treatments was found compared to the values obtained two months before testing and on the day of beginning treatment. However, comparing the group two months before and on the day of beginning cryotherapy treatments, an increase in the MCHC index was found (Tab. 1).

The average values of WBC and PLT after a series of ten treatments were higher compared with the values obtained 2 months before treatment. Elevated levels of WBC have been found when comparing the group two months before and on the day of beginning cryotherapy treatments. PLT values after a series of 10 treatments were higher than the values obtained on the day of starting treatment (Tab. 1).

**Fig. 1.** Comparison of EI values at shear stress from 0.30 to 59.97 Pa in people undergoing systemic cryotherapy before and after a series of treatments.

![Diagram of mean EI values for males before and after systemic cryotherapy](image)
Analyzing the number of El at shear stress from 0.30 to 59.97 [Pa], a decrease in $SS_{1/2}$, $E_{Imax}$ and $SS_{1/2}/E_{Imax}$ values was found before and after systemic cryotherapy (Tab. 2, Fig. 1). The lower the $SS_{1/2}$, $E_{Imax}$ and $SS_{1/2}/E_{Imax}$ values, the greater the deformability of erythrocytes.

Considering the values of AI [%] in males before and after systemic cryotherapy, no statistically significant differences were found. In the study group, after a series of 10 treatments, reduced values of AI [%] were noted in the males following cryotherapy in relation to the measurements taken on the first day of treatments (Tab. 1).

There were no statistically significant differences in values of $T^{1/2}$ [s], AMP [au], blood plasma viscosity or fibrinogen in the males before or after systemic cryotherapy (Tab. 1).

## Discussion

The research presented in this paper is intended to show changes in the rheological properties of blood in young healthy males who underwent a series of 10 systemic cryotherapy treatments at –120°C.

A review of literature indicates a lack of detailed data on the effects of systemic cryotherapy on rheological properties of the blood.

The results of the research carried out so far are difficult to interpret or compare because of differences in their research protocols. Łubkowska and Szygula (2010) showed that the number of cryotherapy sessions (3 min at –130°C) has significant impact on changes in morphological indices [21]. Moreover, it is very often the case that changes observed following cryotherapy are interpreted in relation to the results obtained after applying near 0°C temperature, such as immersion or bathing in cold water. Kępińska et al. (2013) described assessment of the impact of a single systemic cryotherapy treatment (3 min at 120°C) on morphological and rheological properties of the blood in healthy males. The study involved five healthy men (aged 20–25). To analyze the morphological and rheological properties of the blood, blood was drawn immediately prior to treatment, approx. 20 - 30 minutes and 24 hours after treatment. Morphological (RBC, Hb, Ht, MCHC) and rheological properties (elongation index (EI), aggregation index (AI)) were determined. The authors indicated that a single systemic cryotherapy treatment does not result in any statistically significant changes in the morphological or rheological properties of the blood in healthy individuals [22].

The aim of a different study by Kępinska et al. (2014) was to evaluate the effect of a series of cryotherapy treatments (3 min at 120°C) on the morphological and rheological properties of the blood in healthy males. This time, the study involved 10 healthy males, aged 22.1 ± 2.16. 24 cryotherapy treatments were performed (3 times a week, every other day). There was a statistically significant decrease in mean corpuscular haemoglobin concentration and an increase in the average size of the platelets. Again, however, there were no statistically significant changes in the rheological properties of the blood [23].

After a few days of stimulation by cryogenic temperatures, an increase in the level of haemoglobin, platelet count and creatinine concentration as well as severity of glycaemia was observed [24, 25]. Some reports indicate a decrease in erythrocytes [26, 27, 28, 29, 30] and an increase in leukocyte number [21, 31], while others declare no change in the number of erythrocytes and/or white blood cells, most likely due to the low number of sessions [24, 26, 28, 29, 32]. A decrease in leukocytes and erythrocytes in healthy individuals after a series of treatments was observed by Blatteis (1998) [33]. However, Banfi, et al. (2008) showed a decrease in haemoglobin concentration with a simultaneous increase in the average mass of the haemoglobin molecule and the mean haemoglobin concentration in the erythrocyte after completion of treatments (30 seconds at 60°C and 2 min at –110°C) [26].

On the basis of our own research, we found that after a series of 10 treatments, the mean values of erythrocytes, hematocrit and platelet count, were significantly higher compared to measurements taken two months before and on the day of beginning the cryotherapy treatment. However, a significant decrease between these groups was found in the following blood morphology indicators: haemoglobin, MCHC, MCH and MCV. Based on these studies, it can be concluded that systemic cryotherapy is a powerful stimulus and inducement of...
the earlier mentioned symptoms can be explained as acclimatization to the prevailing conditions.

The 2-month gap in systemic therapy application affected the following changes in the studied morphological indicators; there was an increase in leukocytes and MCHC, and a decrease in MCV and hematocrit. We know that hematocrit may undergo a change of 6–8% depending on the state of the organism’s hydration. In the research, HCT decreased by 3.7%, which is a small difference between with the values obtained two months before testing and on the starting date of treatment.

On the basis of the study, an increase in red blood cell deformability at 0.30 Pa and 0.58 Pa shear stress could be observed before and after systemic cryotherapy treatment. The lower the SS1/2, EImax i SS1/2/EImax values, the greater the deformability of erythrocytes. Statistically low values indicate a high deformability of erythrocytes, both before and after systemic cryotherapy, with a decrease in the index of aggregation. However, no significant changes in the level of half time kinetics of aggregation (T½), the total extent of aggregation (AMP), the viscosity of the blood plasma or fibrinogen were noted. The usage of systemic cryotherapy acts as a stimulus by activating the adaptive changes in the deformability of erythrocytes in a constricted blood vessel.

