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ЕЖЕМЕСЯЧНЫЙ НАУЧНЫЙ ЖУРНАЛ

Медицинские новости Грузии

საქართველოს სამედიცინო სიახლენი

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თანამშრომლობითა და მისი პატრონაჟით

ЕЖЕМЕСЯЧНЫЙ НАУЧНЫЙ ЖУРНАЛ

ТБИЛИСИ - НЬЮ-ЙОРК

GMN: Georgian Medical News is peer-reviewed, published monthly journal committed to promoting the science and art of medicine and the betterment of public health, published by the GMN Editorial Board and The International Academy of Sciences, Education, Industry and Arts (U.S.A.) since 1994. **GMN** carries original scientific articles on medicine, biology and pharmacy, which are of experimental, theoretical and practical character; publishes original research, reviews, commentaries, editorials, essays, medical news, and correspondence in English and Russian.

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GMN: Медицинские новости Грузии - ежемесячный рецензируемый научный журнал, издаётся Редакционной коллегией и Международной академией наук, образования, искусств и естествознания (IASEIA) США с 1994 года на русском и английском языках в целях поддержки медицинской науки и улучшения здравоохранения. В журнале публикуются оригинальные научные статьи в области медицины, биологии и фармации, статьи обзорного характера, научные сообщения, новости медицины и здравоохранения.

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GMN: Georgian Medical News – საქართველოს სამედიცინო სიახლენი – არის ყოველთვიური სამეცნიერო სამედიცინო რეცენზირებადი ჟურნალი, გამოიცემა 1994 წლიდან, წარმოადგენს სარედაქციო კოლეგიისა და აშშ-ის მეცნიერების, განათლების, ინდუსტრიის, ხელოვნებისა და ბუნებისმეტყველების საერთაშორისო აკადემიის ერთობლივ გამოცემას. GMN-ში რუსულ და ინგლისურ ენებზე ქვეყნდება ექსპერიმენტული, თეორიული და პრაქტიკული ხასიათის ორიგინალური სამეცნიერო სტატიები მედიცინის, ბიოლოგიისა და ფარმაციის სფეროში, მიმოხილვითი ხასიათის სტატიები.

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тел.: 995(32) 254 24 91, 5(55) 75 65 99
Fax: +995(32) 253 70 58, e-mail: ninomikaber@geomednews.com; nikopir@geomednews.com

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CONTACT ADDRESS IN TBILISI

GMN Editorial Board
7 Asatiani Street, 4th Floor
Tbilisi, Georgia 0177

Phone: 995 (32) 254-24-91
995 (32) 253-70-58
Fax: 995 (32) 253-70-58

CONTACT ADDRESS IN NEW YORK

NINITEX INTERNATIONAL, INC.
3 PINE DRIVE SOUTH
ROSLYN, NY 11576 U.S.A.

Phone: +1 (917) 327-7732

WEBSITE

www.geomednews.com

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1. Статья должна быть представлена в двух экземплярах, на русском или английском языках, напечатанная через **полтора интервала на одной стороне стандартного листа с шириной левого поля в три сантиметра**. Используемый компьютерный шрифт для текста на русском и английском языках - **Times New Roman** (**Кириллица**), для текста на грузинском языке следует использовать **AcadNusx.** Размер шрифта - **12**. К рукописи, напечатанной на компьютере, должен быть приложен CD со статьей.

2. Размер статьи должен быть не менее десяти и не более двадцати страниц машинописи, включая указатель литературы и резюме на английском, русском и грузинском языках.

3. В статье должны быть освещены актуальность данного материала, методы и результаты исследования и их обсуждение.

При представлении в печать научных экспериментальных работ авторы должны указывать вид и количество экспериментальных животных, применявшиеся методы обезболивания и усыпления (в ходе острых опытов).

4. К статье должны быть приложены краткое (на полстраницы) резюме на английском, русском и грузинском языках (включающее следующие разделы: цель исследования, материал и методы, результаты и заключение) и список ключевых слов (key words).

5. Таблицы необходимо представлять в печатной форме. Фотокопии не принимаются. **Все цифровые, итоговые и процентные данные в таблицах должны соответствовать таковым в тексте статьи**. Таблицы и графики должны быть озаглавлены.

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В подписях к микрофотографиям следует указывать степень увеличения через окуляр или объектив и метод окраски или импрегнации срезов.

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http://www.spinesurgery.ru/files/publish.pdf и http://www.nlm.nih.gov/bsd/uniform_requirements.html
В конце каждой оригинальной статьи приводится библиографический список. В список литературы включаются все материалы, на которые имеются ссылки в тексте. Список составляется в алфавитном порядке и нумеруется. Литературный источник приводится на языке оригинала. В списке литературы сначала приводятся работы, написанные знаками грузинского алфавита, затем кириллицей и латиницей. Ссылки на цитируемые работы в тексте статьи даются в квадратных скобках в виде номера, соответствующего номеру данной работы в списке литературы. Большинство цитированных источников должны быть за последние 5-7 лет.

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Please note, materials submitted to the Editorial Office Staff are supposed to meet the following requirements:

1. Articles must be provided with a double copy, in English or Russian languages and typed or compu-ter-printed on a single side of standard typing paper, with the left margin of **3** centimeters width, and **1.5** spacing between the lines, typeface - **Times New Roman** (**Cyrillic**), print size - **12** (referring to Georgian and Russian materials). With computer-printed texts please enclose a CD carrying the same file titled with Latin symbols.

2. Size of the article, including index and resume in English, Russian and Georgian languages must be at least 10 pages and not exceed the limit of 20 pages of typed or computer-printed text.

3. Submitted material must include a coverage of a topical subject, research methods, results, and review.

Authors of the scientific-research works must indicate the number of experimental biological species drawn in, list the employed methods of anesthetization and soporific means used during acute tests.

4. Articles must have a short (half page) abstract in English, Russian and Georgian (including the following sections: aim of study, material and methods, results and conclusions) and a list of key words.

