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MOBILE DEVICE FOR BIOMECHANIC AND KINEMATIC ASSESSMENT OF HUMAN BODY

Bartosz Breninek[1], Kacper Gruszczyński[1], Bartłomiej Lubiatowski[1], Mariusz Nowak[2*]

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Abstract:
The article describes the implementation of a measurement system for remote orthopedic diagnostics and plans for the development of a final version - a commercial one without many disadvantages in relation to existing solutions. As a result of research experiments and construction works, a prototype set capable of remote human orthopedic diagnostics was created. Data processing algorithms will ensure effective monitoring of performed exercises with accurate mapping of performed movements on a computer or mobile device in the form of a human avatar. Developed, specialized algorithms for proper data processing will ensure the minimization of energy consumption by system. The final effect of the construction, research and experimental works carried out will be a commercial version of the extended mobile device for remote orthopedic diagnostics and motor skills of the human body. The device being developed will be characterized by high accuracy and stability of operation.

Keywords:
Inertial Measurement Unit (IMU), motion, Mobile Diagnostics System, biomechanics

Introduction

Diseases of the musculoskeletal system are classified as civilization diseases and are today a serious problem all over the world. United Nations Organization's demographic forecasts predict that after 2030 people over 65 will account for more than 23% of the population in developed countries and over 10% in developing countries [1]. According to the estimates of the Department of Economic and Social Affairs, 80% of people over 65 appear to have locomotor system diseases related to osteoarthritis. Another group of people affected by musculoskeletal disorders are professional athletes and people practicing sports at an amateur level. In the diseases of the musculoskeletal system, proper rehabilitation therapy is very important. Rehabilitation of people with diagnosed degenerative diseases of the musculoskeletal system, after injuries and after surgery, is usually a long-term and costly process. A certain solution to these limitations is rehabilitation in the place of residence, if possible, carried out by the patient himself. However, such rehabilitation must be constantly monitored [2-9]. In this situation it is necessary to use the possibilities of

telemedicine, allowing for remote rehabilitation of the motor organs and the study of proprioception. To ensure the supervision of patient's rehabilitation in accordance with medical guidelines, in order to verify its correctness, it is necessary to use an appropriate IT system consisting of advanced sensors recording movement. Such a system should enable accurate measurement, mapping and visualization of the movement of the human body based on the measurement of non-gravitational acceleration, angular velocity and strength of the magnetic field direction. The collection of measurement data and the use of simple kinematics principles will allow to precisely calculate the orientation of the measuring sensor in three-dimensional space and thus to map the movement of the patient's limbs in real time. Based on the data sent through such a remote system, the physiotherapist could assess the quality of exercises performed and progress in rehabilitation.

Solutions in the IT industry supporting physiotherapists operate on the market. However, existing solutions have some limitations. These restrictions include, among others:

- they only provide information in the form of an error reproducing the given position of the joint (angle) in one plane of movement,
- they allow measuring only the difference between the set and reproduced angle - the result is defined as the error of active reproduction of the joint position (EARJP),
- the result is given only in the form of an absolute value, there is no underestimation or overestimation of the reconstructed angle of movement,
- there is no possibility of multifaceted examination, and thus the possibility of measuring not only position reproduction, but also the trajectory and quality of the performed task,
- the reference point is most often the direction of gravity, which does not allow the assessment of the quality of the movement (too little data needed to assess and determine the quality of movement),
- very often they offer only information regarding the difference in angular positions and the current angular position of a given joint in real time.

The answer to the growing need for professional research and diagnostics carried out by physiotherapists is an innovative device with a system of sensors enabling accurate measurement, mapping and displaying in the user interface of the movement of the human body, based on acceleration, card speed and earth's magnetic field. The authors of the study undertook to develop an IT system that would be free from restrictions existing in existing systems. In this IT system, the sensors will communicate wirelessly creating a portable "full body motion capture" set that will allow displaying the avatar of the human character on the computer screen. This system will allow simultaneous measurement of joint position sensation (reproduction of angular position of the joint), measurement of kinesthesia - sensation of movement in the joint and measurement of muscle tension sensation. The device will be able to make a multifaceted (3D) measurement of the movement of the whole body, 12 main joints and the spine in one test.

Materials and Methods

Detailed design assumptions

The definition of the implemented project assumed the design, construction, testing and marketing of a computer system, which will include a specialized set of human body motion sensors and a 3D graphic interface application. The system will be able to measure the power of the movement (activity), measure the amplitude of the movement - the ability to count the number of series and repetitions, and track the movement path, measure muscle work performed, jump height and flight time, measure motion speed and / or angular speeds, the rate of generation Force (Rate of Force Development), measuring time under load in a given repetition (Time Under Tension). All these features and device parameters will allow you to monitor, test and diagnose athletes and patients. The system IT for telemedicine is to be characterised by the least possible energy consumption, which should allow the mobile devices to work for a long time without having to recharge the battery. Achieving low energy consumption will be possible, among other things, thanks to the use of algorithms for snoozing selected blocks of the mobile information system.

Elements of the system and development works

Initially, the Hardware Development Kit was developed. Wireless communication was established in the low-energy standard without legal restrictions (ISM band) - Bluetooth Low Energy (BLE). Therefore, the nRF52-DK development board equipped with the nRF52832 microcontroller system with the Cortex-M4F core with 64 kB RAM and 512 kB Flash memory, Bluetooth Low Energy (BLE) and connectivity in the 2.4 GHz band was used. A set of sensors – a 3-axis accelerometer, a 3-axis gyroscope and a 3-axis magnetometer, integrated in a single chip – MPU-9250 9DoF was used for initial human body mobility experiments [10]. The selected set of sensors belongs to the IMU family - Inertial Measurement Unit. The prepared set of equipment – Hardware Development Kit - nRF 52832 DK and MPU-9250 sensors is presented in Fig. 1.

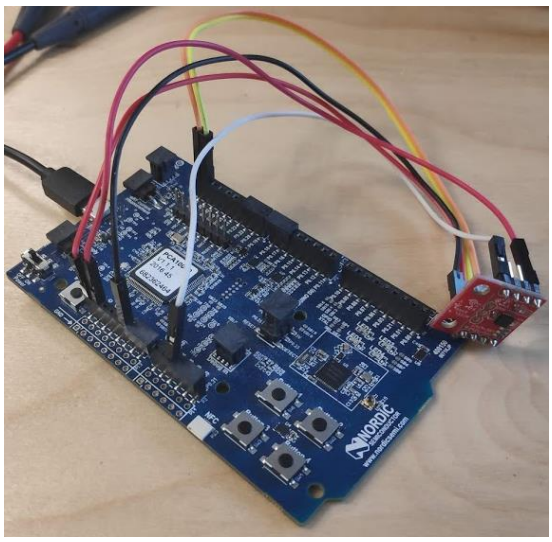

Fig. 1. Hardware Development Kit - nRF 52832 DK and MPU-9250 sensors
Source: own study

After hardware tests (measurements and communication), the development of target prototype sets began. The prototype set was made on a breadboards type plate (RSQ Motion Sensor, RSQ Motion HUB, RSQ Motion Sensor on DevKit), which allows for free configuration changes and verification of compatibility of selected components and the rightness of defined conceptual assumptions of the complete system of remote orthopedic diagnostics. Assembled measuring modules with batteries, ready for testing, is presented in Fig. 2.

Ultimately, sixteen (15 sensors – RSQ Motion Sensor Peripheral and reference point – RSQ Motion Hub Central) motion capture sensors will be combined into a coherent communication network that guarantees real-time data transmission. From the hardware side, wireless communication is implemented using the BMD-300 modules [11]. The BMD-300 module operates in the Bluetooth 5.0 Low Energy standard, has integrated analog and digital peripheral components and a DC-DC voltage converter with an advanced energy management system. The manufacturer of BMD-300 module dedicates it to applications in IoT and in wearable applications. In addition, the module has been equipped with an integrated, high-performance antenna.

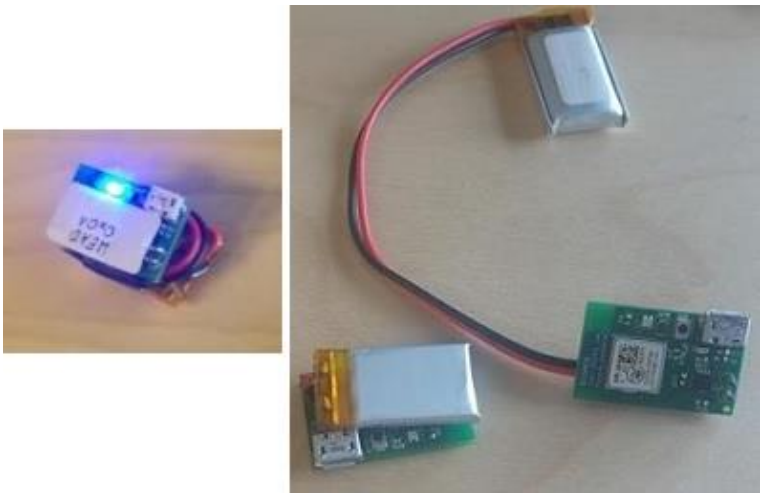

Fig. 2. Measuring modules with batteries
Source: own study

The concept of the PICONET network was chosen for the implementation of communication [12]. Presented assumptions of the designed wireless communication will ensure the low level of energy consumption by the designed mobile IT system for remote orthopedic diagnostics. The block diagram of the implemented measurement system solution is presented in Fig. 3.