This form of treatment leads to increased constriction of the spleen and ejection of the erythrocytes stored in it into the bloodstream, resulting in differences in their deformability. Each day, 200-250 billion erythrocytes decompose under physiological conditions, and systemic cryostimulation probably forces a faster breakdown of red blood cells. This phenomenon requires further study.

Also observed was also a significant increase in EI values at 1.13 [Pa] shear stress which proves that regular immersion in cold water has an effect on the increase in erythrocyte deformability in a constricted vascular system. In our study, even though “a different kind of cold” was applied, the same relationship could be observed [34]. In subsequent studies, in order to confirm earlier reports, Teległów et al. (2014) compared a group of winter swimmers with a group undergoing systemic cryotherapy. Nonetheless, the authors found that these interventions had no effect on the parameters of aggregation [35].

As suspected, the conducted studies showed changes in the rheological properties of the blood in young healthy males undergoing systemic cryotherapy. However, these studies require expansion to become acquainted with the body’s response under these conditions.

References


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Tables: 2
Figures: 1
References: 35

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ANALYSIS OF MUSCLE STRENGTH USING A DYNAMOMETER IN WOMEN’S PROFESSIONAL CYCLING TEAM

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¹ Academic Laboratory of Movement and Human Physical Performance “DynamoLab”, Medical University of Łódź, Poland

Key words: dynamometry, objective movement analysis, cycling, muscle strength

Abstract

Purpose: There is a need for objective movement analysis in professional sport. The aim of the work was to perform a dynamometric analysis in order to determine the muscular strength of a female professional cycling team.

Basic procedures: The material comprised five female athletes from the TKK Pacific professional cycling team. A Primus RS dynamometer was used to measure isometric muscle strength before and after a maximal exercise stress test performed using Ultima PFX CardiO2 system and 12-channel wireless Mortara ECG. During dynamometry, isometric examination was performed of the flexion and extension of the right and left knee joint muscles, as well as right and left hip joint muscles. Statistical analysis was performed using Microsoft Excel 2010 and Statistica v.10. p = 0.05 was accepted as the level of statistical significance.

Main findings: No significant differences in muscle strength were found between the analyses performed before and after the strength tests. However, decreases or increases in muscle strength were confirmed in individual athletes, and advice was given regarding changes in training. Strength imbalances related to the antagonistic muscles of the lower limbs were observed in the case of three athletes.

Conclusion: The objective analysis of muscle strength, as well as the provision of individual examination protocols and interpretation of the results may personalize the training process and reduce the risk of overloads on the musculoskeletal system.

Introduction

In professional sport, there is a need to perform objective movement analysis in order to decrease the risk of musculoskeletal overloads. One such group of athletes is represented by professional cyclists, who are particularly vulnerable to overloads in the lumbar spine and lower limbs, with particular emphasis on the knee joint [1].

A method of decreasing the risk of injury related to overloads is motion analysis. One aspect of this analysis is evaluation of muscle strength, which can be objectively performed using a dynamometer. Various methods can be used to perform dynamometric examination of the lower extremities [2, 3, 4]. Specifically, the dynamometer used in DynamoLab, and hence in this study, is the Primus RS (BTE Technologies, USA), which enables the assessment and training of muscle strength during isometric, isotonic and isokinetic work. Previous studies state that strength and muscle fatigue after exercise, as well as muscle balance disorders in people practicing cycling can be assessed isometrically [5, 6].

The aim of the study was to conduct dynamometric analysis in order to determine the muscular strength of a female professional cycling team.
Material and methods
The study group comprised five athletes of the TKK Pacific professional cycling team. The mean age of the group was 25 ± 5 years and mean BMI 20.5 ± 0.7 kg/m². BMI for all athletes was within normal limits. Muscle strength in isometric work was evaluated with a Primus RS dynamometer. Dynamometry was performed twice, once before and once after the maximum exercise test to identify changes in muscle strength caused by fatigue. The dynamometry and the exercise test were performed in the Academic Laboratory of Movement and Human Physical Performance, “DynamoLab”, of the Medical University of Łódź. The specific exercise test protocol was carried out using the CardiO2 Ultima PFX system (MedGraphics, USA), Excalibur Sport ergometer (Lode B.V., Netherlands) and wireless 12 channel Mortara ECG (Mortara Instrument, Inc., USA). During dynamometry, the following isometric contractions were studied: extension and flexion of the right and left knee and hip.

The individual results of particular athletes were studied and appropriate guidelines for training were provided. Preliminary statistical analysis was conducted with Microsoft Excel 2010 and Statistica v 10. The accepted level of significance was p = 0.05.

Results
Elements of descriptive statistics were used. The mean, median, minimum, maximum and standard deviation of the results are given in Tables 1–4.

<table>
<thead>
<tr>
<th>Table 1. Descriptive statistic values for isometric muscle contractions during extension in the knee joints before and after the exercise test (the force values are expressed in Newtons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extension of the knee joint</td>
</tr>
<tr>
<td>right lower limb – before exercise test</td>
</tr>
<tr>
<td>right lower limb – after exercise test</td>
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<tr>
<td>left lower limb – before exercise test</td>
</tr>
<tr>
<td>left lower limb – after exercise test</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2. Descriptive statistic values for isometric muscle contractions during flexion in the knee joints before and after the exercise test (the force values are expressed in Newtons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexion of the knee joint</td>
</tr>
<tr>
<td>right lower limb – before exercise test</td>
</tr>
<tr>
<td>right lower limb – after exercise test</td>
</tr>
<tr>
<td>left lower limb – before exercise test</td>
</tr>
<tr>
<td>left lower limb – after exercise test</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 3. Descriptive statistic values for isometric muscle contractions during flexion in the hip joints before and after the exercise test (values of force are expressed in Newtons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extension of the hip joint</td>
</tr>
<tr>
<td>right lower limb – before exercise test</td>
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<tr>
<td>right lower limb – after exercise test</td>
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<tr>
<td>left lower limb – before exercise test</td>
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<tr>
<td>left lower limb – after exercise test</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 4. Descriptive statistic values for isometric muscle contractions during extension in the hip joints before and after the exercise test (the force values are expressed in Newtons)</th>
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<tr>
<td>Flexion of the hip joint</td>
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<td>right lower limb – before exercise test</td>
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<td>left lower limb – before exercise test</td>
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<td>left lower limb – after exercise test</td>
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</tbody>
</table>
Analysis of muscle strength using a dynamometer in Women’s Professional Cycling Team

The mean change in muscle strength during the exercise test, expressed as the percentage change in strength after the test, was also analyzed (Fig. 1). A significant increase in muscle strength greater than 10% was observed only for flexion of the left hip joint (15.44%), while a significant decrease was found for right hip extension (–11.02%).