5. Tables must be presented in an original typed or computer-printed form, instead of a photocopied version. **Numbers, totals, percentile data on the tables must coincide with those in the texts of the articles.** Tables and graphs must be headed.

6. Photographs are required to be contrasted and must be submitted with doubles. Please number each photograph with a pencil on its back, indicate author's name, title of the article (short version), and mark out its top and bottom parts. Drawings must be accurate, drafts and diagrams drawn in Indian ink (or black ink). Photocopies of the X-ray photographs must be presented in a positive image in **tiff format**.

Accurately numbered subtitles for each illustration must be listed on a separate sheet of paper. In the subtitles for the microphotographs please indicate the ocular and objective lens magnification power, method of coloring or impregnation of the microscopic sections (preparations).

7. Please indicate last names, first and middle initials of the native authors, present names and initials of the foreign authors in the transcription of the original language, enclose in parenthesis corresponding number under which the author is listed in the reference materials.

8. Please follow guidance offered to authors by The International Committee of Medical Journal Editors guidance in its Uniform Requirements for Manuscripts Submitted to Biomedical Journals publication available online at: http://www.nlm.nih.gov/bsd/uniform_requirements.html
http://www.icmje.org/urm_full.pdf
In GMN style for each work cited in the text, a bibliographic reference is given, and this is located at the end of the article under the title "References". All references cited in the text must be listed. The list of references should be arranged alphabetically and then numbered. References are numbered in the text [numbers in square brackets] and in the reference list and numbers are repeated throughout the text as needed. The bibliographic description is given in the language of publication (citations in Georgian script are followed by Cyrillic and Latin).

9. To obtain the rights of publication articles must be accompanied by a visa from the project instructor or the establishment, where the work has been performed, and a reference letter, both written or typed on a special signed form, certified by a stamp or a seal.

10. Articles must be signed by all of the authors at the end, and they must be provided with a list of full names, office and home phone numbers and addresses or other non-office locations where the authors could be reached. The number of the authors (co-authors) must not exceed the limit of 5 people.

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12. Sending in the works that have already been assigned to the press by other Editorial Staffs or have been printed by other publishers is not permissible.

Articles that Fail to Meet the Aforementioned Requirements are not Assigned to be Reviewed.

ავტორთა საყურადღებოდ!

რედაქციაში სტატიის წარმოდგენისას საჭიროა დავიცვათ შემდეგი წესები:

1. სტატია უნდა წარმოადგინოთ 2 ცალად, რუსულ ან ინგლისურ ენებზე,დაბეჭდილი სტანდარტული ფურცლის 1 გვერდზე, 3 სმ სიგანის მარცხენა ველისა და სტრიქონებს შორის 1,5 ინტერვალის დაცვით. გამოყენებული კომპიუტერული შრიფტი რუსულ და ინგლისურენოვან ტექსტებში - **Times New Roman (Кириллица)**, ხოლო ქართულენოვან ტექსტში საჭიროა გამოვიყენოთ **AcadNusx.** შრიფტის ზომა – 12. სტატიას თან უნდა ახლდეს CD სტატიით.

2. სტატიის მოცულობა არ უნდა შეადგენდეს 10 გვერდზე ნაკლებს და 20 გვერდზე მეტს ლიტერატურის სიის და რეზიუმეების (ინგლისურ,რუსულ და ქართულ ენებზე) ჩათვლით.

3. სტატიაში საჭიროა გაშუქდეს: საკითხის აქტუალობა; კვლევის მიზანი; საკვლევი მასალა და გამოყენებული მეთოდები; მიღებული შედეგები და მათი განსჯა. ექსპერიმენტული ხასიათის სტატიების წარმოდგენისას ავტორებმა უნდა მიუთითონ საექსპერიმენტო ცხოველების სახეობა და რაოდენობა; გაუტკივარებისა და დაძინების მეთოდები (მწვავე ცდების პირობებში).

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5. ცხრილები საჭიროა წარმოადგინოთ ნაბეჭდი სახით. ყველა ციფრული, შემაჯამებელი და პროცენტული მონაცემები უნდა შეესაბამებოდეს ტექსტში მოყვანილს.

6. ფოტოსურათები უნდა იყოს კონტრასტული; სურათები, ნახაზები, დიაგრამები - დასათაურებული, დანომრილი და სათანადო ადგილას ჩასმული. რენტგენოგრამების ფოტოასლები წარმოადგინეთ პოზიტიური გამოსახულებით **tiff** ფორმატში. მიკროფოტოსურათების წარწერებში საჭიროა მიუთითოთ ოკულარის ან ობიექტივის საშუალებით გადიდების ხარისხი, ანათალების შეღებვის ან იმპრეგნაციის მეთოდი და აღნიშნოთ სურათის ზედა და ქვედა ნაწილები.

7. სამამულო ავტორების გვარები სტატიაში აღინიშნება ინიციალების თანდართვით, უცხოურისა – უცხოური ტრანსკრიპციით.

8. სტატიას თან უნდა ახლდეს ავტორის მიერ გამოყენებული სამამულო და უცხოური შრომების ბიბლიოგრაფიული სია (ბოლო 5-8 წლის სიღრმით). ანბანური წყობით წარმოდგენილ ბიბლიოგრაფიულ სიაში მიუთითეთ ჯერ სამამულო, შემდეგ უცხოელი ავტორები (გვარი, ინიციალები, სტატიის სათაური, ჟურნალის დასახელება, გამოცემის ადგილი, წელი, ჟურნალის №, პირველი და ბოლო გვერდები). მონოგრაფიის შემთხვევაში მიუთითეთ გამოცემის წელი, ადგილი და გვერდების საერთო რაოდენობა. ტექსტში კვადრატულ ფჩხილებში უნდა მიუთითოთ ავტორის შესაბამისი N ლიტერატურის სიის მიხედვით. მიზანშეწონილია, რომ ციტირებული წყაროების უმეტესი ნაწილი იყოს 5-6 წლის სიღრმის.