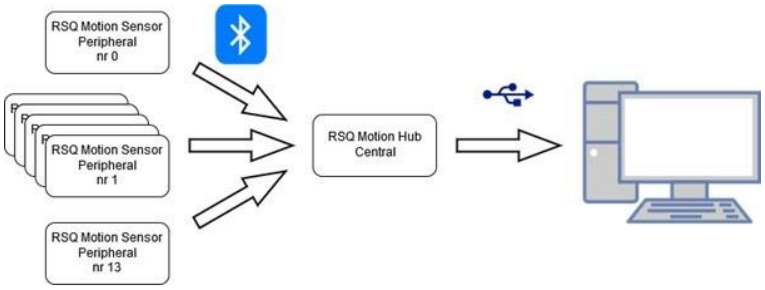

Fig. 3. The block diagram of implemented measurement system solution
Source: own study

Results and discussion

Communication between RSQ Motion Sensor and RSQ Motion HUB using Bluetooth protocol was tested. In orthopedic rehabilitation, proprioception testing is very important. Proprioception study is carried out on the principle of passive assisted pattern presentation and active reproduction of the joint position. With this, it is possible to assess the person's ability to actively position the joint in a specific position. This technique allows for the highest repeatability and the sensitivity testing. The results of proprioception tests are presented as differences between the pre-set angle and the reconstructed angle. Therefore, it is important to study the correctness and accuracy of the readings from the limb movement measurement devices.

Experimental research

To test the correctness of the readings from the measurement sensors in the prototype set, a laboratory set was used to allow movement (rotary encoder) to which the prototype measurement set was attached. The laboratory kit for testing is presented in Fig. 4.

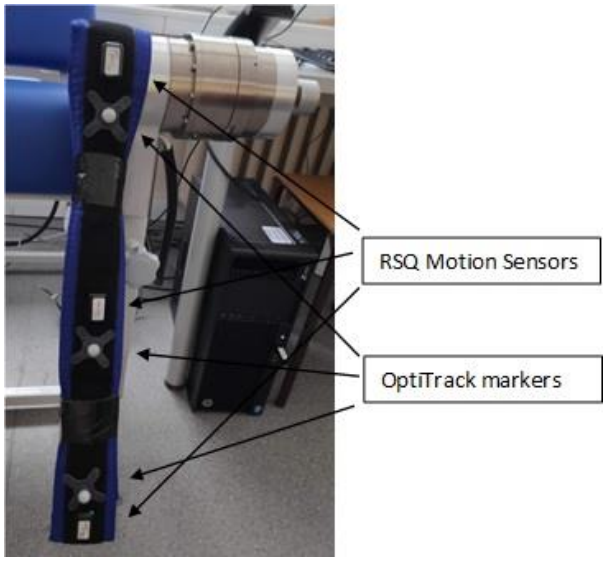

Fig. 4. The laboratory kit for testing the accuracy of measurement readings
Source: own study

Read data was sent to a PC in which the RSQ Motion Demo application was used to visualize the movements of the limbs. The developed avatar in the RSQ Motion Demo application is presented in Fig. 5.

Fig. 5. Avatar in the RSQ Motion Demo application
Source: own study

Received measurement data were sent to the PC, to the Matlab environment in order to verify the accuracy of the readings. The calculation process and the use of quaternions for calculating the orientation in space is described in detail in the Madgwick Technical Report [13]. A quaternion data and independent readings of acceleration, angular velocity and magnetic field strength were sent directly to the Matlab computing environment. Comparison of limb position readings from the prototype measurement system was made in relation to the readings made from the OptiTrack system [14]. The OptiTrack system requires the installation of markers (see gray markers in Fig. 4) whose movements are recorded by the cameras and sent to the computer system. The courses of changes in the position of the limb obtained from the prototype RSQ system were compared with the readings obtained from the OptiTrack system. The comparison is presented in Fig. 6. The analysis of measurement data shows proper accuracy and repeatability of readings.

The set-points for the experiment are motions in one axis (Y) in sequence: $0^\circ \rightarrow 5^\circ \rightarrow 0^\circ \rightarrow 30^\circ$ $0^\circ \rightarrow 45^\circ \rightarrow 0^\circ \rightarrow 60^\circ \rightarrow 0^\circ \rightarrow 75^\circ \rightarrow 0^\circ \rightarrow 90^\circ \rightarrow 75^\circ \rightarrow 60^\circ \rightarrow 45^\circ \rightarrow 30^\circ \rightarrow 15^\circ \rightarrow 0^\circ \rightarrow 90^\circ \rightarrow$ $0^\circ \rightarrow 60^\circ \rightarrow 0^\circ$. The sampling time was set at 0.01 seconds. The set sequence of movements was performed within 60 seconds. 6000 samples were obtained during the test. Such a sequence of motion guarantees the ability to analyze the correctness of the reading of movements. In the Fig. 6, the bold line shows the readings from the RSQMotion prototype system, and the standard line shows the readings from the OptiTrack reference system. The horizontal offset is the result of the lack of synchronization of the start of both reading systems (the start was carried out manually). The vertical shift results from the fact that the floor is the reference for the OptiTrack system, while the RSQ Motion system uses the gravity indicator as a reference. The calculated relative error according to relationship (1) for a series of measurements was less than 3%.

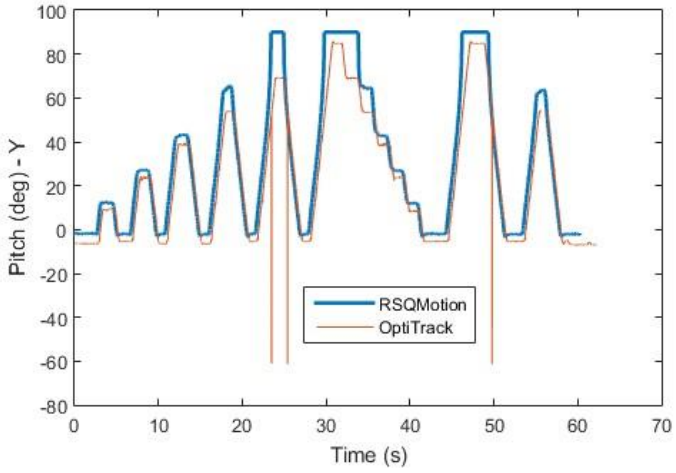

Fig. 6. Courses of changes of angles limb
Source: own study

$$\delta_y = \frac{Y_{RSQ\ Motion\ Sensor} - Y_{OptiTrack}}{Y_{OptiTrack}} \cdot 100\% \quad (1)$$

where:
$Y_{RSQ\ Motion\ Sensor}$ – reading the displacement axis Y of the RSQ Motion Sensor [deg],
$Y_{OpTitrack}$ – reading the displacement axis Y of the OptiTrack reference system [deg].

The OptiTrak system lost samples by the lack of registration of markers at certain times, which caused the peaks shown in Fig. 6 (inaccurate operation of the OptiTrack system is independent of the researchers). The test results confirm the correct and consistent implementation of the measurement system prototype and allow for further development work.

Another study proper operation of the system was carried out using a Kuka robot. Experiments were carried out with motion in 3 axes - x, y, z. The laboratory kit using the Kuka robot for testing is shown in Fig. 7. Asked been movements in 3 axes that the robot Kuka performed. Movements made by the robot were recorded by the OptiTrack system and by the tested RSQ Motion Sensor. The measurement data was sent to a computer, to the Matlab environment, to verify the accuracy of the readings. The set values of the experiment are movements in each axis (X, Y, Z) in the sequence: 0˚ → 10˚ → 0˚ → 20˚ → 0˚→ 30 ˚→ 0˚ → 40˚ → 0˚ → 50˚ → 0˚ → 60˚ → 0 → 70˚ → 0˚ → 80˚ → 0˚ → 90˚ → 0. In this experiment, it also happened that the OptiTrack system lost samples (this is independent of the researchers) as can be seen in Fig. 8.

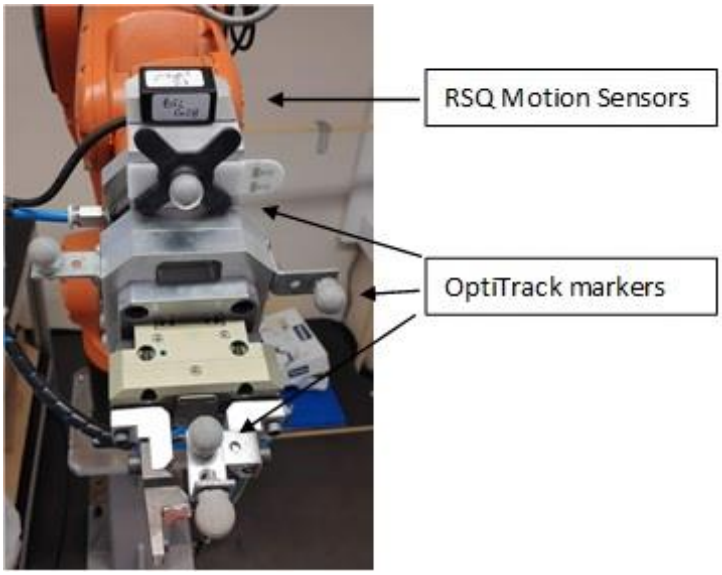

Fig. 7. The laboratory kit with Kuka robot for testing the accuracy of measurement readings
Source: own study

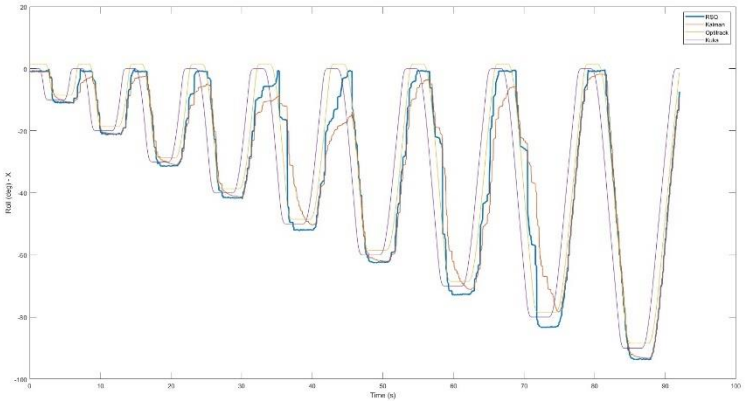

Fig. 8. Courses of changes in the x-axis angles
Source: own study

Four courses of change in read orientation changes are shown in Fig. 8. The "Kuka" course of changes is the setpoint. The "OptiTrack" course of changes is a reading from the reference system. The course of changes "Kalman" is the orientation determined in the Matlab environment based on measurement data from the accelerometer, gyroscope and magnetometer with interference filter Kalman. The course of changes "RSQ" are readings from the tested RSQ Motion Sensor system, where the orientation is determined in the IT system using quaternions and Madgwick algorithm. The test results indicate the correctness of calculations and the correct operation of the RSQ Motion Sensor system.