Distribution was analyzed using the Shapiro-Wilk Test of normality. The only abnormal distribution was found for isometric muscle contractions during flexion of the left hip before the exercise test.

Verification of statistical hypotheses was performed with parametric and nonparametric tests. The Student’s t-test was used for normally-distributed data, while the

Table 5. Individual results of athletes with regard to significant (>10% change) increases or decreases in muscle strength after the exercise test, as well as training recommendations.

<table>
<thead>
<tr>
<th>Athlete</th>
<th>Significant (&gt;10%) increase in strength after exercise test for the following movements:</th>
<th>Significant (&gt;10%) decrease in strength after exercise test for the following movements:</th>
<th>Recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>flexion of the left knee joint, flexion of both hip joints</td>
<td>extension the left knee joint</td>
<td>to emphasize the balance between flexion and extension of the left knee in strength training</td>
</tr>
<tr>
<td>2.</td>
<td></td>
<td>extension of the left knee, flexion of both knee joints</td>
<td>to emphasize flexion and extension of the knee joints in strength training</td>
</tr>
<tr>
<td>3.</td>
<td>extension of the right knee, flexion of the right knee</td>
<td></td>
<td>as a small decrease in strength was observed only for the flexion in the hips, no new recommendations in training were provided</td>
</tr>
<tr>
<td>4.</td>
<td>flexion of the right hip</td>
<td>flexion of both knee joints, extension of the right hip</td>
<td>to emphasize knee flexion and the balance between flexion and extension of the right hip joint in strength training</td>
</tr>
<tr>
<td>5.</td>
<td></td>
<td>extension of the left knee, flexion of both knee joints and both hip joints</td>
<td>to emphasize both knee and hip joint flexion in strength training</td>
</tr>
</tbody>
</table>
Wilcoxon signed-rank test was used for abnormally distributed data. Neither test revealed any differences between the measurements taken before and after the exercise test for any movement.

Each athlete was given a personal assessment based on individual results and anthropometric data. Appropriate recommendations for training were provided (Table 5).

Discussion

Although manual muscle tests are used to assess muscle strength, they have many limitations, and thus a more objective approach using dynamometers has been proposed [7]. Assessment of muscle strength in different types of muscle work is also important in cycling. This is confirmed by Bieuzen et al. [8] who indicate that the level of maximum force has influence on muscle activation during pedaling. The ability to trigger maximum force by the lower limbs depends on the number of repetitions per minute and the roles of the different muscles during pedaling.

Objective dynamometric assessment may decrease the risk of injuries related to overloads in athletes. In a study by De Bernardo et al. [9] based on a group of 51 professional cyclists, the average age of 25, similar to those used in the present study, only 8 demonstrated no injuries related to musculoskeletal system overload. Among the remaining cyclists, 68.5% of injuries involved the lower extremities. Muscle disorders can lead to overloads of the musculoskeletal system and in turn, to an increased risk of injury. Athletes examined in DynamoLab belonged to the same age group as those in the case study of De Bernardo et al. Therefore, taking into consideration the specificity of the sport, special attention should be paid to overloads of the lower limbs in cyclists.

On the basis of their individual dynamometric results, advice on strength training was required for all but one of the athletes examined in the preset study. This shows that changes in muscle strength after maximum exercise involved most of the athletes. Individual recommendations for strength training can have positive impact on decreasing the risk of overloads in individual athletes.

Strength training is an essential element of cycling training and thus, should be part of training programs. Peak power in cycling is dependent on the cross-section of the muscle, a value increased by strength training together with the strength of the lower limb [10, 11]. The result of strength training is believed to be an increase of the strength of type I muscle fibers, which can delay the fatigue process: activation of less efficient type II muscle fibers is delayed and endurance during exercise is increased [12]. The strength training introduced to cycling training improves not only capacity during exercise, but also factors which are capacity dependent. Oxygen consumption during moderate efforts is lower and, in the case of the professional cyclist, maximum torque during pedaling occurs earlier [13, 14].

McIntyre et al. [15] note that isometric strength of the quadriceps femoris muscle after cycling until the presence of fatigue was 10% lower than measured before exercise. However, Leveritt et al. [16] report no change in muscle strength for lower limb extension during 8- and 32-hour endurance exercises. In the present study, no statistically significant differences in muscle strength (in Newtons) were observed before and after exercise within the group. However, individual athletes did demonstrate the reserve or loss of muscle strength during the test, which may prove to be valuable in proposing changes in strength training. An imbalance was also observed in muscle strength of antagonistic muscle pairs in the lower limbs. These results reveal the need for further research based on kinesiological electromyography with the aim of normalizing muscle tone in athletes.

The relationship between muscle tension and the force generated by the lower limbs has been confirmed by Bieuzen et al. [8]. In a cross-sectional study of cyclists with a similar level of maximum oxygen consumption and peak power in aerobic efforts, reduced electromyographic activity was noted in athletes who generated greater maximum strength in the lower extremities during pedaling. This may contribute to delaying the processes related to muscle fatigue.