9. სტატიას თან უნდა ახლდეს: ა) დაწესებულების ან სამეცნიერო ხელმძღვანელის წარდგინება, დამოწმებული ხელმოწერითა და ბეჭდით; ბ) დარგის სპეციალისტის დამოწმებული რეცენზია, რომელშიც მითითებული იქნება საკითხის აქტუალობა, მასალის საკმაობა, მეთოდის სანდოობა, შედეგების სამეცნიერო-პრაქტიკული მნიშვნელობა.

10. სტატიის ბოლოს საჭიროა ყველა ავტორის ხელმოწერა, რომელთა რაოდენობა არ უნდა აღემატებოდეს 5-ს.

11. რედაქცია იტოვებს უფლებას შეასწოროს სტატია. ტექსტზე მუშაობა და შეჯერება ხდება საავტორო ორიგინალის მიხედვით.

12. დაუშვებელია რედაქციაში ისეთი სტატიის წარდგენა, რომელიც დასაბეჭდად წარდგენილი იყო სხვა რედაქციაში ან გამოქვეყნებული იყო სხვა გამოცემებში.

აღნიშნული წესების დარღვევის შემთხვევაში სტატიები არ განიხილება.

Содержание:

COMPARISON OF WEARABLES FOR SELF-MONITORING OF HEART RATE IN CORONARY REHABILITATION PATIENTS

[1,2]Heyken M., [1,3]Horstmann H., [2]Kerling A., [4]Albrecht K., [5]Kedia G., [2]Kück M., [2]Tegtbur U., [2]Hanke A.A.

[1]The authors contributed equally to the work and share first authorship
[2]Institute of Sports Medicine, Hannover Medical School, Hannover, Germany
[3]Department of Orthopedic Surgery, Diakovere Annastift, Hannover, Germany
[4]Brandenburg State Institute for Legal Medicine, Potsdam, Germany
[5]Department of Urology, Diakovere Friederikenstift, Hannover, Germany

The world's leading cause of morbidity and mortality is ischemic heart disease [2,48]. Physical activity (PA) is one major aspect in prevention and therapy of ischemic cardiovascular disease. Several recommendations and guidelines have been established to guide physical activity (PA) in these patients [4,15,16,22,27,32,39]. However, recommendations include 2-5 sessions per week with a duration of 20 to 60 minutes each and an intensity of 50% of the maximum heart rate (HR) for endurance training [16,32]. In Germany, the health insurance companies cover the costs for participation in heart rehabilitation sport groups for 90 units (regular duration) over a period of 30 months [6]. Thus, according to previous mentioned recommendations it is necessary for patients to perform training sessions without attended monitoring as established during PA in rehabilitation sport groups. In this context self-monitoring of HR comes into play to guide intensity of non-supervised PA. While mobile HR monitoring with a chest band was gold standard for a long time, in 2013 the first wrist-worn HR monitor continuously measuring HR without chest band appeared on the ISPO (international sporting goods trade fair, Munich, Germany). The Mio Alpha, released by Canadian developer Physical Enterprise, was graduated as 'product of the year' [40].

In contrast to HR monitors with chest band measuring electric impulses directly over the heart according to the principle of electrocardiography (ECG), wrist-worn devices are able to determine pulse rate at the wrist utilizing photoplethysmography, which is a simple optical measurement technology operating with a light source and photodetector to determine volumetric variations of blood circulation in microvascular bed of tissue to derive pulse rate [5].

Light emitting diodes as well as an opto-electronical sensor are installed at the bottom of HR monitors. LEDs emit either green (wavelength of 490-575nm) or red (650-780nm) light impulses that shine approximately three to four millimeters percutaneously. Due to specific algorithms, processing data of reflected light, the HR monitor is able to establish a continuous measuring of pulse rate [1,42].

Henceforth, various manufacturers installed the technique of photoplethysmography for HR monitoring into so-called wearables evolving a new market [21]. Meanwhile, these models are not merely able to measure HR but also offer functions of other activity monitors, such as pedometers, accelerometers, and GPS to provide an individual estimation of activity intensity and energy expenditure [43].

According to the estimates by IDC (International Data Corporation) the Market of wearables will prospectively increase from 113.2 million devices in 2017 to 222.3 devices in 2021 with an annual growth rate of 18.4% [19].

In the present comparative study the accuracy of HR monitoring of seven fitness trackers and smartwatches of popular manufacturers is examined in patients attending supervised cardiac rehabilitation training. Following devices were included: Garmin Forerunner 35, Mio fuse, Fitbit Charge HR (FibitHR), Fitbit Surge (FitbitS), Apple Watch (Series 1) and an inexpensive product distributed by an online electronic shop (Pearl Fitness-Tracker FBT-50.HR PRO.V4). Furthermore, Withings was included as device with different measuring principles using light of different wavelengths and measuring at the fingertip instead of the wrist. Aim of the study was the comparison of display HR readings to actual HR measurements as delivered by gold standard ECG.

Material and methods. Following institutional review board approval this study was conducted in accordance with the Helsinki Declarations and European Union´s Convention on Human Rights and Biomedicine. The study was performed at the Institute of Sports Medicine at Hannover Medical School, Hannover, Germany. Patients in cardiac rehabilitation sport groups were asked to participate by wearing a wrist-worn HR monitor during exercising after oral and written consent. Inclusion criteria were age >18 years and a sinus rhythm on the electrocardiogram (ECG). Exclusion criteria were atrial fibrillation on ECG, pregnancy, or participation in other studies during the last three months. Patients with atrial fibrillation (AF) were excluded to minimize bias produced by pulse loss caused by AF [30].

Devices

Garmin Forerunner 35

Garmin features functions of a GPS, accelerometer and an HR monitor, based on Garmin´s own elevate-technology (*Forerunner® 35 | Garmin*, no date). The optical HR sensor utilizes three LEDs and an electro-optic lens enabling continuous HR monitoring. Frequency of measurements depends on user's activity.

Mio Fuse

Mio features functions of a triaxial accelerometer and an HR monitor, based on the patented technology of Mio Global in cooperation with Philips Electronics Technologies Research [34]. HR monitoring is enabled by two LEDs and an electro-optic lens, measuring the blood flow of capillaries and processing data due to a complex algorithm to a continuous HR [33].