Minimizing energy consumption

One of the main construction assumptions is to minimize the energy consumption of the sensor system. Experimental research was carried out, the purpose of which was to determine the energy consumption of sensors in the single measurement mode, continuous measurements and standby mode. The critical value at this stage is the minimum working time set at 4.5 hours. Now, the RSQ Motion Sensor consumes energy: dormant - 58μA, awake – 14mA. There are also attempts to charge the battery in wireless mode in the Qi standard, which uses the phenomenon of magnetic induction to transfer electricity. During the tests, the effect of this kind of charging on the battery life and measurement accuracy will be checked. Different ways to save energy stored in sensors' batteries will be tested. It is expected to develop and investigate the awakening algorithm of the device under the influence of the applied force, the algorithm of putting the unused device into sleep, and the impact of the frequency of sending and receiving data on energy consumption.

Conclusions

More and more people suffer from the diseases of the musculoskeletal system associated with osteoarthritis. Treatment of locomotive organs is often based on the long-term rehabilitation, which, due to costs, is more and more often carried out individually by the patient in the place of residence. In this situation, telemedicine comes in handy, allowing for remote supervision of the patient's rehabilitation and verification of its compliance with the medical guidelines. In order to verify the correctness of the implementation of rehabilitation and to monitor the progress of regaining the efficiency of the motor organs, it is necessary to use an appropriate IT system, in which a set of specialized sensors will accurately record movements, send them wirelessly, in real time, to a human avatar displaying device that allows you to closely monitor the exercises performed by the patient and support the person supervising the rehabilitation. This study presents development of a mobile system of remote orthopedic diagnostics. Conducted tests of the correctness of the location reading and performed movements and analysis of these readings in the Matlab environment indicate the correctness of the prototype performance and authorize to continue development works and further research. Ultimately, it is planned to develop a mobile set consisting of 16 miniaturized sensors with maximum dimensions of 25x25x10mm, weighing less than 20g with the implemented appropriate, accurate measurement algorithms and algorithms ensuring the minimization of energy consumption by sensors. The assumed values for battery operation time are one week of work in the sleep mode and a minimum of 8 hours with the sensor working uninterrupted. As a target, the graphic environment will be developed based on a graphics engine capable of displaying read measurement values in a way that allows detecting deviations from the preset rehabilitation exercises. The set under development will be optimal due to its weight, dimensions and ability to work on one battery charge. It is planned to make the final version of a set of sensors placed in a housing made of plastic that provide adequate strength, resistance to moisture, large shocks and falls. The final version of the system will be a commercial development for applications in remote orthopedic diagnostics and for the supervision of the implementation of the rehabilitation of motor organs. The current version of the system is already being tested by physiotherapists for the study of proprioception.

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RENAL INVOLVEMENT IN SJOGREN'S SYNDROME- CASE REPORT

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Abstract:
Sjogren's syndrome is a chronic autoimmune disease, associated with a lymphocytic and plasmacytic infiltrate concerning mainly exocrine glands and leading to "sicca syndrome". This immune process may affect not only salivary, parotid and lacrimal glands, but also disrupt function of nonexocrine organs, including kidneys. In this case study, we present a female patient with severe decrease of GFR, metabolic acidosis, polydipsia and polyuria in the course of Sjogren's syndrome. Problematic and multi- faced medical history of the patient highlights the importance of proper diagnosis and therapy as well as awareness of possible multiorgan manifestation of Sjogren's syndrome.

Keywords:
Sjogren's syndrome, interstitial nephritis, renal manifestation, autoimmune disorder

Introduction

Sjogren'ssyndrome is a multisystem disorder that is heterogeneous in its presentation, course and outcome [1]. It is a chronic autoimmune disease in which lymphocytic infiltration causes disruption of multiorgan function. Primary Sjogren's syndrome (pSS) is predominantly affecting the exocrine glands, causing xerostomia (dry mouth) and xerophthalmia (dry eyes) described as sicca symptoms. The Secondary Sjogren's syndrome (sSS) is associated with another autoimmune disease, usually rheumatoid arthritis [2]. Systemic manifestations including pulmonary, renal, dermatological, gynecological and nervous system involvement may cause troubles in diagnostic and therapeutic process. Most widely accepted criteria for diagnosing Sjogren's syndrome are the one, created by American College of Rheumatology and European League Against Rheumatism in 2016. They start with inclusion criteria (dryness of mouth or eyes, or suspicion of SS based on ESSDAI questionnaire) and then consist of 5 criteria with weight of 1 or 3 points: labial salivary gland with focal lymphocytic sialadenitis and focus score ≥1, presence of anti- SSA (Ro) antibodies, ocular surface staining score ≥5 on at least one eye, result of Schrimer test ≤5mm/5 min on at least one eye and unstimulated whole saliva flow rate ≤0,1ml/ min. Early diagnosis is important to prevent further complications, like transformation to lymphoma which occurs in 6- 10% of cases [3].

The prevalence of renal involvement in Sjogren's syndrome has been reported to range from 2 to 67 percent [4]. This variability may be caused by different definitions of kidney involvement in pSS. Renal manifestation of pSS is the result of two distinct pathophysiological processes: epithelial disease with lymphocytic infiltration resulting in tubulointerstitial nephritis and non-epithelial disease with a complex-mediated process resulting in glomerulopathy [5]. Chronic tubulointerstitial nephritis is the most common renal manifestation of pSS [6] and can be confirmed in renal biopsy as invasion and damage of tubules.

Case Report

Our patient was a 34-year-old female reported to Rheumatology Department of Regional Hospital No. 2 of Św. Jadwiga Królowa in Rzeszówin April 2018 complaining of dryness of eyes and mouth, pain in knee joints and thoracolumbar spine, polydipsia and polyuria, which made SS a suspected diagnosis. With height of 167 cm and weight 86,5kg, her BMI was 31,02 (1st stage obesity). During the first hospitalization in our Department, the patient underwent a number of tests including: basic metabolic panel, complete blood count with differential, evaluation of bone marrow morphology, urinalysis, 24- hour urine collection, analysis of lipids and autoimmune work up. Obtained results presented in Tab. 1 - 4 revealed: hyperchloremia, high creatinine and urea, with very low GFR= 24ml/min and metabolic acidosis (pH of vein blood 7,25 with pO_2= 18mmHg). In urinalysis we found leukocytes and high 24-hour urine protein excretion (561 mg/24h). Other tests revealed mild anemia, very high immunoglobuline G level (with negative result of monoclonal protein test) and presence of antinuclear antibodies (ANA): SS-A, Ro-52, SS-B, Ku. In addition, we detected presence of high HE 4 marker dedicated to diagnostics of ovarian cancer.

In abdomen's ultrasound we found kidneys with significantly thinned cortex (on average 8mm), with features of chronic renal disease and presence of central cysts (6-7mm). The size of parotid glands and salivary glands in ultrasound were reduced with hypoechogenic areas. Suspecting Sjogren's syndrome, we run Schirmer test and observed reduced secretion of lacrimal glands (right eye secretion= 3mm, left eye secretion= 1mm).

Consulting endocrinologist and gynecologist suggested performing dehydration- vasopressin testand cytology in ambulatory care as well as repeating HE 4 marker test in 3 months respectively.

Taking into consideration the clinical picture of our patient- persistent decrease of GFR, metabolic acidosis and polyuria, the patient was diagnosed with Sjogren's Syndrome, with chronic renal disease in stage G4, polyclonal gammapathy and nephrogenic diabetes insipidus. Consulting nephrologist assessed kidney failure as chronic renal disease in stage G4 in the course of Sjogren's syndrome and scheduled kidney's biopsy. The histological biopsy revealed active interstitial and tubular inflammation with heavy chronic infiltration of plasma cells- consistent with distal renal tubular acidosis in the course of Sjogren's syndrome.

Hydroxychloroquine was the first-line SS treatment we offered to the patient, along with recommended calcium, vitamin D and iron.Other recommendations consisted of limitation of protein and salt usage in patient's diet as well as maintaining therapy with acetylsalicylic acid.

Tab. 1. Basic metabolic panel

Na	K	Chloride	Osmolality	GFR	BUN	Uric acid
135 mmol/l	3,8 mmol/l	112 mmol/l	168 mosm/kg H2O	24ml/min/1,73 m2	55 mg/dl	5,1 mg/dl

Source: patient's medical documentation

Tab. 2. Urinalysis

Urine pH	Leukocytes	Total protein	Osmolality	Culture	24- hor urine collection	Protein in 24- hour urine collection
7	++ (10-20)	9,0 g/dl	291 mosm/kgH2O	negative	3100 ml	561 mg/24h

Source: patient's medical documentation

Tab. 3. Complete blood count

WBC	RBC	HGB	HCT	MCV	MCH	MCHC	PLT	OB
3,66 $10^3/\mu l$	3,48 $10^6/\mu l$	10,9 g/dl	32,7%	93,9fL	31,4pg	33,4 g/dl	180 $10^3/\mu l$	42 mm/h

Source: patient's medical documentation

Tab. 4. Autoimmune work up

IgA	IgG	IgM	pANCA	cANCA	SS-A	Ro-52	SS-B	Jo-1
3,26 g/l	34,4 g/l	1,14 g/l	negative	negative	positive	positive	positive	Cut-off score

Source: patient's medical documentation

In additional capillaroscopy test we found dilated capillaries, single avascularisation areas, giant capillaries and micro extravasation areas, which may convey the idea of microangiopathy typical for scleroderma.

During the second hospitalization, the patient presented: elevated creatinine level (2,26mg/dl) metabolic acidosis (pH of vein blood= 7,28), anemia and proteinuria (360mg/24h) as well as increased IgG levels (25,6 g/l). The Addis count measuring urinary casts over time was increased in the number of leukocytes and erythrocytes.