The imbalance in muscular strength demonstrated by particular athletes examined in the present study influenced the analysis of the percentage mean change in muscle strength in the group as a whole after the exercise test. Significant increases in muscle strength for left hip joint flexion and decreases in right hip joint extension were observed. The analysis of the dynamometry results herein demonstrate that in order to reduce the risk of overloads, it is important to introduce individual procedures and give special recommendations and not only take statistical results for the entire group into consideration.

Conclusions

On the basis of the examination and analysis of the results, the following conclusions have been drawn:

1. objective analysis of muscle strength using a dynamometer can help to individualize the training process;
2. in order to reduce the risk of overloads within the musculoskeletal system, it is essential to individualize the examination and interpretation of the results related to objective analyses of muscle strength.
References


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Figures: 1
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THE STRUCTURE OF DYNAMIC AND KINEMATIC LIMB MOTION IN A TAEKWON-DO EUROPEAN CHAMPION DURING TURNING KICKS

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Key words: Taekwon-Do, biomechanics of martial arts, strength tests, movement analysis

Abstract

Aim. The aim of this study was to identify the dynamic and kinematic factors influencing the movement of turning kicks on the basis of the obtained limb speed values, pressure on the ground and kick time.

Material and methods. The subject of our study was a 17-year-old athlete, weighing 75 kg, 179 cm tall, holder of the 1st Dan degree, winner of the European ITF Taekwon-Do championship. The study used the Italian BTS Spa Smart-D system for complex motion analysis.

Results. Indicators describing the structure of space-time movement markers placed on the foot and wrists of both arms were registered, thus defining their speed change as a function of time. The mean values of the parameters were used to determine the curve of velocity changes as a function of the relative length (performing kick) of the competitor’s lower limb. The mean maximum speed of the foot and arms was determined in this manner in regard to X, Y and Z axes, respectively, and also the kick time, maximum pressure of the supporting foot on the ground as well as the pressure force of the kicking foot during its take-off.

Conclusions. Kicking foot speed correlates with the sweeping movement of the arms (r = 0.64 for the right arm and r = 0.61 for the left). This may indicate that kinetics of the turning kick may depend on the correctness and dynamics of the arm sweep. The measurement results of the pressure force of the supporting foot on the ground show three characteristic peaks. The first is evident shortly after foot take-off and strongly correlates with the speed of the kicking foot (r = 0.91). The second appears at the time of obtaining maximum speed of the other foot and the third informs about returning to initial stance.

Introduction

A growing number of researchers have been in search of biomechanical identification of factors influencing the effectiveness of strike performance [1-6]. With this knowledge, we can increase the ability to learn and perform the fastest and most powerful strokes. This issue is particularly important in taekwon-do, in which the results are often determined by a single strike. In its Olympic version, taekwon-do has been exclusively narrowed down to only sportsmanship. However, in the traditional version, (International Taekwon-Do Federation) the fights consists of five competitions: sport sparring, traditional sparring, pattern, special techniques and power test [6].
Power test consist of breaking the largest number of boards as possible with five different strikes, which include two techniques of hand strikes and three kicks. One of these kicks is the turning kick (according to taekwon-do terminology: bandae dollyo chagi).

In literature we can find studies describing kicks after turning which consider how rotation affects their kinetics [7]. Changes in body segment angles, centre of mass and acceleration changes in momentum during turning kicks (dollyo chagi) are analyzed [8]. A description of the structure of the turning kicks performed during foot take-off can be found [9]. Side kicks performed after turning (dwit chagi) were also examined [10]. It is believed that turning kicks result in higher speed than kicks without turning. This was confirmed by other researchers [2, 11].

The aim of this study is kinetic identification of turning kick factors based on the obtained foot speeds, pressure on the ground and time of kicking. Assuming the existing criteria for biomechanical analysis of sports techniques [12], and in particular the measurement techniques used in taekwon-do [13], four phases of movement have been taken into account: initial stance (preparatory phase), foot take-off, leg extension, final stance. And here, the following research questions are put forward:
1. At what moment is foot speed the highest?
2. What kinetic factors influence kick kinetics?

The answers to these questions may contribute to a better, more efficient method of performing these types of strikes when breaking hard objects or self-defence.

**Study material and method**

The subject of our study was a 17-year-old athlete, weighing 75 kg, 179 cm tall, holder of the 1st Dan degree, winner of the European ITF Taekwon-Do Championship.

In the study, the subject performed 6 turning kicks from the L-stance forearm guarding block position (according to taekwon-do terminology: niunja sogi palmok debi maki). In practice, such a manner of performing this kick is used in strength test competitions. The general diagram of movement phases performed by the subject is presented in Fig. 1.

The study used the Italian BTS Spa Smart-D system for complex motion analysis. It consisted of six cameras reflecting emitted infrared radiation, which read the position of markers placed on the competitor’s body in real time. This made it possible to register the picture of the body’s movement as well as evaluate the obtained kinetic parameters. The movements were recorded with an accuracy of 0.3-0.45 mm. The recording was made at a frequency of 120 Hz. For registration of the pressure on the ground, the Kistler 9812C piezoelectric platform was used.

Indicators describing the structure of space-time movement markers placed on the foot and on the wrists of both hands were registered, thus defining their speed change as a function of time. The mean values of the parameters were used to determine the curve of velocity changes as a function of the relative length (performing kick) for the competitor’s lower limb.

In this manner, the mean maximum speed of the foot and arms was determined with respect to the X, Y and Z axes, respectively. Further determined were kick time and supporting foot maximum pressure on the ground as well as the pressure force of the kicking foot during take-off.

Based on the obtained data, the mean values and standard deviations were calculated. All calculations were performed using MS Excel.