Fitbit Charge HR

FitbitHR features functions of a 3-axis accelerometer, an altimeter and an HR monitor, based on Fitbit´s own PurePulse technology [9]. Due to green LED light, being absorbed and reflected by the skin, both FitbitHR and FitbitS are able to detect changes of blood flow. The so-called "PurePulse" technology uses the data processing a continuous HR [10].

Fitbit Surge

In addition to the function of an altimeter, triaxial accelerometer and an HR monitor of its predecessor FitbitHR, FitbitS also features functions of a GPS and a triaxial gyroscope. The technology of HR monitoring of FitbitS is also based on Fitbit´s own PurePulse technology with green LEDs and an opto-electronical sensor [41].

Withings Pulse™ Ox

Withings features functions of a triaxial accelerometer, gyro sensor, altimeter and an HR monitor [47]. The HR monitor uses an opto-electronic sensor and in contrast to wrist-worn devices, red LEDs to measure HR at the fingertip of the index finger.

The sensor detects slight variation in color of the skin that are synchronous to the user's pulse [17].

Apple Watch Series 1

Apple features functions of an accelerometer, gyro sensor and an HR monitor [3]. Apple uses green LEDs and light-sensitive photodiodes, which determine HR according by photoplethysmography. To compensate low signal levels, Apple is able to raise brightness and scanning frequency [20].

Pearl Fitness-Tracker FBT-50.HR PRO.V4 (Pearl FT)

Pearl is a distributor of inexpensive technical products. Pearl provides a continuous HR monitoring featured by two green LEDs and a photoelectrical sensor [38].

Procedures. During routine exercise in cardiac rehabilitation groups participants performed training on bicycle ergometers and were routinely connected to an ECG (Ergoline ERS 2, Ergoline GmbH, Bitz, Germany). To ensure that HR monitors were worn adequately, the devices' correct placement was confirmed by the same examiner on every participant complying with the manufacturer's instructions. Most manufacturers recommend to wear the HR monitor two to three finger's breadth proximal to processus styloideus ulnae [37]. The devices were attached close-fitting to prevent movement, without limiting circulation. Jewellery and watches were removed to limit bias. In addition, the patients were asked to grab the handlebar and to sit upright. The bicycle ergometer protocol lasted 20 minutes with a 4 minutes warm-up of increasing resistance and a 16 minute constant load phase, followed by 2 minutes of cool-down. In the course of rehabilitation, the workout resistance was individually adapted to the state of health and performance level of every participant. To avoid errors from readout of measured values, every measurement was supervised by the examiner. Display HR readings as well as ECG HR values were recorded simultaneously at six predefined time-points during training: at minutes 0, 4, 8, 12, 16, and 20.

Data analysis was performed utilizing Microsoft Excel for Windows (Microsoft, Redmont, WA, USA) and GraphPad Prism 6 (GraphPad Software, La Jolla, CA, USA). Data are displayed as mean±standard deviation (SD) and the range as applicable. Distribution of gender was tested by a chi-square test. Differences of load during training (in watt during constant load phase), age and heartrate were compared by a one-way ANOVA for unrepeated measures with Tukey *post-hoc* analysis to assess differences between the groups.

To analyze correlation and to demonstrate accuracy, Pearson's correlations and Bland-Altman-Plots were prepared after positive testing of normal distribution by a Kolmogorov Smirnov test. A p value below 0.05 was considered to be significant. Correlation was assigned into three different groups: excellent, reasonable, and poor. A coefficient of determination (R square - R^2) above 0.95 was considered to be excellent, while a R^2 from 0.95-0.85 was considered to be reasonable and below 0.85 to be poor.