The patient was started on corticosteroids: Encorton(40 mg for 2 weeks with planned reduction of 5 mg every week to final dose of 15mg per day) and Azathioprine (50mg 2x1). In addition, consulting nephrologist suggested inclusion of potassium citrate with control of kalemia and acid-base balance. The patient was also referred to hematology outpatient clinic for evaluation due to IgG elevation.

In the follow-up consultation, the patient reported adverse reactions to the steroids, including weight gain and corticosteroid-induced psychosis, so reduction of Encorton was needed. The third hospitalization brought improvement of parameters: chloremia (105mmol/l), pH (7,38)and IgG (13,5g/l) - in normal levels, decrease of proteinuria(230mh/24h) and ESR (29mm/h) and stabilization of GFR (27ml/min) and creatinine (2,28mg/dl).

After 5 months of maintained treatment, the patient presented further disruption in CBC and increase of ESR, IgG level as well as mild metabolic acidosis. The patient was consulted by dermatologist because of reported periodic outbreaks of rash, involving the abdomen area and hair loss since few months. Identification of etiology of the skin disorder was impossible. The hair loss, visible in examination, was connected with usage of Azathioprine in treatment of underlying disease. Implemented recommendations included Minoxidil and dermatological consultation if the rash appears again.

In further follow-up the patient was hospitalized in the Department of Infectious Diseases, due to viral meningitidis. Along with worsening of morphology parameters, Azathioprine was discontinued. Dose of corticosteroid was increased for 3 months, but then our patient reported swelling of lower extremities, varicose veins, stretch marks, memory impairment and weight gain (BMI= 32,6), and the baseline dose of corticosteroid was restored.

Discussion

Sjogren's syndrome is a chronic autoimmune disease concerning 3% of the population. It can present as a primary Sjögren's syndrome (pSS), or in addition to another autoimmune disease (like rheumatoid arthritis or systemic lupus erythematosus), secondary Sjögren's syndrome (sSS). pSS has a strong female propensity and is more prevalent in Caucasian women, with the mean age of onset usually in the 4th to 5th decade [7]. The presentation, course and outcome in SS may vary and apart from primary symptoms- dryness of eyes and mouth, described as "sicca symptoms", manifestation of SS may concern every system and organ in the system (lungs, kidneys, thyroid, nervous system, skin and many others) [8].

Presented patient's SS manifestation included kidneys involvement in the form of chronic tubulointerstitial nephritis- the most common renal manifestation of Sjogren's syndrome [6]. The clinical manifestations of the interstitial nephritis include mild elevation of plasma creatinine concentration, benign urinalysis disturbances and disorder of tubular function: nephrogenic diabetes insipidus, hypokalemia and distal renal tubular acidosis [9], which was present in our patient.

The optimal treatment is not clearly defined for renal manifestation of SS. Hydroxychloroquine is the current first- line treatment for systemic therapy, and steroids can be used in patients non-responsive to treatment. If the interstitial nephritis is severe and active, it is recommended to prescribe a course of glucocorticosteroids, followed by azathioprine if renal function is worsening [10]. Our patient was started on glucocorticosteroids and azathioprine due to stage G4 active renal intestinal infiltrationsand severe decrease of GFR. The adverse effects of those immunosupresive medications should be monitored and taken into account while maintaining the dosage.

Rash is not a common finding in patients with SS and is reported in 10-30% cases. It is commonly a non-palpable purpura in the lower extremities, but it can have other presentation as well [11]. To diagnose a dermatological manifestation of Sjogren's syndrome, it is necessary to perform biopsy of the lesion on the affected area to expose the inflammatory infiltrate specific to autoimmune disease.

Conclusion

Presented patient was diagnosed with Sjogren's Syndrome with chronic tubulointerstitial nephritis and polyclonal gammapathy. In the course of disease the patient presented many disturbances in laboratory tests, adverse effects to the treatment and possible dermatological manifestation of Sjogren's syndrome. We report this case to raise the clinical awareness of multi-organ manifestation of Sjogren's syndrome. Proper treatment of this disease can result in improved tubular functioning and slowing the progression of kidney disease, which demonstrates the importance of rapid and accurate diagnosis.

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PARTICIPATION OF BMP-7 AND SOLUBLE FORM OF ICAM-4 IN THE DEVELOPMENT AND PROGRESSION OF ENDOMETRIOSIS

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Abstract:
Endometriosis is a disease of unknown origin, characterised by the presence of active mucosa of the uterine body outside of its normal location. What still remains unknown are the mechanisms facilitating the adhesion of endometrial cells to the peritoneum, allowing them to move into faraway locations in the body, thus initiating the ectopic development of that tissue and letting it survive. The molecules participating in intercellular interactions and interactions between cells and extracellular matrix cells as well as in the processes of angiogenesis and apoptosis are bone morphogenetic proteins and intercellular adhesion molecules (ICAM). The study aimed to determine whether BMP-7 and sICAM-4 participate in the occurrence and development of endometriosis. In the peritoneal fluid of 60 women with endometriosis (at stage 1, 2, 3 and 4) and 20 women from the reference group, the BMP-7 and sICAM-4 concentrations were determined with the ELISA method. A very statistically significant increase in the sICAM-4 and BMP-7 concentrations was found compared to those concentrations in the reference group ($p<0.0001$). This was mostly evident in women with stage 1 and 2 endometriosis. Changes in the concentration of the studied parameters show that they play a role in the occurrence and development of the disease.

Keywords:
endometriosis, BMP-7, soluble form of ICAM-4

Introduction

Endometriosis is a disease of unknown etiology. It is characterised by the presence of active mucosa of the uterine body outside its normal location [1 ÷ 3]. There are many theories trying to explain the development of endometriosis, but none of them explains all cases of the disease. The basic mechanism of development of endometriosis foci is retrograde menstruation, i.e. travelling of menstrual blood through the Fallopian tubes to the peritoneal cavity. However, the process is also observed in healthy females, so other factors must participate in the growth of

endometrial implants as well. Over the last years, Dmowski's immunological theory has gained ground, according to which one of the main conditions for exfoliated endometrial cells to implant, survive and develop ectopically is abnormal function of immune system cells. The most probable explanation of most cases of endometriosis seems to be the combination of the theory of the "reflux" of menstrual blood and abnormal immunological supervision.

Ectopic endometrium reacts to hormones secreted during the menstrual cycle. Each month, a new mucosa grows, which – exfoliating – causes internal bleedings, but the ectopic endometrial fragments are not excreted from the body. In consequence, inflammation develops that is most frequently located within the organs of the true pelvis. The inflammation leads to change in the volume and composition of the peritoneal fluid in patients with endometriosis. Mediators of immune system found in that fluid form a specific environment which facilitates the survival of implants of ectopic endometrium. As a result, the peritoneal fluid in patients with endometriosis is a vital biological material to study [4, 5].

When the immune system functions normally, fragments of endometrium should be eliminated from the ectopic sites. Abnormal cytotoxicity of macrophages and NK cells *(Natural killers)* distorts the process of removing endometrial tissue from the peritoneal cavity. In patients with endometriosis, the ability of immune system cells to identify, capture and destroy ectopic fragments of the uterine mucosa. What may be responsible for difficulties in endometrial cell recognition and distortion of the immune response against those antigens are intracellular adhesion molecules (ICAM). Therefore, in patients with endometriosis it is necessary to perform tests aiming to learn about the role of molecules responsible for intercellular interactions, including ICAMs. [6 ÷ 12].

ICAMs are a part of the mucosa of cells in many organs and tissues of the body, but they can also occur in the soluble form in biological fluids as sICAM (soluble intercellular adhesion molecule). The soluble forms are created as a result of enzymatic cutting of extracellular domains of molecules off the cellular surface. This may occur with participation of metal metalloproteinase-9 (MMP-9), matrix metalloproteinase-2 (MMP-2), tumour necrosis factor-α converting enzyme (TACE) and elastases. Soluble adhesion molecules may change the activity of proper receptors on cellular surface, which may distort the processes of adhesion and result in migration of cells to remote regions of the body [13 ÷ 15].

Angiogenesis is also regarded as one of the important processes responsible for the development of the disease. Significant factors participating in that process are bone morphogenetic proteins (BMP) [16]. The literature reports that ICAMs and BMPs play an important role in a lot of physiological and pathological processes in the body. BMPs protect endothelial cells against apoptosis, which facilitates their intensified proliferation and reconstruction of blood vessels and creates conditions for the development of a new vascular network [17 ÷ 20].

So far, the functions of only some membranous forms of cell adhesion molecules in the pathogenesis of endometriosis have been discovered. However, the participation of the soluble form of ICAM-4 and BMP-7 (Bone Morphogenetic Protein 7) has not been studied so far.

ICAM-4 (intracellular adhesion molecule-4, LW antigen) occurs on red blood cells, leukocytes and blood platelets. Its expression on red blood cells is expressed particularly strongly and is a carrier of LW antigen from the LW system. The molecule binds with ligands found in leukocytes,

erythrocytes, monocytes/macrophages, blood platelets and vascular endothelial cells such as αLβ2 (CD11a/ CD18, LFA-1), αIIbβ3, α2β4, αvβ5, αvβ1 and $L_M\beta_2$ (Mac-1). On normal red blood cells, ICAM-4 is not available for proper ligands. The molecule is exposed on cells in diseases, which is related to their transformation to the adhesive state. Erythrocytes can then adhere to leukocytes, monocytes, blood platelets and vascular endothelial cells. As a result, pathological adhesion to the vascular endothelium may occur, which is a cause of thrombosis and total closure of the vascular lumen [21, 22].

The bone morphogenetic protein-7 (osteogenic protein-1, OP-1) is a growth factorproduced by vascular endothelial cells, blood platelets, macrophages, NK cells, neutrophils and lymphocytes. It is secreted to bodily fluids after those cells are activated [23, 24]. The BMP-7 molecule participates in proliferation, differentiation, migration and apoptosis of many cells, including vascular endothelial cells and is a factor required in the process of decidualisation of endometrium, one necessary for proper implantation, protection and nutrition of the embryo [23, 25]. Increase in the BMP-7 concentration in bodily fluids may lead to intensification of proliferation and migration of vascular endothelial cells and uncontrolled formation of new blood vessels [26 ÷ 30].