**Results**

![Fig. 1. Subsequent phases of turning kick movement (bandae dollyo chagi) – side view](image-url)
Initial stance: The competitor stands in the L-stance forearm guarding block position (according to taekwon-do terminology: niunja sogi palmok debi maki) with the right leg in front. Consistent with the rules of taekwon-do [14], in this stance, 70% of body weight should be placed on the back foot, and 30% on the front. Both feet should be slightly turned inward, and the toes of the front foot should be aligned with the heel of the foot in the back. Both knees are slightly bent. The term “initial stance” encompasses information on the starting location of the test and stance.

Foot take-off: The competitor shifts his body weight to the front foot. In order to perform rotation with the back, he turns the trunk with his hands contrary to the in-

Fig. 2. Subsequent phases of turning kick movement (bandae dollyo chagi) – front view

Fig. 3. Change in foot speed during the execution of turning kick in % function of foot position
tended movement. And then, dynamically un-twisting his body, he slightly raises his arms, opening them widely. The inertia of the upper body helps with foot take-off. Arms give the body additional rotation and performing the sweep, they pull the rebounding leg behind them.

**Leg extension:** With the completion of foot take-off, the phase of leg extension begins. The force of the foot take-off and inertia lifts the foot upwards. The foot reaches its maximum height. During movement, the knee-joint is almost extended.

**Leg fall:** After reaching the highest point, the foot reduces height to return to initial stance. The body performs a full turn. The competitor balances the body so as to keep control.

**Final stance:** After performing a 360 degree turn, the competitor returns to the initial stance.

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**Fig. 4.** Change in foot speed during the execution of turning kick in % function of foot position.

**Fig. 5.** Change in right (supporting) foot pressure during turning kick. 1. Moment directly following left foot take-off. 2. Moment of attaining maximum speed. 3. Final stance.
The structure of dynamic and kinematic limb motion in a taekwon-Do European champion...

**Table 1. Chosen kinetic parameters of bandae dollyo chagi kick**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Average</th>
<th>SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum foot speed (m/s) OX</td>
<td>10.79</td>
<td>0.46</td>
<td>10.03–11.38</td>
</tr>
<tr>
<td>Foot take-off speed (m/s) OY</td>
<td>8.22</td>
<td>0.33</td>
<td>7.83–8.76</td>
</tr>
<tr>
<td>Speed of foot approach (m/s) OZ</td>
<td>7.81</td>
<td>0.67</td>
<td>6.90–9.09</td>
</tr>
<tr>
<td>Right hand speed (m/s)</td>
<td>8.41</td>
<td>0.92</td>
<td>6.87–9.39</td>
</tr>
<tr>
<td>Left hand speed (m/s)</td>
<td>8.95</td>
<td>0.28</td>
<td>8.68–9.40</td>
</tr>
<tr>
<td>Kick time (s)</td>
<td>1.01</td>
<td>0.11</td>
<td>0.81–1.17</td>
</tr>
<tr>
<td>Force of ground reaction of supporting leg</td>
<td>997.9</td>
<td>58.1</td>
<td>954.7–1064.0</td>
</tr>
<tr>
<td>during take-off phase [N]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Force of ground reaction of supporting leg</td>
<td>925.8</td>
<td>100.4</td>
<td>813.5–1007.0</td>
</tr>
<tr>
<td>during kicking phase [N]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Take-off force of kicking leg [N]</td>
<td>525.4</td>
<td>256.8</td>
<td>364.7–821.5</td>
</tr>
</tbody>
</table>

**Discussion**

It is difficult to compare the results with other studies because there is no literature containing measurement results for turning kicks (bandae dollyo chagi). The described kicks used in special techniques competitions [9] which are similar in structure (performed with a jump) give the competitor a different goal – to achieve the maximum height of the broken board, and not as in this case, to break the maximum number of boards. This is manifested in different structure and movement indicators. Kicks executed after turning tend to achieve higher kinematic values. Speed of the side kick after turning (dwit-chagi) is between 6.71-9.14 m/s [11]. Side kick (without turn) achieved a speed of 5.20-6.87 m/s. Thus, the addition of turning increased the foot speed by about 28%. The mean speed value of the turning kicks (bandae dollyo chagi) obtained in these studies amounted to 11.44 m/s. The same competitor obtained the speed of about 10.42 m/s for the reverse turning kick (dollyo chagi) [15]. In this case, the difference is smaller, equaling 8.8%.

Precise measurement of distance has impact on the dynamics of kicking [16-17]. In these studies, the highest speed was reached at an average leg length equal to 78% of the maximum value (Fig. 3, 4).

It was noticed that the speed of the kicking foot is correlated with the arm sweep movement (for right-arm r=0.64, for the left-arm r=0.61). It can be expected that the correct and dynamic sweep of the arms depends on the turning kick kinetics. The resulting measurements of pressure on the ground of the supporting foot show three characteristic peaks (Fig. 5). The first reveals itself immediately after foot take-off. This value correlates closely with the speed of the kicking foot (r=0.91). The second comes at the time of obtaining maximum speed of the other foot and the third maksium informing about returning to the initial stance.

On the basis of the conducted observations, it can be stated that the speed of the analyzed kick depends on the take-off force of the kicking foot and the sweep speed of both arms. Arm movement gives strong rotation to upper
body parts during the first phase, pulling the rebounding
leg with them. The greater the foot take-off foot force
and speed of both arms, the higher the kick speed. As
in other studies [17], in Fig. 6 it is graphically presented
how given kinetic factors affect the speed of the tested
bandae dollyo chagi.

This study is an introduction to more extensive re-
search on the subject. Only the comparison of individual
characteristics of movement mechanics of top taekwon-
do competitors may allow for the hypotheses matured
here to be verified. The results and considerations herein
presented constitute comparative material for other re-
searchers, and for the author, a starting point for further
research. Additional studies are required to determine the
impact of movement on the arms and torso on achieved
speed as well as optimal distance. It would be worth
analysing taekwon-do kicks during a real fight, which
would allow to understand what variables of movement
affect the kicking effectiveness.