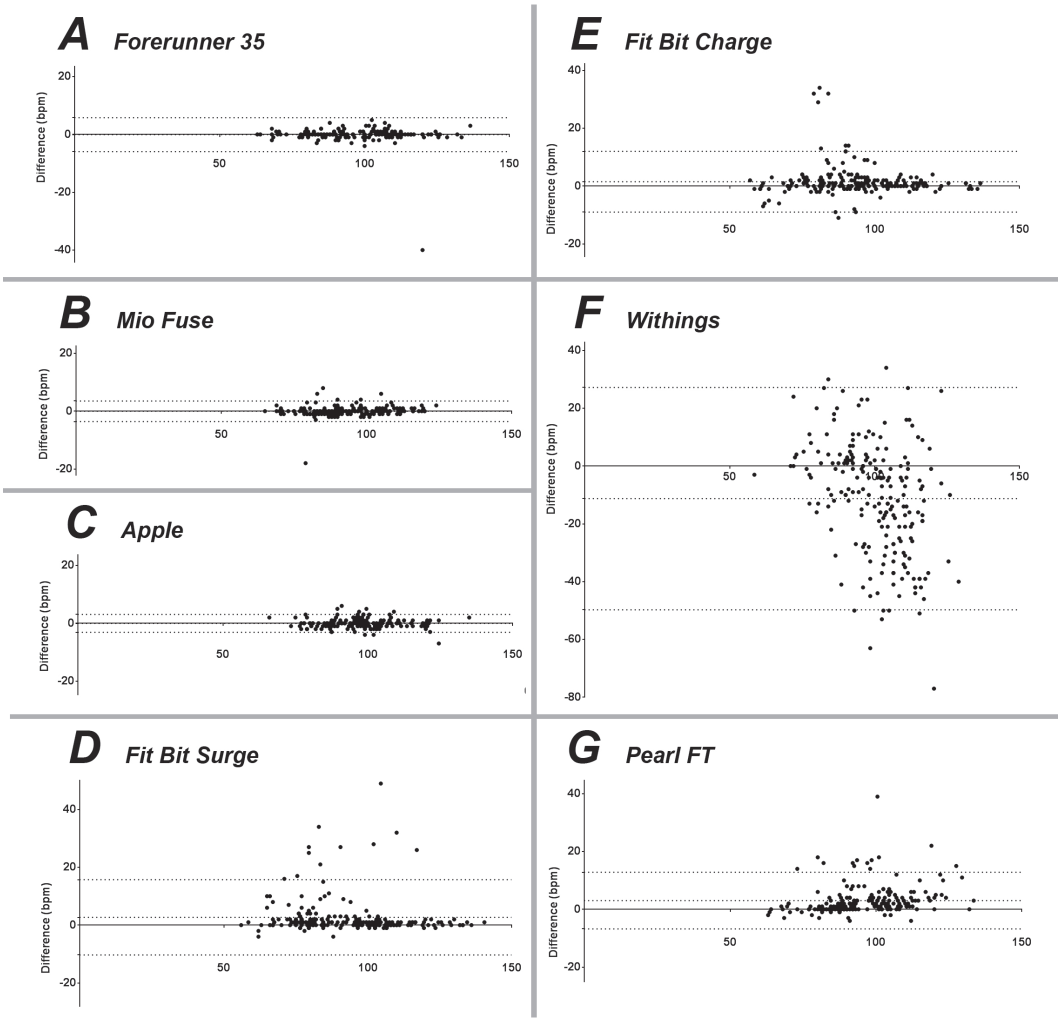

Fig. 1 (panels A-G): Bland-Altman-Plots of results. Dots display calculated differences between measurements. X-axis indicates HR as assessed by ECG. Y-axis shows differences of HR readings between ECG and devices. Dotted lines indicate upper and lower 95% confidence intervals as well as average difference between HR readings

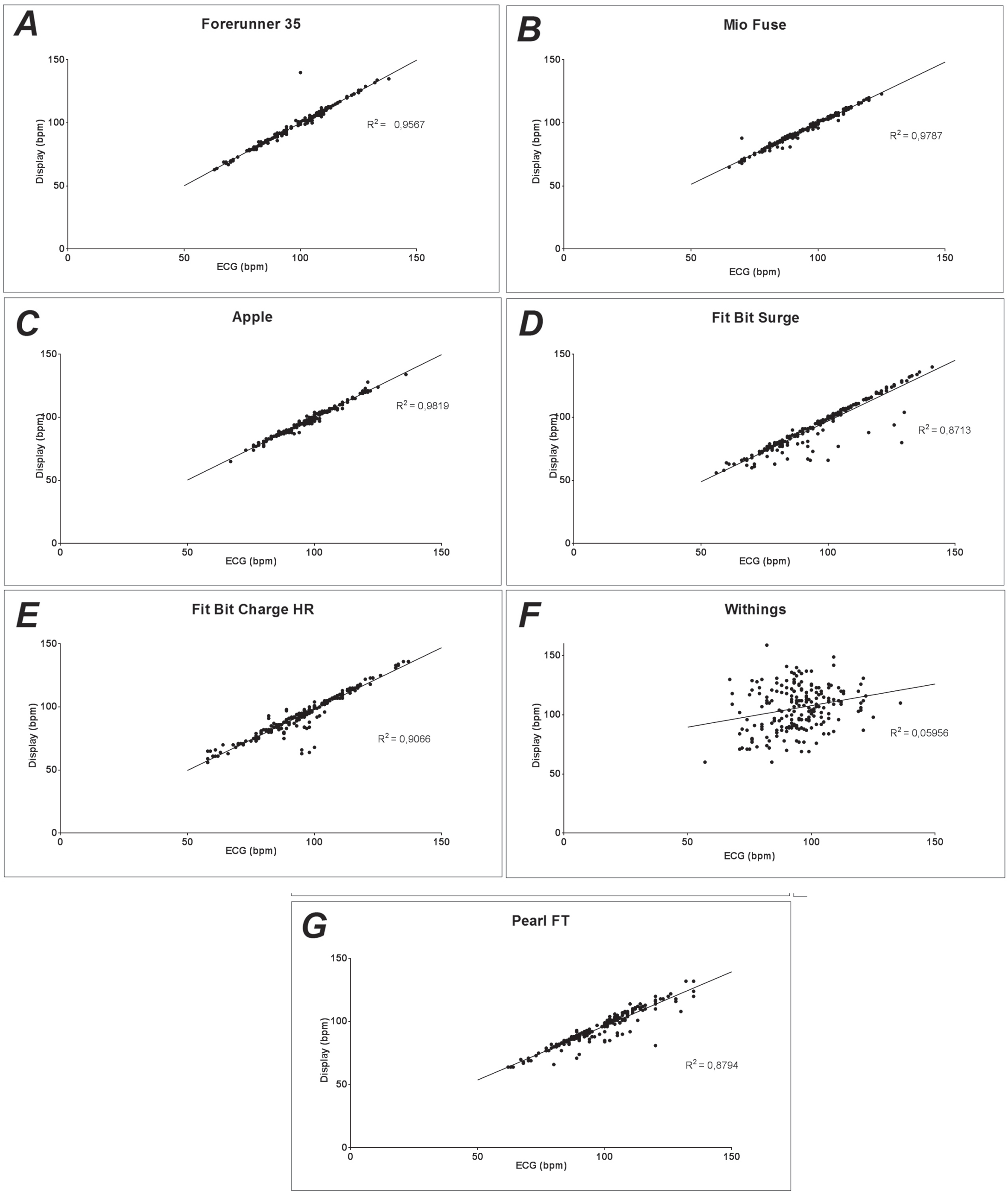

Fig. 2 (panels A-G): Pearson's correlation of measurements. The coefficient of determination (R^2) for each correlation is displayed inside each panel

Results and discussion. Every device has been tested on 35 patients, collecting 210 measurements, respectively. Thus, 1470 HR measurements were recorded across all devices. Average age of participants was 69.6 y.o. (range 48-88 years); all had cardiac underlying diseases, but nevertheless a sinus rhythm. 104 participants were male, and 54 were female without differences between groups. Average HR has been 96bpm (±14.5bpm; range 56-141bpm) without differences between groups. Average constant load was 67.8W (±25W; range 10-110W) with no differences between groups.