The determination of the BMP-7 concentration and the soluble form of ICAM-4 in the peritoneal fluid of patients with endometriosis may be useful in explaining the pathomechanism of adhesion of ectopic endometrial fragments to the peritoneum and colonisation of sites outside the uterus. In addition, in may help explain the pathogenesis of abnormal immunological supervision in the peritoneum of patients with endometriosis.

Objective

The paper aims to determine whether sICAM-4 and BMP-7 participate in the pathogenesis of endometriosis.

Study material

The study covered 80 females at the age from 21 to 49 (mean age was 31.3 ± 6.7) who underwent laparoscopy to determine the causes of primary infertility. The studied females were patients of the Department of Gynaecology and Obstetrics in Kornel Gibiński University Clinical Centre in Katowice. The inclusion criteria were as follows: written informed consent to participation in the study, regular menstrual cycles taking 28 ± 4 days, good general health, primary infertility, abstinence from hormonal agents within 3 months before laparoscopy and excluded progression of autoimmune diseases and non-malignant or malignant lesions in the ovary and the uterus. The exclusion criteria were as follows: lack of written informed consent to participation in the study, irregular menstrual cycles (not taking 28 ± 4 days), administration of drugs modulating the immune system functions, administration of hormonal agents, poor general health, non-malignant or malignant lesions in the ovary or the uterus.

60 females at the age from 21 to 49 with diagnosed endometriosis in the true pelvis, as diagnosed during laparoscopy and confirmed by histopathological examination, qualified for the study group (mean age = 31.9 ± 7.0). The extent and intensity of endometrial lesions in the peritoneal cavity

was assessed according to the American Fertility Society (rAFS), with classification into stage 1, 2, 3 and 4 endometriosis. In 20 patients, stage 1 endometriosis was diagnosed, in 16 – stage 2 endometriosis, stage 3 endometriosis was diagnosed in 15 patients and stage 4 endometriosis was identified in 9 patients.

The control group included 20 females at the age from 21 to 46 (mean age = 30.4 ± 6.1), who on laparoscopy were not diagnosed with endometriosis or other pathological lesions in the true pelvis. All females were informed about the purpose of the examinations and gave their consent to sampling of their peritoneal fluid for scientific purposes. Consent for study no. KNW-6501-57/07 of the Bioethics Committee of the Medical University of Silesia in Katowice was obtained.

The study material consisted of the peritoneal fluid collected during laparoscopy from females at the proliferative phase of menstrual cycle. Directly after sampling, the peritoneal fluid was centrifuged at 2500 rpm for 10 minutes at 4^{o}C to separate the fluid from cells. After centrifugation, the fluid from above the sediment was divided into small portions and stored at -80^{o}C until determinations were performed.

Methods

The concentration of the following soluble cell adhesion molecules was determined in the peritoneal fluid with enzyme-linked immunoabsorbent assays (ELISA) by Clound-Clone Corp., Houston, USA:

- sICAM-4, test sensitivity: 0.35 ng/ml,
- BMP-7, test sensitivity: 14.7 pg/ml.

Statistical analysis

The obtained results were analysed statistically with Statistica for Windows, ver. 12.0, and Microsoft Excel. The Shapiro–Wilk test was employed to assess the distribution of the obtained results. As all obtained results corresponded to the normal distribution, Student's t-test was used to analyse the results. The arithmetic mean ($\bar{x}$) and standard deviation (SD) were calculated for each parameter. If there was equality of variances for the studied parameters, one-way ANOVA was used. The significance of differences was additionally verified with post-hoc Tukey's HSD test. The correlation between the studied parameters was verified with Pearson correlation coefficient (R). The level of statistical significance was $p \leq 0.05$.

Results

sICAM-4 concentration

In the peritoneal fluid of patients with endometriosis, a very statistically significant increase in the soluble ICAM-4 (sICAM-4) concentration was found compared to the concentration of that parameter found in the control group ($p<0.0001$). The above results are presented in Tab. 1.

Tab. 1. sICAM-4 concentration in the peritoneal fluid of patients with endometriosis and patients from the control group

Study group	n	sICAM-4 concentration in peritoneal fluid [ng/ml]	
		range	$\bar{x} \pm SD$
Females with endometriosis	60	0.14 – 2.50	0.92 ± 0.70*
Females from the control group	20	0.05 - 0.53	0.27 ± 0.16

Source: own calculations

n – number of group members
$\bar{x}$ – arithmetic mean
SD – standard deviation
* $p<0.0001$ compared to control group

The mean sICAM-4 concentration in the peritoneal fluid was 0.27 ng/ml in controls; in patients with stage 1 endometriosis it was 1.21 ng/ml, in patients with stage 2 endometriosis 1.84 ng/ml, in patients with stage 3 endometriosis 0.42 ng/ml and in patients with stage 4 endometroisis 0.26 ng/ml. Statistical analysis showed very significant increase in the sICAM-4 concentration in the peritoneal fluid in stage 2 endometriosis ($p<0.0001$) and stage 1 endometriosis ($p<0.0001$) compared to the concentration of that parameter in the control group. On the other hand, a statistically insignificant increase in the sICAM-4 concentration was found in the peritoneal fluid of patients with stage 3 endometriosis a slight decrease in sICAM-4 concentration was found in patients with stage 4 endometriosis, compared to the control group. The highest very statistically significant concentration of that parameter was observed in patients with stage 2 endometriosis compared to the control group ($p<0.0001$). The results are presented in Fig. 1.

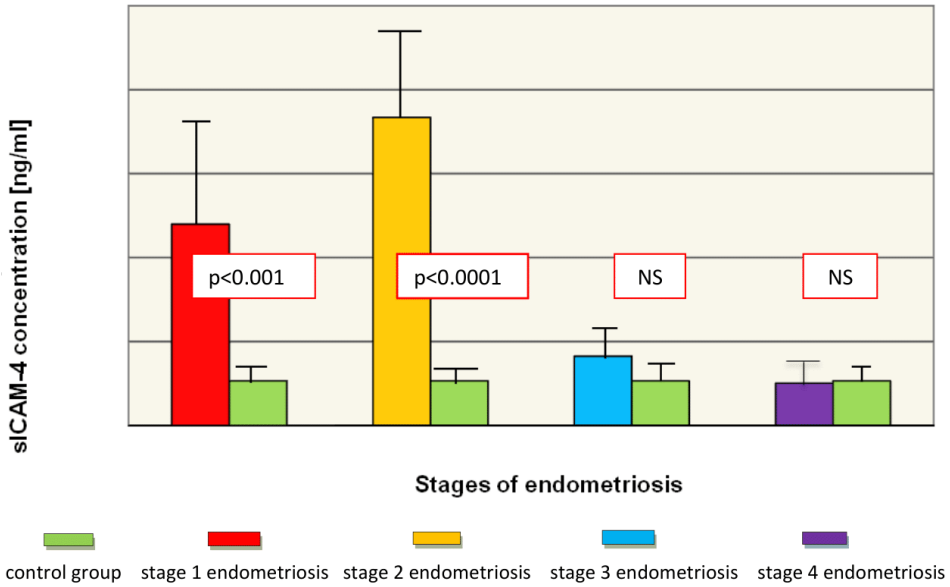

Fig. 1. The mean sICAM-4 concentration in peritoneal fluid in patients with consecutive stages of endometriosis and patients from the control group
Source: own calculations

Moreover, a very statistically significant negative correlation between sICAM-4 concentration and consecutive stages of the disease was found in the peritoneal fluid of study group patients ($R = -0.633$ and $p<0.0001$). The results are presented in Fig. 3.

BMP-7 concentration

In the peritoneal fluid of patients with endometriosis, a very statistically significant increase in the BMP-7 concentration was found compared to the concentration of that parameter found in the control group *($p<0.0001$)*. The above results are presented in Tab. 2.

Tab. 2. BMP-7 concentration in the peritoneal fluid of patients with endometriosis and patients from the control group

Study group	n	BMP-7 concentration in peritoneal fluid [ng/ml]	
		range	$\bar{x} \pm SD$
Females with endometriosis	60	0.19 - 3.76	1.21 ± 0.63*
Females from the control group	20	0.13 - 0.70	0.44 ± 0.18

Source: own calculations

n – number of group members
$\bar{x}$ – arithmetic mean
SD – standard deviation
* $p<0.0001$ compared to control group

The mean BMP-7 concentration in the peritoneal fluid of controls was 0.44 ng/ml in controls; in patients with stage 1 endometriosis it was 0.89 ng/ml, in patients with stage 2 endometriosis 0.93 ng/ml, in patients with stage 3 endometriosis 0.83 ng/ml and in patients with stage 4 endometriosis 0.76 ng/ml. Statistical analysis showed increase in the BMP-7 concentration in the peritoneal fluid of patients with endometriosis at all stages compared to the control group. The highest BMP-7 concentration was observed in the peritoneal fluid of patients with stage 1 endometriosis compared to the control group and it was very statistically significant *(p<0.0001)*. The results are presented in Fig. 2.