Nonetheless, I hope that introducing this informa-
tion will allow trainers and competitors conduct more
efficient research regarding turning kick (bandae dollyo
chagi) performance enhancement.

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MOVEMENT ANALYSIS IN TANDEM TRACK CYCLISTS USING VIDEO ANALYSIS

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Key words: objective movement analysis, track cycling, video analysis

Summary

Purpose: Cycling is a sport in which the risk of overload and injuries is very high. The aim of this study is to perform movement analysis of tandem track cyclists using a video system.

Basic procedures: Male and female tandem track cyclists of the Polish national team were examined. To evaluate the position of the track cyclist during rest and track cycling, CONTEMPLAS video movement analysis system was used. Trunk, elbow, hip, knee and ankle angles were measured. Data analysis was performed using Microsoft Excel 2010 and Statistica v.10. The level of statistical significance was p = 0.05.

Main findings: Statistically significant differences with regard to the hip joint were observed between the position of the cyclist at rest and during track cycling. No significant differences regarding the trunk, elbow, knee or ankle joints of the cyclist were observed neither on the track nor on a cycle trainer.

Conclusion: Interpretation of the results obtained from the use of objective movement analysis contributes to the individualization of therapy and training.

Introduction

Cycling is a sport characterized by repetitive sub-maximal loading movement in which the risk of injuries and overload is very high. During one hour of training, an athlete can perform up to 5,000 pedal movements [1]. Injuries can be related to incorrect cycle fitting or equipment, improper cycling position or training. Several studies in athletes have demonstrated that the most common injury is connected with the knee joint [2, 3, 4, 5].

In order to understand the movement which is performed during cycling better, and to determine a standard method of description, one complete circular movement is divided into two phases. The first phase, the power phase, begins when the crank is in 12 o’clock position, at top dead center (TDC), and ends when the crank is in 6 o’clock position, at bottom dead center (BDC). During this phase, the cyclist transfers energy to move the cycle forward. The second phase, the recovery phase, encompasses movement from the 6 o’clock position of the crank, from BDC, to the 12 o’clock position of the crank, TDC [1, 6] (Fig. 1).

Motion analysis systems are commonly used in sport, since they represent an objective measurement tool. They have been used e.g. to correlate ball velocity during maximal instep soccer kicking in males [7], to evaluate the flight position in ski jumping [8] and to analyze weightlifters’ lower limb range of motion during squatting[9]. The aim of the present study is to perform a movement analysis of tandem track cyclists with a video-based system.
**Materials and methods**

The study group was composed of both male and female members of the national Polish tandem track cycling team. The mean age was 29 ± 2 years. BMI values of the subjects were within the normal limits. CONTEMPLAS video movement analysis system was used to evaluate the position of the cyclist along the sagittal plane on a trainer and during cycling on a track. Readings were taken at the BGZ indoor Arena velodrome, Pruszków (Poland). Angular changes of the upper limb, elbow, hip, knee and ankle joints were rated relative to the trunk. For the statistical analysis of the results, Microsoft Excel 2010 and Statistica v. 10 (Statsoft Polska) were used. The level of significance was regarded as alpha = 0.05.

**Results**

Elements of descriptive statistics were used. The mean, standard deviation, median, minimum and maximum values are given in Tables 1–4.

**Table 1.** Descriptive statistics of the tested parameters using the trainer with the crank at 6 o’clock position (BDC)

<table>
<thead>
<tr>
<th>Evaluated area</th>
<th>Mean [°]</th>
<th>SD [°]</th>
<th>Median [°]</th>
<th>Minimum [°]</th>
<th>Maximum [°]</th>
</tr>
</thead>
<tbody>
<tr>
<td>trunk vs. upper limb</td>
<td>71.00</td>
<td>4.50</td>
<td>71.60</td>
<td>65.00</td>
<td>75.80</td>
</tr>
<tr>
<td>elbow joint</td>
<td>15.08</td>
<td>10.37</td>
<td>13.30</td>
<td>4.40</td>
<td>29.30</td>
</tr>
<tr>
<td>hip joint</td>
<td>98.75</td>
<td>4.13</td>
<td>98.75</td>
<td>93.90</td>
<td>103.60</td>
</tr>
<tr>
<td>knee joint</td>
<td>145.70</td>
<td>1.25</td>
<td>145.55</td>
<td>144.40</td>
<td>147.30</td>
</tr>
<tr>
<td>ankle joint</td>
<td>109.73</td>
<td>13.03</td>
<td>107.70</td>
<td>97.80</td>
<td>125.70</td>
</tr>
</tbody>
</table>

**Table 2.** Descriptive statistics of the tested parameters using the trainer with the crank at 12 o’clock position (TDC)

<table>
<thead>
<tr>
<th>Evaluated area</th>
<th>Mean [°]</th>
<th>SD [°]</th>
<th>Median [°]</th>
<th>Minimum [°]</th>
<th>Maximum [°]</th>
</tr>
</thead>
<tbody>
<tr>
<td>trunk vs. upper limb</td>
<td>72.93</td>
<td>7.37</td>
<td>74.00</td>
<td>63.90</td>
<td>79.80</td>
</tr>
<tr>
<td>elbow joint</td>
<td>14.88</td>
<td>11.88</td>
<td>14.05</td>
<td>1.20</td>
<td>30.20</td>
</tr>
<tr>
<td>hip joint</td>
<td>53.13</td>
<td>8.19</td>
<td>52.35</td>
<td>45.30</td>
<td>62.50</td>
</tr>
<tr>
<td>knee joint</td>
<td>67.58</td>
<td>3.28</td>
<td>68.55</td>
<td>62.90</td>
<td>70.30</td>
</tr>
<tr>
<td>ankle joint</td>
<td>85.48</td>
<td>13.93</td>
<td>86.15</td>
<td>68.30</td>
<td>101.30</td>
</tr>
</tbody>
</table>
The Shapiro-Wilk test of normality was used to analyze the distribution. As the distribution of all evaluated parameters was found to be normal, the parametric Student’s t-test was performed to verify the statistical hypothesis. The results of the Student’s t-test are given in Tables 5–6. Statistically significant differences were observed between the position of the cyclist during rest and track cycling with regard to the position of the hip joint. In both cases, the hip joint angle was smaller on the trainer than the track both at TDC and BDC.