Accuracy of measurements is displayed in Bland-Altman-Plots of differences between measurements of ECG and HR monitors (Fig. 1).

Correlation of measurements is shown in Fig. 2. According to the coefficient of determination (R^2) excellent correlation between measurements was attained by Apple (R^2=0.9819), Mio (R^2=0.9787) and Garmin (R^2=0.9567). Reasonable correlation was shown by FitbitHR (R^2=0.9066), Pearl FT (R^2=0.8794), and FitbitS (R^2=0.8713), while Withings (R^2=0.0596) presented poor correlation.

Aim of this study was to validate results of up-to-date wrist-worn HR monitors during supervised cardiac rehabilitation training in comparison to ECG-monitoring as existing gold standard under clinical conditions.

According to Terbizan et al., suggesting a minimum correlation of 0.9 in 2002 is acceptable for the use by a recreational athlete without any medical application [44]. Accuracy of the seven tested HR monitors can be subdivided into three groups: Apple, Mio and Garmin performed with excellent correlation to ECG results and thus are of possible value for cardiac patients.

FitbitHR, FitbitS, and Pearl FT exposed reasonable correlations to ECG standard, meeting criteria for recreational use. Withings achieved poor correlation to ECG, which cannot be accepted for use in cardiac patients, nor even for recreational use.

The rapid technical progress brought highly sophisticated electronic devices such as wrist-worn HR monitors into our lives. Before wrist-worn HR monitors came onto market in 2013, chest straps had been indispensable for monitoring of HR under non-clinical conditions. Introducing photoplethysmography for HR monitoring as an uncomplicated alternative, monitoring of HR in daily life became accessible and attractive for everyone.

Even though, wearables were created for recreational use, self-assessment of HR in cardiac rehabilitation patients is of great need, since ECG monitoring can be achieved during supervised training only as stated above. Thus, monitors are used in a more medically applied manner for monitoring of vital parameters when training is performed outside the rehabilitation units and thus, reliability and accuracy become even more important [29].

Few studies have shown that HR interval analysis by HR monitor based on chest straps provide excellent results with differences functionally not relevant [14]. Our study aimed at comparing seven different wrist-worn HR monitors in cardiac rehabilitation patients to ECG in conditions approximated to the reality trial. In contrast to some previous studies, we used ECG as reference measurements instead of using HR monitors with chest strap [28,29].

Our study revealed that the best results were attained by Apple, Mio and Garmin. Similar to our study, Dooley et al. found the highest congruence with ECG for Apple [29]. Our findings show better results for the HR monitor of Garmin compared to FitbitHR, which was contrary to Dooley´s results. In fact, we were testing the Garmin Forerunner 35, while Dooley et al. has been testing Garmin Forerunner 225. Both, the excellent results for Apple and Mio are also supported by the study of Hough et al., having tested wrist-worn HR monitors on cycle ergometer against a chest-worn HR monitor by Polar [18].

The following devices: FitbitHR, Pearl and FitbitS, showed reasonable results with correlations to ECG standard. To some extent, the results are comparable to a previous study that showed reasonable results for FitbitHR (r=0.933), having been tested during a 30-minute treadmill protocol under walking and running intensity [43]. Another study, conducted by Jo et al. tested FitbitHR and FitbitS as well. In this study FitbitHR (r=0.85) also performed better than FitbitS (r=0.77). A further issue is that Jo et al. compared both HR monitors in different sports activities, such as running on treadmill, climbing stairs and plyometric activities [24]. Pearl FT has not been tested yet in any other studies as mentioned above. In a previously published research letter by Wang et al. three of the devices tested here were examined in young, healthy adults exercising on a treadmill with comparable findings [45]. However, they state that cardiac patients increasingly rely on such devices, but neither test subjects nor intensity was comparable to cardiac patients in their study. Thus, we adopted methods to cardiac rehabilitation patients to assess reliability in a closer to life setting.

Although, Withings is mentioned in studies by Kaewkannate et al., Ferguson et al. and Kooiman et al., HR measurement accuracy has not been tested [8,25,26]. There are versatile reasons for the unsatisfactory results of Withings. Possible reasons could be difficult handling of a technique sensitive device during physical activity (e.g. movement between sensor and finger during exertion on bicycle ergometer), or the use of red light instead of green light, which is discussed in more detail below. Furthermore, influences of the converting algorithm of the PPG signal into HR measurements or differing data collection rates are conceivable.

Accuracy of HR monitoring by photoplethysmography may be influenced by the wavelength of the HR monitor. Past studies have shown that in contrast to red light (wavelength 650-780nm), green light (wavelength of 490-575nm) displays superior modulation being relatively free from motion artefacts [7,23,31]. The reason is that the maximum penetration depth of red light is substantially higher than that of green light leading to more motion artefacts, which is in line with our findings. While Withings utilizes red light it performed worst even though used wavelength might not be the only reason for poor correlation with electrocardiogram, but also handling of Withings by measuring at a finger tip.

Based on the technique of photoplethysmography itself the use of such HR monitors in cardiac rehabilitation patients should be evaluated with care. Only the peripheral pulse can be detected causing system dependent limitations for the use of wrist-worn HR monitors [1]. In cases of sinus rhythm, the photoplethysmography can provide accurate values. Thus, HR of patients with disorders of stimulus conduction of the heart normally is not an accurate measurement [30]. Nevertheless, a recent study has shown that photoplethysmography based HR measurement in presence of atrial fibrillation as a common heart rhythm also can be detected, but appropriate hard- and software would be crucial [35]. Further studies are necessary to prove this. However, for reduction of bias we decided to exclude patients without sinus rhythm from the study.

There are many aspects to consider in purchase decisions between tested wearables. One is definitely the price. The tested devices range from around 40€ (Pearl) to 500€ (Apple). A low budget device (like Pearl) has not been tested and compared to major brands in any studies before. It seems remarkable that accuracy of the tested low budget device was found acceptable. Without achieving excellent results of Apple, Mio and Garmin, Pearl´s results were still comparable to the FitBit major brand results. However, since we investigated HR monitoring only, and no other features of the devices included in highly complex smart watches (e.g. Apple) the prices are hard to compare and cannot be the only factor to consider for purchase decisions. Based on our study, we can only give recommendations according to accuracy of the tested parameters.