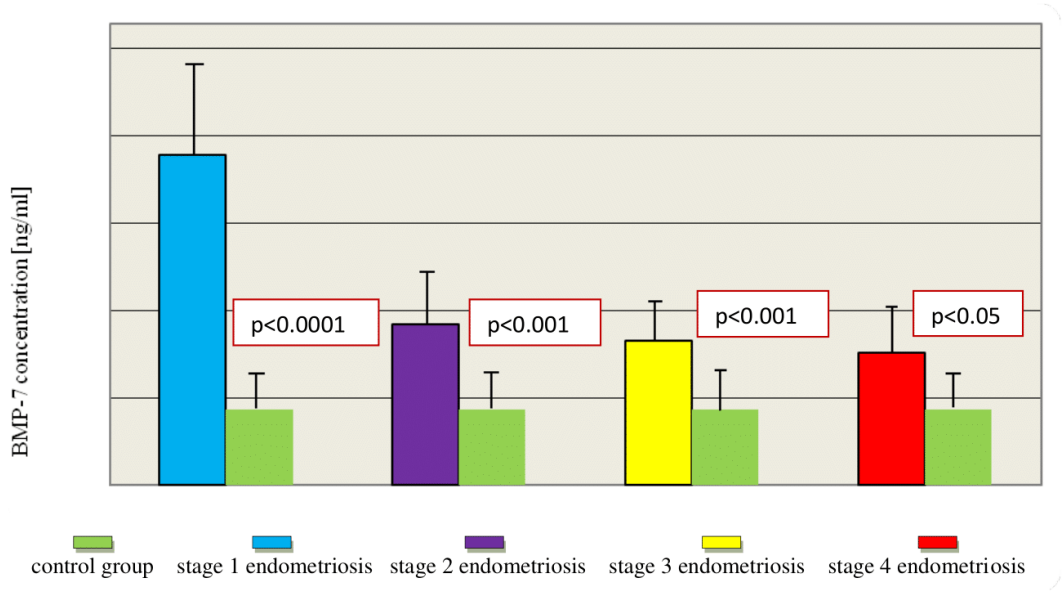

Fig. 2. Mean BMP-7 concentration in the peritoneal fluid of patients with consecutive stages of endometriosis and in controls
Source: own calculations

Moreover, a very statistically significant negative correlation was found between the BMP-7 concentration in the peritoneal fluid and the stage of endometriosis (p<0.0001; R = - 0.832). Analysis of the results showed a very statistically significant correlation between the BMP-7 and sICAM-4 concentration in the peritoneal fluid of patients with endometriosis (p<0.0001; R = -0.0475). The results are presented in Fig. 3 to 7.

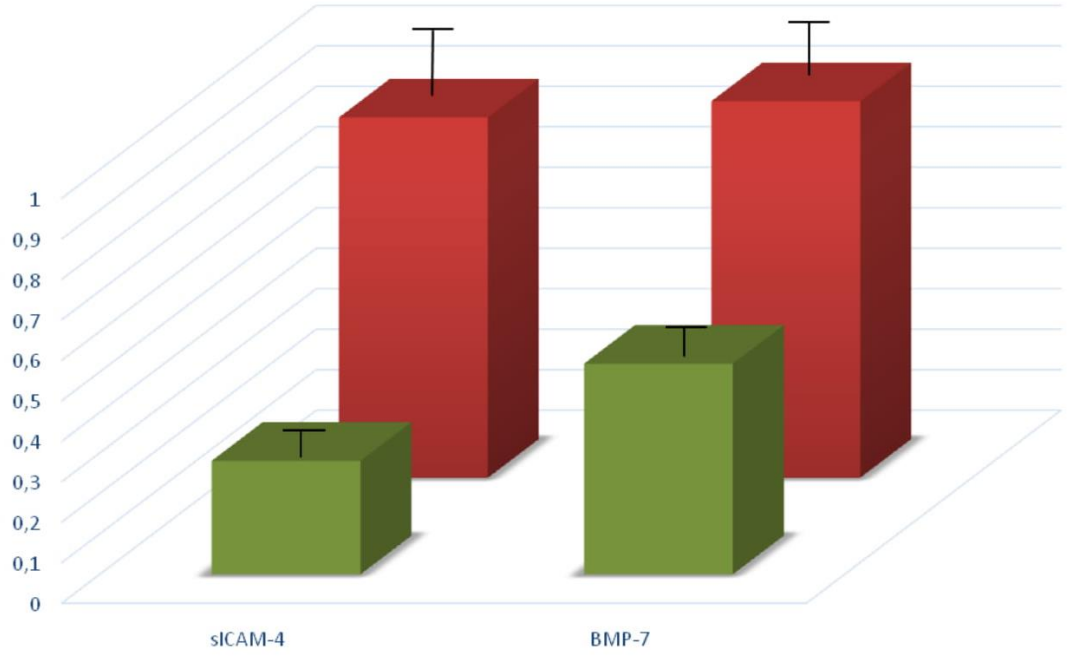

Fig. 3. The sICAM-4 and BMP-7 concentration in the peritoneal fluid of controls and patients with endometriosis
Source: own calculations

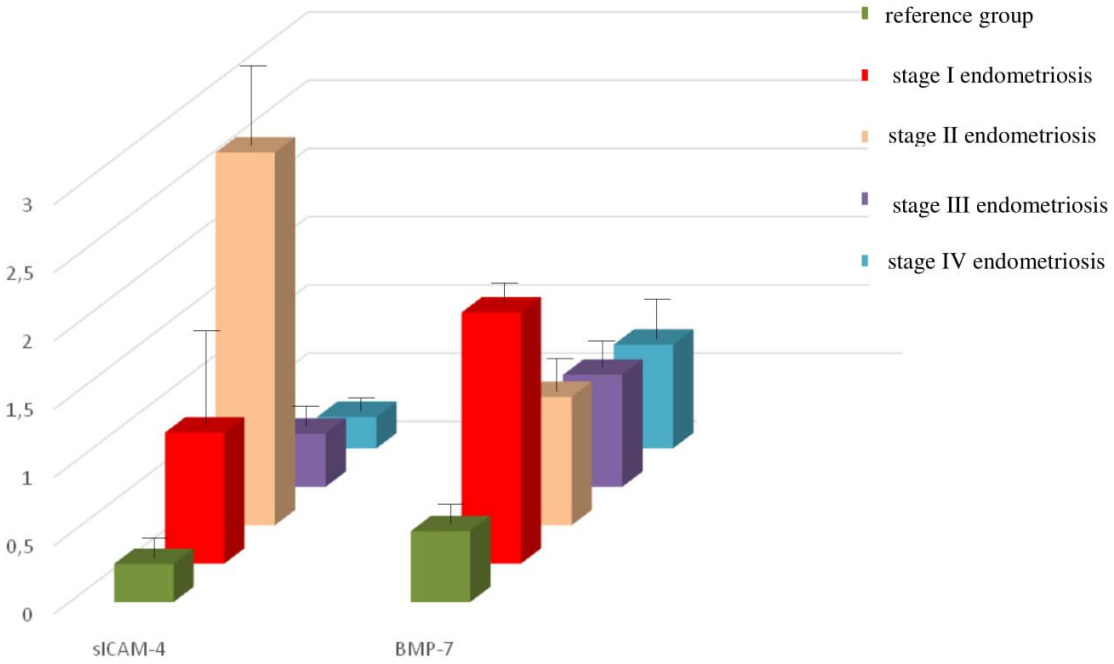

Fig. 4. The sICAM-4 and BMP-7 concentration in the peritoneal fluid of patients with successive stages of endometriosis and patients from the control group
Source: own calculations

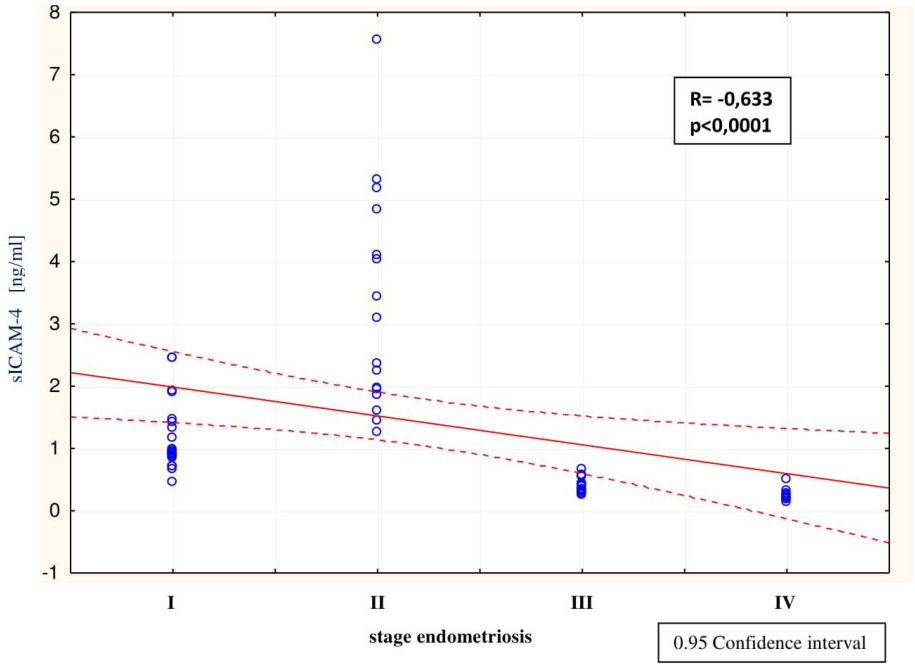

Fig. 5. Linear regression curve illustrating the correlation between the sICAM-4 concentration in the peritoneal fluid of patients with endometriosis and successive stages of the disease
Source: own calculations

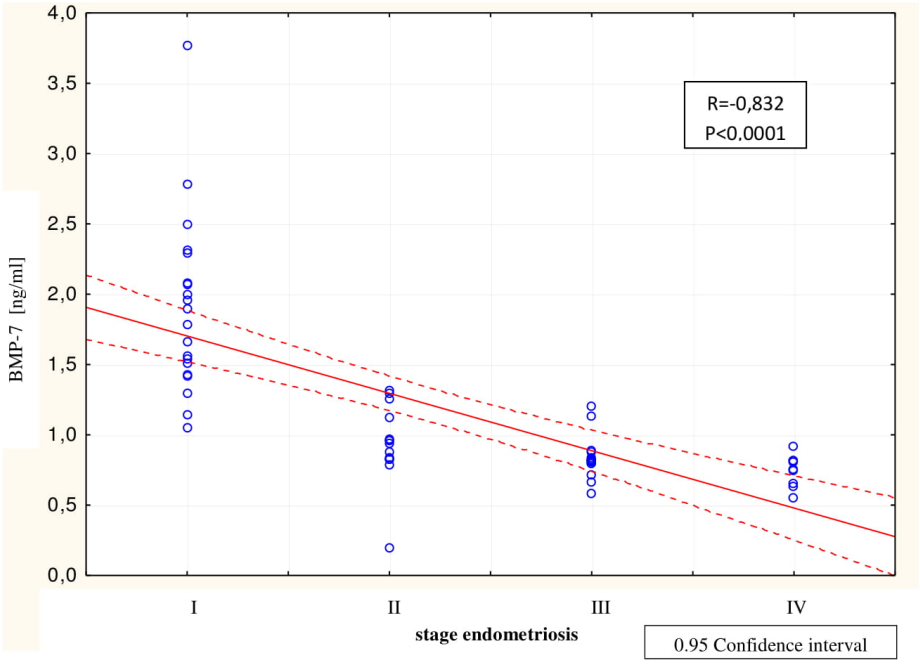

Fig. 6. Linear regression curve illustrating the correlation between the BMP-7 concentration in peritoneal fluid and the stage of endometriosis
Source: own calculations