Following data analysis, the cyclists were given individual recommendations related to their bike position. The bike fitting guidance are given in Table 7.

Table 3. Descriptive statistics of the tested parameters while cycling on the track with the crank at the 6 o’clock position (BDC)

<table>
<thead>
<tr>
<th>Evaluated area</th>
<th>Mean [°]</th>
<th>SD [°]</th>
<th>Median [°]</th>
<th>Minimum [°]</th>
<th>Maximum [°]</th>
</tr>
</thead>
<tbody>
<tr>
<td>trunk vs. upper limb</td>
<td>69.90</td>
<td>5.87</td>
<td>71.15</td>
<td>61.90</td>
<td>75.40</td>
</tr>
<tr>
<td>elbow joint</td>
<td>5.33</td>
<td>3.61</td>
<td>4.40</td>
<td>2.10</td>
<td>10.40</td>
</tr>
<tr>
<td>hip joint</td>
<td>105.43</td>
<td>2.79</td>
<td>105.85</td>
<td>101.70</td>
<td>108.30</td>
</tr>
<tr>
<td>knee joint</td>
<td>146.18</td>
<td>4.51</td>
<td>146.80</td>
<td>140.60</td>
<td>150.50</td>
</tr>
<tr>
<td>ankle joint</td>
<td>108.15</td>
<td>3.89</td>
<td>107.15</td>
<td>104.70</td>
<td>113.60</td>
</tr>
</tbody>
</table>

Table 4. Descriptive statistics of the tested parameters while cycling on the track with the crank at 12 o’clock position (TDC)

<table>
<thead>
<tr>
<th>Evaluated area</th>
<th>Mean [°]</th>
<th>SD [°]</th>
<th>Median [°]</th>
<th>Minimum [°]</th>
<th>Maximum [°]</th>
</tr>
</thead>
<tbody>
<tr>
<td>trunk vs. upper limb</td>
<td>68.50</td>
<td>7.15</td>
<td>68.00</td>
<td>60.70</td>
<td>77.30</td>
</tr>
<tr>
<td>elbow joint</td>
<td>11.08</td>
<td>4.84</td>
<td>11.70</td>
<td>4.60</td>
<td>16.30</td>
</tr>
<tr>
<td>hip joint</td>
<td>60.28</td>
<td>5.70</td>
<td>59.15</td>
<td>54.70</td>
<td>68.10</td>
</tr>
<tr>
<td>knee joint</td>
<td>69.23</td>
<td>4.84</td>
<td>70.75</td>
<td>62.20</td>
<td>73.20</td>
</tr>
<tr>
<td>ankle joint</td>
<td>82.75</td>
<td>6.20</td>
<td>81.30</td>
<td>76.90</td>
<td>91.50</td>
</tr>
</tbody>
</table>

Table 5. Results of the Student’s t-test for evaluated parameters using the trainer and during cycling on the track with the crank at 6 o’clock position (BDC)

<table>
<thead>
<tr>
<th>Evaluated parameter</th>
<th>Mean [°]</th>
<th>SD [°]</th>
<th>Differences [°]</th>
<th>SD of difference [°]</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>trainer – trunk vs. upper limb</td>
<td>71.00</td>
<td>4.50</td>
<td>1.10</td>
<td>5.66</td>
<td>0.3883</td>
<td>0.7236</td>
</tr>
<tr>
<td>track – trunk vs. upper limb</td>
<td>69.90</td>
<td>5.87</td>
<td>68.00</td>
<td>60.70</td>
<td>2.60976</td>
<td>0.07970</td>
</tr>
<tr>
<td>trainer – elbow joint</td>
<td>5.33</td>
<td>3.61</td>
<td>9.75</td>
<td>7.47</td>
<td>2.60976</td>
<td>0.07970</td>
</tr>
<tr>
<td>track – elbow joint</td>
<td>98.75</td>
<td>4.13</td>
<td>59.15</td>
<td>54.70</td>
<td>0.00303</td>
<td>0.00303</td>
</tr>
<tr>
<td>trainer – hip joint</td>
<td>105.43</td>
<td>2.79</td>
<td>–6.68</td>
<td>1.51</td>
<td>–3.86233</td>
<td>0.04073</td>
</tr>
<tr>
<td>track – hip joint</td>
<td>145.70</td>
<td>1.25</td>
<td>–7.15</td>
<td>4.14</td>
<td>–0.48437</td>
<td>0.66129</td>
</tr>
<tr>
<td>trainer – knee joint</td>
<td>146.18</td>
<td>4.51</td>
<td>–0.47</td>
<td>4.50</td>
<td>0.30617</td>
<td>0.77949</td>
</tr>
<tr>
<td>track – knee joint</td>
<td>109.73</td>
<td>13.03</td>
<td>1.58</td>
<td>10.29</td>
<td>0.33498</td>
<td>0.75969</td>
</tr>
<tr>
<td>trainer – ankle joint</td>
<td>108.15</td>
<td>3.89</td>
<td>10.29</td>
<td>8.27</td>
<td>0.33498</td>
<td>0.75969</td>
</tr>
</tbody>
</table>

Table 6. Results of the Student’s t-test for evaluated parameters using the trainer and during cycling on the track with the crank at 12 o’clock position (TDC)