Limitations. Wrist-worn HR monitors were carefully attached to the patient's wrist according to manufacturer's instructions. However, too small or very large wrists could present as a problem for placing the HR monitor as needed. Moreover, unusual amount of subcutaneous fat could lead to problems with light absorption on which the photoplethysmography principle is based. In addition, poor peripheral perfusion could cause insufficient signaling including patients with low blood pressure as well as high temperature differences of the environment, reducing peripheral blood supply, too [11]. Moreover, former studies have shown that different skin types do have a different capability of light reabsorption, which might lead to divergent results [7].

Since we tested during the cardiac rehabilitation courses, the patients were only using bicycle ergometer under controlled conditions. While performing other more plyometric exercises such as running, swimming or climbing, relating to more motion of the wrist, the results may vary. Jo et al. have shown distinct results with motion artefacts for exercises of high intensity and rapid motion [24]. Consequently, rapid motion of the wrist during sports activities seems to correlate with more deviated measurement results compared to ECG [13,23,42].

The comparison of wrist-worn HR monitor and ECG could lead to a methodical delay in measurements caused by the latency period needed by collecting and processing data and the anatomical location of measurements at wrist (wrist-worn HR monitor) and at chest (ECG). Latency period varies from model to model and can last up to two to five seconds. There is no information furnished by manufacturers about latency period of the models. The anatomical reason for delay depends to a large extent on arm length, elasticity of the arteries and volume mass of the blood, which approximately ranges from 0.05sec to 0.25sec and, to a minor extent, on the velocity of the cardiac conduction [36,46]. Since the subjects were exercising constant endurance activity instead of interval training and we were manually collecting the data in our test setup every four minutes, we consider this not to be of clinical relevance.

Furthermore, gold standard of data assessment of the HR monitors would be a comparison of beat-by-beat accuracy. However, since our purpose was to provide a practical advice, what kind of HR monitor would be useful, we compared the data that are available to the consumer - our patients. Therefore, classification of display readings is of higher value, in our opinion. Moreover, manufacturers of HR monitors do not guarantee access to the raw data of HR monitoring.

A further limitation of this study is the rapidly fluctuating market requirements. Manufacturers are constantly updating their devices, both software by updates and hardware due to new models. The devices we tested might have outdated software and hardware. Scientific studies examining HR monitors are not able to keep up with the volatility of the markets and to present results of new models until later ones appear on the market.

Conclusion. This study investigated the accuracy of HR monitoring on bicycle ergometer of seven wrist worn wearables of different manufacturers in cardiac rehabilitation patients during bicycle ergometer activity. The results of this study are encouraging and point out the potential beneficial use with accurate measurement of HR for non-supervised PA in the following devices: Apple, Mio and Garmin, which showed excellent accuracy. However, the use of FitbitHR, Pearl and FitbitS may also be beneficial with at least reasonable results, whereas Withings showed poor results and cannot be recommended.

Further studies are needed to assess functioning outside of controlled environments in daily life and during different activities. Furthermore, especially in cardiac patients, HR monitoring in presence of arrhythmia and arrhythmia detection would be desirable. Thus, application of such devices in cardiac patients can be of great value but should be recommended with care.

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SUMMARY

COMPARISON OF WEARABLES FOR SELF-MONITORING OF HEART RATE IN CORONARY REHABILITATION PATIENTS

[1,2]Heyken M., [1,3]Horstmann H., [2]Kerling A., [4]Albrecht K., [5]Kedia G., [2]Kück M., [2]Tegtbur U., [2]Hanke A.A.

[1]The authors contributed equally to the work and share first authorship; [2]Institute of Sports Medicine, Hannover Medical School, Hannover, Germany; [3]Department of Orthopedic Surgery, Diakovere Annastift, Hannover, Germany; [4]Brandenburg State Institute for Legal Medicine, Potsdam, Germany; [5]Department of Urology, Diakovere Friederikenstift, Hannover, Germany

The leading cause of morbidity and mortality in the world is ischemic heart disease. Physical activity is a major approach in prevention and therapy of cardiac diseases. Self-heart-rate-monitoring in daily life is an important point for health awareness of cardiac patients. Aim of this study was validation of measurement accuracy of seven different devices against ECG-monitoring during cardiac rehabilitation training on a bicycle ergometer.

Tested devices were: Garmin Forerunner 35 (Garmin), Mio Fuse (Mio), Fitbit Charge HR (FitbitHR), Fitbit Surge (FitbitS), Withings Pulse™ Ox (Withings), Apple Watch Series 1 (Apple) and Pearl Fitness-Tracker (FBT-50.HR PRO.V4). All devices were tested on 35 participants with six timed measurements during 20 minutes constant load bicycle ergometer workout for each. Simultaneousely, ECG measurements were recorded. Pearson´s correlations were assessed.

Apple, Mio, and Garmin showed excellent accuracy with close correlation to ECG for self-monitoring of heart rate (HR) during cycling. FitbitHR, Pearl and FitbitS presented reasonable results. In contrast, Withings showed poor correlation to ECG with significant differences.

We found significant differences between the tested devices. Since accuracy is of major importance for cardiac patients, only Apple, Mio and Garmin could be recommended. However, further research within distinct clinical and non-clinical settings is necessary and should take different types of physical activities into account.

Keywords: Heart rate monitoring, wearable, rehabilitation, photoplethysmography.

РЕЗЮМЕ

СРАВНЕНИЕ НОСИМЫХ УСТРОЙСТВ ДЛЯ САМОКОНТРОЛЯ СЕРДЕЧНОГО РИТМА ВО ВРЕМЯ РЕАБИЛИТАЦИИ У КОРОНАРНЫХ ПАЦИЕНТОВ

[1,2]Хеукен М., [1,3]Хорстманн Х., [2]Керлинг А., [4]Албрехт К., [5]Кедия Г.Т., [1,2,]Кюк М., [2]Тегтбур У., [2]Ханке А.А.