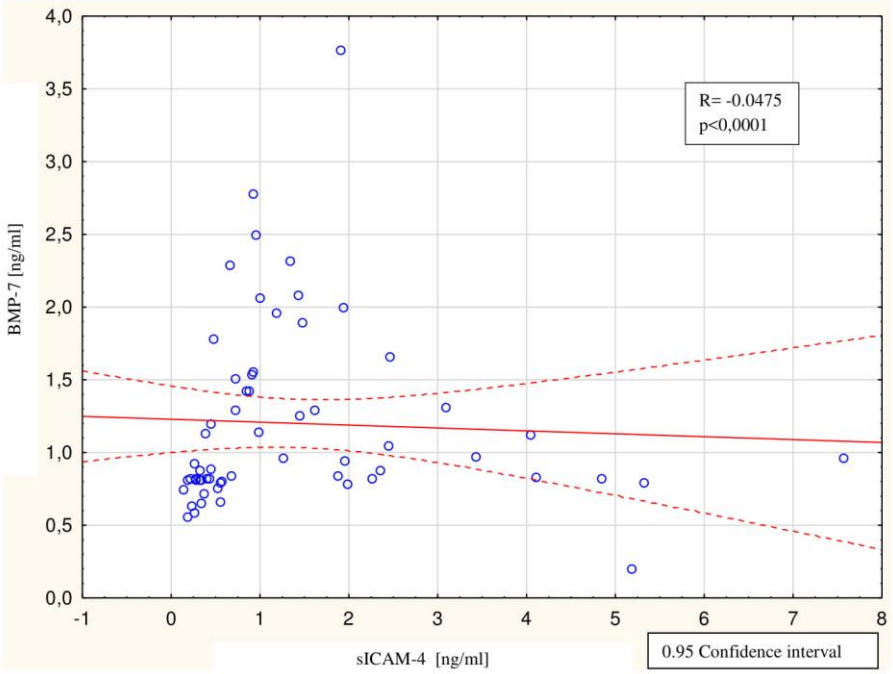

Fig. 7. Linear regression curve illustrating the correlation between the sICAM-4 concentration and the BMP-7 concentration in the peritoneal fluid of patients with endometriosis
Source: own calculations

Discussion

The concentration of soluble cell adhesion molecules and bone morphogenetic proteins in bodily fluids may be different in different diseases. So far, the role of soluble ICAM-4 (sICAM-4) and BMP-7 in patients with endometriosis has not been studied. The determination of the concentration of those molecules in the peritoneal fluid of patients with endometriosis may be useful in explaining the mechanism of implantation of ectopic endometrial fragments to the peritoneum and colonisation of sites outside the uterine cavity. In addition, it may help in explaining their participation in the process of abnormal immune response towards ectopic endometrial cells in the peritoneal cavity of patients with endometriosis and their facilitation of angiogenesis.

Analysis of the results showed increased sICAM-4 concentration of the peritoneal fluid of patients with endometriosis compared to the control group. This particularly pertained to patients with stage 1 and 2 endometriosis. The largest lesions at stage 1 and 2 may indicate that sICAM-4 contributes mostly at an early stage of the disease. In endometriosis, red blood cells found in menstrual blood undergo haemolysis as the blood does flow back. This leads to the exposure of phosphatidylserines and the intensification of ICAM-4 expression on red blood cells and the release of its soluble form. This contributes to increased ability of sICAM-4 on erythrocytes to bind integrin receptors located on the vascular endothelium, monocytes, leukocytes, blood platelets and NK cells [31]. Kaul et al. [21] pointed to the fact that it can cause vascular endothelium damage, which increases the risk of adhesion of other cells to its surface. Ectopic endometrial cells might also be damaged. A negative correlation between the sICAM-4 concentration in the peritoneal fluid of patients with endometriosis and successive stages of the disease. Increase sICAM-4 concentration in the peritoneal fluid of patients with endometriosis may result from the presence

of ectopic endometrial cells and indicate early stage of the disease. However, the decreased sICAM-4 concentration in peritoneal fluid of patients with endometriosis may suggest the presence of non-active, fibrotic and scar endometrial lesions, observed in patients with advanced endometriosis. There have been no studies so far that would assess the sICAM-4 concentration in the peritoneal fluid of patients with endometriosis. However, the participation of that molecule was demonstrated in various neoplasms and in sickle-cell anaemia [31, 32, 33]. Corey et al. [34] demonstrated that reduction in the expression of ICAM-4 on the vascular endothelium contributes to decreased migration of T-lymphocytes to tissues, which promotes the development of neoplasms. Studies on the participation of the soluble ICAM-4 in immune response were conducted by Hermand et al. [22]. They demonstrated that the combination of sICAM-4 with integrin LFA-1 of T-lymphocytes and NK cells may distort the migration of those cells to tissues and prevent the lytic synapse from forming.

BMP-7 exhibits pleiotropic effects [35, 36] on the basis of assessment of expression of BMP-7-coding gene demonstrated that that protein inhibits the proliferation of uterine endometrial cells and is a significant regulator of decidualisation. Similar conclusions were drawn by Monsivais et al. [37], who suggest that BMP-7 is an important factor of implantation of a blastocyst and contribute to normal embryonal development. Analysis of the study results indicates that it might be that increased BMP-7 concentration, demonstrated in the peritoneal fluid of patients with endometriosis may distort decidualisation, which may have a negative effect on fertility of those patients. This may result not only from the occurrence of endometriosis-related fibrous lesions and adhesions, but also from distorted release of BMP-7 to the peritoneal fluid and resulting expression of that protein on the surface of endometrial cells.

The results obtained in this study may indicate that sICAM-4 and BMP-7 participate in the development and progression of endometriosis. Thanks to ICAMs, intercellular integrity is maintained and new tissues form. If those interactions are distorted, a cell loses its ability to receive signals from its surroundings. This may lead to apoptosis or facilitate cells travelling to distant parts of the body via blood or lymph vessels [38, 39, 40]. The obtained results confirm the existence in patients with endometriosis of disorders of immune response towards ectopic endometrial cells, which disorders facilitate the migration of cells to sites outside the uterine cavity. The soluble form of ICAM-4 may contribute to distortion of adhesion and migration, allowing endometrial cells to travel to distant places in the body and facilitating the implantation of endometrial fragments in the peritoneal mesothelium. What plays a significant role in the process of endometrial implantation in ectopic sites is a change in expression or concentration of molecules related to the local angiogenesis induction. Bone morphogenetic proteins are required in the process, including BMP-7. Blood vessel formation in the ectopic endometrial cell may initiate the proliferation of endometrial cells and allow their survival in ectopic sites.

In summary, it might be concluded that significant changes in the sICAM-4 and BMP-7 concentrations have been demonstrated in the peritoneal fluid of patients with endometriosis. Through participation of those molecules in the regulation of the immune response, adhesion, migration and angiogenesis, the molecules may participate in the development and progression of endometriosis.

Conclusions

The conducted study led to the following conclusions:

1. Changes in the concentration of the studied soluble molecules in the peritoneal fluid of patients with endometriosis prove their function in the development of the disease.
2. Changes in the sICAM-4 and BMP-7 concentrations observed at successive stages of the disease confirm the participation of those molecules in the development of endometriosis.
3. The distorted distribution of BMP-7 demonstrated in the peritoneal fluid of patients with endometriosis may be a significant factor affecting decidualisation in patients with endometriosis. In consequence, it may lead to the problems with conception and miscarriages occurring in those women.

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FIREFIGHTERS HEAT LOAD VS. THE SPECIALISED CLOTHING

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Abstract:
The heat load is one of the main causes of health hazard among firefighters. Excessive increase in body temperature can reduce the ability to assess the situation or leads to reduced performance and increased accidents at work. Therefore, the aspect of properly selected clothing that allows heat exchange between the human and the environment is very important.
One of the factors affecting the heat exchange between human and the environment is the thermal insulation of the clothing. In the tests, with the use of a thermal manikin, the thermal insulation of the currently used special clothing was measured. Based on the obtained results, the firefighter's heat load was estimated by indicators: PMV and WBGT, taking into account 4 classes of metabolic rate. The ranges of comfort temperature for mentioned activities have been determined.
Based on the test results and calculations, it was shown that special clothing is a barrier in heat exchange between the user and the environment.

Keywords:
heat load, clothes, PMV, WBGT, thermal insulation

Introduction

Firefighters often work in difficult environmental conditions. During work, they participate, inter alia in rescue and fire-fighting operations, or in removing the effects of accidents or natural disasters. In order to protect, not only others but also themselves, they must be as focused as possible when performing their tasks . Optimal conditions for such work should create the so-called thermal comfort, characterized by a thermoneutral state of the human body.