<table>
<thead>
<tr>
<th>Evaluated parameter</th>
<th>Mean [°]</th>
<th>SD [°]</th>
<th>Differences [°]</th>
<th>SD of difference [°]</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>trainer – trunk vs. upper limb</td>
<td>72.93</td>
<td>7.37</td>
<td>4.43</td>
<td>4.82</td>
<td>1.83649</td>
<td>0.16361</td>
</tr>
<tr>
<td>track – trunk vs. upper limb</td>
<td>68.50</td>
<td>7.15</td>
<td>4.84</td>
<td>7.26</td>
<td>1.04704</td>
<td>0.37201</td>
</tr>
<tr>
<td>trainer – elbow joint</td>
<td>14.88</td>
<td>11.88</td>
<td>11.08</td>
<td>7.26</td>
<td>3.45709</td>
<td>0.04073</td>
</tr>
<tr>
<td>track – elbow joint</td>
<td>11.08</td>
<td>4.84</td>
<td>53.13</td>
<td>8.19</td>
<td>0.48437</td>
<td>0.66129</td>
</tr>
<tr>
<td>trainer – hip joint</td>
<td>60.28</td>
<td>5.70</td>
<td>67.58</td>
<td>3.28</td>
<td>0.33498</td>
<td>0.75969</td>
</tr>
<tr>
<td>track – hip joint</td>
<td>67.58</td>
<td>3.28</td>
<td>67.58</td>
<td>3.28</td>
<td>0.33498</td>
<td>0.75969</td>
</tr>
<tr>
<td>trainer – knee joint</td>
<td>69.23</td>
<td>4.84</td>
<td>69.23</td>
<td>6.81</td>
<td>-0.48437</td>
<td>0.66129</td>
</tr>
<tr>
<td>track – knee joint</td>
<td>85.48</td>
<td>13.93</td>
<td>85.48</td>
<td>16.27</td>
<td>0.33498</td>
<td>0.75969</td>
</tr>
</tbody>
</table>
Discussion

Both 2-D and 3-D motion capture systems have become very popular in recent years as a tool for evaluating the limitations of patients and athletes, both inside and outside the laboratory [10]. Kinematic analysis is regarded as an important approach to understanding joint movement changes and adaptation to the fatiguing process during cycling [11, 12].

Although cycle fitters emphasize the role of proper position of the cyclist, it is difficult to define a single formula regarding bike position that would be appropriate for all cyclists. Numerous studies on the biomechanics of cycling reveal many different bike fitting recommendations related to the configuration of the cycle and the cyclist [13, 14]. Fonda et al. [15] suggest that seat height is the most important parameter to be taken into consideration during bike fitting. Correct saddle height enhances muscle work in the longitudinal plane; when the position is too low, excessive flexion of the knee occurs, leading to patellofemoral joint injuries and knee extensor overload. If the position is too high, hamstring tendon problems can occur, together with an increased risk of iliotibial band syndrome: the second most frequent knee injury experienced by cyclists [1, 6]. Dinsdale [16] reports the best saddle position to be between 25° and 35° of knee flexion in the BDC phase. A knee angle closer to 25° is optimum for anaerobic power output and aerobic economy.

The knee joint angle increases from 75°–85° at TDC to 145°–155° at BDC [1]. Burke [14] states that the normative knee joint angle at BDC is 150°, according to the Howard method, and ranges from 145°–150° according to the Pruitt method. In the present study, one out of the four athletes required knee position correction on the trainer in the BDC phase and two cyclists needed knee position correction at the track in the BDC phase. For maximum pedaling efficiency, foot forces should be directed perpendicular to the crank. The ankle angle should be 20° plantar – flexed at 5 o’clock, and approximately 10° dorsiflexed from about 11 o’clock through to 2 o’clock [16]. The findings of the present study indicate that ankle position correction is required for three of the four cyclists on the trainer and in all athletes during cycling at the track.

In literature, it is recommended that cyclists maintain a proper position on the bike and employ efficient techniques for optimal performance. Bini et al. [17] show that the hip extension is greater than normal at high performance, and ankle dorsiflexion is prominent during the latter stages of an fatigue test. At the same time, the force exerted on the pedals does not change. Most likely, this type of change leads to better maintenance of work output during fatigue. It has also been noted that the dorsal flexion range of movement is increased, the ankle plantar flexors are enabled and the force production is increased as the cyclist fatigues [18, 19].

Umberger et al. [20] report that cycling is predominantly a sagittal plane activity and no differences exist between 2-D or 3-D analysis with regard to knee and ankle joint measurements. The 3-D approach to cycling analysis may be needed only to calculate ankle inversion and eversion. Both Sayers et al. [21] and Umberger et al. [20] demonstrate that the high level of sagittal plane movement consistency presented by the cyclist is typical of the sport and would contribute to joint overload. They note a significantly reduced consistency in the axial orientation of the tibia, as well as great variability in transversal plain movement in the knee joint, which may represent a stabilizing mechanism in the joint during fatigue in frontal and transverse plain movements. Hence,
there is considerable non-sagittal plane movement variability during the drive phase.

Although Gregersen et al. confirm that cyclist movement analysis in the sagittal plane has an important role, they also propose evaluating the movement patterns from the frontal and transverse planes [22]. They observe that the loads responsible for lower limb overload and injuries are the non–driving moments of the knee: varus or valgus knee and internal or external knee rotation. Additionally, proper frontal knee movement analysis can help predict patello–femoral pain.

Conclusions

1. The video motion capture system gives additional and objective information about the position of the cyclist during cycling.
2. The video motion capture system can determine the risk of injuries with a better accuracy.
3. The video motion capture system is a valuable tool to correctly fit the cycle to the cyclist.
4. Video movement analysis contributes to the individualization of therapy and training.

References

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