The feeling of the thermal comfort is influenced inter alia by the type of used protective clothing. It provides protection, e.g. against high temperature, but can also become an obstacle to heat exchange - a barrier that does not let for transport heat from the human body (which was produced e.g. during physical effort). In such situations, the firefighter may be exposed to heat load. The heat produced by the human body cannot be transported outside causing its accumulation inside the organism. Excessive increase in body temperature can reduce the ability to assess the situation or lead to reduced performance and increased accidents at work [1]. The heat load caused by high temperature is also one of the main causes of health hazard among firefighters [2]. Therefore, it

should not allow the situation of large heat accumulation in the human body. That is why choosing the right protective clothing for firefighter is so important

Clothing used by firefighters should meet a number of requirements regarding: vapor permeability, resistance to mechanical damage and visibility, especially in difficult weather conditions. In addition, clothing should not restrict the firefighter's movements and prevent him from performing his duties [1]. All personal protective equipment used by firefighters in Poland, including special clothing, is classified in category III - they are subject to evaluation in accredited laboratories. The result of this process is the EC type-examination certificate, which confirms compliance with the requirements of Directive 89/686/EEC, in particular PN-EN 469 (according to [3]).

There are also a number of internal documents in which these requirements must be met [1]. Special clothing consists of a jacket and pants that meet the requirements of PN-EN 469 [4]. It has a multilayer structure, and each of its elements has an appropriate protective function [5].

This article presents research on the heat protection of special clothing sets used in Poland. Then, based on this results, the heat load indices were calculated to show the range of temperature when the firefighter should feeling thermal comfort.

Thermal insulation of the specialised clothing for firefighters

One of the factors affecting the heat exchange between human and the environment is the thermal insulation (heat protection) of the clothing. The thermal insulation tests are performed using a thermal manikin and a climatic chamber. In the tests carried out at CIOP-PIB, a Newton type manikin (Fig. 1) [5] and a Weiss type climatic chamber were used.

Fig. 1. Thermal manikin Newton
Source: own photo

Three sets of currently used and commercially available special clothing were selected for testing (Fig. 2) [5]. The tested ensembles differed only in the percentage of aramid fibers.

Fig. 2. An example of a set of special clothing for a firefighter on a thermal manikin
Source: own photo

Thermal insulation tests were done according to standards: PN-EN ISO 15831 [6] and PN-EN 342 [7]. For the measurement of thermal insulation, the heat exchange mode was used while maintaining a constant manikin's surface temperature of 34 °C, with variable power supplied to each segment of the manikin (depending on the clothing set tested). Total thermal insulation (I_T) was calculated on the basis of formula (1):

$$I_T = \frac{(t_s - t_a) \times A}{H_c} \quad (1)$$

where:

t_s – mean temperature of manikin's surface [°C];

t_a – air temperature inside the climatic chamber [°C];

A – total area of the manikin [m^2];

H_c – total heat power delivered to the manikin [W].

The obtained values of the total thermal insulation of clothing ensembles are presented in Tab. 1 [5].

Tab. 1. The total thermal insulation of specialised clothing

	Ensemble 1	Ensemble 2	Ensemble 3	Mean value
I_T, $m^{2o}C/W$	0.274	0.263	0.262	0.266
Sd	0.002	0.001	0.002	0.007

Source: own calculation and [5]

The obtained thermal insulation values were similar, therefore the average value from the above three sets of clothing was used to calculate the thermal load.

Thermal load of firefighters

An imbalance in heat exchange between human and the environment leads to the accumulation of heat in the body. One of the elements affecting the proper heat exchange is the clothing used. Based on the obtained results (thermal insulation), two indicators of the heat load of a firefighter (dressed in special clothing), were estimated:

- PMV (Predicted Mean Vote) [8];
- WBGT (Wet Bulb Globe Temperature) [9].

PMV index

The PMV (Predicted Mean Vote) index is used to assess the feeling of thermal comfort in closed space [8]. It is a function of many variables, including metabolic rate and thermal insulation of clothing.

The abovementioned indicator was estimated (assuming that a worker is wearing special clothing) for 4 metabolic rate classes (light work 100 W/m^2, average work 165 W/m^2, heavy work 230 W/m^2, very heavy work 260 W/m^2) in depending on the air temperature [8] (Fig. 3).

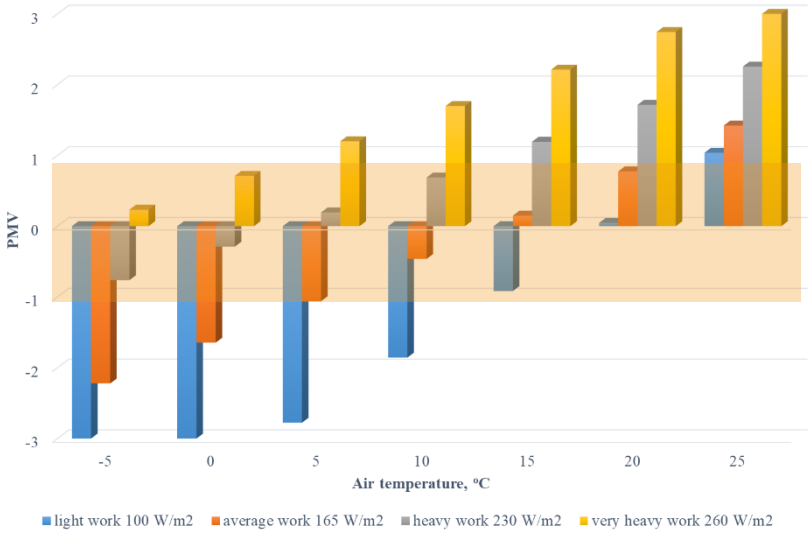

Fig. 3. The value of the PMV index depending on the air temperature (for the special clothing used)
Source: own calculation

According to Fig. 3, performing heavy work by firefighters dressed in special clothing (e.g. during rescue operations), in conditions close to thermal comfort may only take place when the air temperature would not exceed approx. 5 °C.

WBGT index

Calculations of the firefighter's heat load value (WBGT index) were carried out, based on the standard PN-EN ISO 7243 [9]. The calculations also took into account the effect of clothing ($WBGT_{eff}$), by using the CAV (*clothing adjustment value*) factor:

– CAV=0 – standard work clothes,
– CAV=13 – simulation of special clothing with additional headgear.

The obtained $WBGT_{eff}$ values depending on the air temperature are shown in Fig. 4. The figure also includes the allowable (critical) values of WBGT during heavy (415 W) and very heavy (520 W) work.

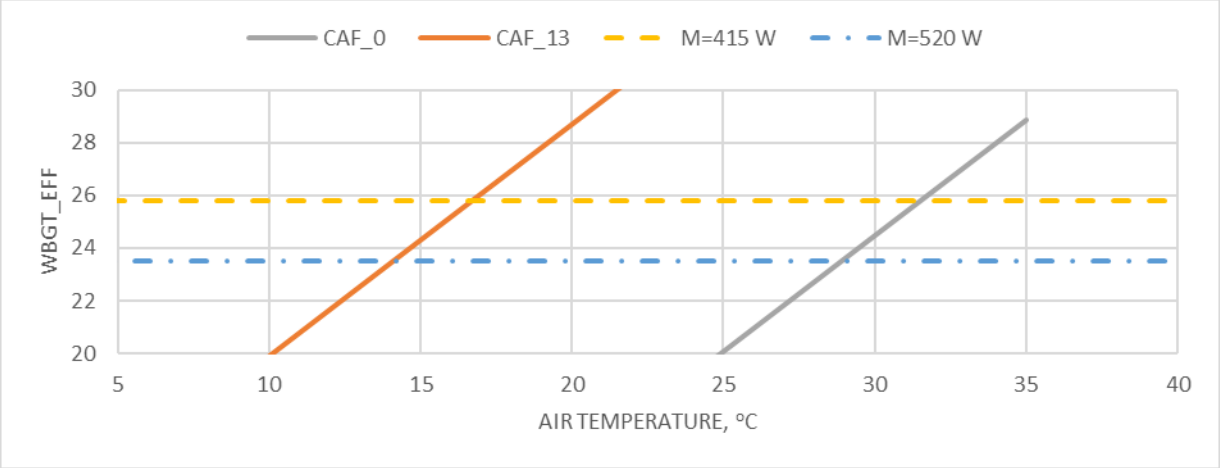

Fig. 4. The dependence of $WBGT_{eff}$ on air temperature (assuming $t_g = t_a$, $V_a = 0.45$ m / s, RH = 50%), for different sets of clothing with critical values of WBGT for metabolic rates 415 W and 520 W
Source: own calculation and [10]

Based on the Fig. 4, it can be concluded that a worker performing heavy work (415 W) dressed in work clothes can be exposed during a work shift to an environment with an air temperature <31.5 °C. However, when using special clothing (barrier clothing with a headgear), the temperature should be <16.5 °C. In the case of very hard work (520W), a worker dressed in work clothes or special clothing (with a headgear) could work in air temperatures <29 °C and <14 °C, respectively.

Summary

The analysis of assessments feeling of thermal comfort and the analysis of the conditions of thermal comfort (PMV index) of users of special clothing showed that at an air temperature of 20 °C, the firefighter could feel thermal comfort, he should only perform light work.

At 25 °C, doing light work (by firefighter wearing special clothing) already causes feeling of thermal discomfort. Special clothing is a barrier to heat exchange between the user and the environment. The clothing caused that only at lower air temperature can firefighters perform their work in thermal comfort conditions. During rescue operations, firefighters experience thermal

discomfort and air temperature ranges considered as comfortable are often exceeded. For firefighters wearing special clothing, the WBGT limit values are often exceeded during rescue operations.

Concluded, the firefighters are exposed not only to external factors, but also to heat produced from their own bodies.

To reduce the negative effects of heat load (caused by clothing and temperature), it is recommended to include frequent rotations of firemen during rescue operations to prevent excessive heat load on the their bodies.

New solutions are constantly being sought to improve the heat exchange between the firefighter and the environment without the negative impact of the external environment on the firefighter's body

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PROMOVENDI

Oferujemy:
- skład i łamanie tekstu,
- wydruk książek abstraktów
i monografii z numerem ISBN,
- oprawę graficzną wydruków,
- organizację konferencji,
- pomoc w organizacji konferencji,
- obsługę informatyczną
i administracyjną konferencji.