[1]Авторы внесли равный вклад в работу и разделяют первое авторство; [2]Ганноверский медицинский университет, Институт спортивной медицины, Ганновер; [3]Диаковере Аннаштифт, Отделение ортопедической хирургии, Ганновер; [4]Бранденбургский государственный институт судебной медицины, Потсдам; [5]Диаковере Фридерикенштифт, Отделение урологии, Ганновер, Германия

Основной причиной заболеваемости и смертности в мире считается ишемическая болезнь сердца. Физическая активность является основным подходом к профилактике и лечению сердечных заболеваний. Самоконтроль сердечного ритма в повседневной жизни является значимым моментом в выздоровлении кардиологических пациентов.

Целью исследования явилась проверка точности измерений семи различных устройств в сравнении с ЭКГ-мониторингом во время кардиореабилитационных тренировок на велоэргометре.

Исследованы следующие устройства: Garmin Forerunner 35 (Garmin), Mio Fuse (Mio), Fitbit Charge HR (FitbitHR), Fitbit Surge (FitbitS), Withings Pulse™ Ox (Withings), Apple Watch Series 1 (Apple) и Pearl Fitness-Tracker (FBT-50.HR PRO.V4). Все устройства были протестированы на 35 участниках с шестью измерениями на время в течение 20 минут тренировки на велоэргометре с постоянной нагрузкой. Параллельно записывались измерения ЭКГ. Оценены корреляции Pearson-а.

Для самоконтроля сердечного ритма, Apple, Mio и Garmin показали превосходную точность с близкой корреляцией с ЭКГ во время эргометрии. FitbitHR, Pearl и FitbitS показали сопоставимые результаты. В отличие от этого, Withings показал слабую корреляцию с ЭКГ со значительными различиями.

Обнаружили серьезные различия между исследованными устройствами. Поскольку точность имеет большое значение для кардиологических пациентов, с целью самоконтроля сердечного ритма можно порекомендовать только Apple, Mio и Garmin. Однако необходимы дальнейшие исследования в разных клинических и неклинических условиях, которые должны учитывать различные виды спортивной активности.

რეზიუმე

ტარებადი მოწყობილობების შედარება გულისცემის თვითკონტროლისთვის კორონარულ პაციენტებში რეაბილიტაციის პირობებში

[1,2]მ. ჰეუკენ, [1,3]ჰ. ჰორსტმანნ, [2]ა. კერლინგ, [4]კ. ალბრეხტ, [5]გ.კედია, [2]მ. კუეკ, [2]უ. ტეგტბურ, [2]ა.ა. ჰანკე

[1]ავტორებმა შეასრულეს თანაბარი სამუშაო და ინაწილებენ პირველ ავტორობას
[2]ჰანოვერის სამედიცინო უნივერსიტეტი, სპორტული მედიცინის ინსტიტუტი,ჰანოვერი, ერმანია; [3]დიაკოვერე ანნაშტიფტი, ორტოპედიური ქირურგიის განყოფილება, ჰანოვერი, გერმანია; [4]ბრანდენბურგის სასამართლო მედიცინის სახელმწიფო ინსტიტუტი, პოცდამი, ერმანია; [5]დიაკოვერე ფრიდერიკენშტიფტი, უროლოგიის განყოფილება, ჰანოვერი, გერმანია

მსოფლიოში ავადობისა და სიკვდილიანობის ძირითადი მიზეზს წარმოადგენს გულის იშემიური დაავადებაა. ფიზიკური აქტივობა უმთავრესი მიდგომაა გულის დაავადებების პროფილაქტიკაში და თერაპიაში. გულისცემის თვითკონტროლი ყოველდღიურ ცხოვრებაში მნიშვნელოვანია კარდიალური პაციენტების გამოჯანმრთელებაში.

კვლევის მიზანი იყო შვიდი სხვადასხვა მოწყობილობის გაზომვის სიზუსტის შეფასება ელექტროკარდიოგრამის მონიტორინგთან შედარებით პაციენტებში ერგომეტრზე ვარჯიშის დროს.

გამოსაცდილი მოწყობილობები იყო: Garmin Forerunner 35 (Garmin), Mio Fuse (Mio), Fitbit Charge HR (FitbitHR), Fitbit Surge (FitbitS), Withings Pulse™ Ox (Withings), Apple Watch Series 1 (Apple) da Pearl Fitness-Tracker (FBT-50.HR PRO.V4). ყველა მოწყობილობა შემოწმდა 35 მონაწილეზე, ექვს დროული გაზომვით 20 წუთის განმავლობაში მუდმივი დატვირთვისას ერგომეტრზე. პარალელურად დაფიქსირდა ელექტროკარდიოგრამული (ეკგ) გაზომვები. შეფასდა Pearson-ის კორელაციები.

შედეგები: გულისცემის თვითკონტროლისთვის ერგომეტრიის დროს, Apple-მა, Mio-მ და Garmin-მა აჩვენეს შესანიშნავი სიზუსტე ეკგ-სთან მჭიდრო კორელაციით. FitbitHR-მა, Pearl-მა და FitbitS-მა წარმოადგინეს შეჯერებული შედეგები. ამის საპირისპიროდ, Withings-მა აჩვენა სუსტი კორელაცია ეკგ-სთან მნიშვნელოვანი განსხვავებებით.

ავტორების მიერ აღმოჩენილია სერიოზული განსხვავებები ტესტირებულ მოწყობილობებს შორის. ვინაიდან სიზუსტეს უდიდესი მნიშვნელობა აქვს კო-

რონარულ პაციენტებისთვის, მხოლოდ Apple, Mio და Garmin შეიძლება იყოს რეკომენდებული. ამასთანავე, შემდგომი გამოკვლევები აუცილებელია კლინიკურ და არაკლინიკურ გარემოში, სადაც უნდა გათვალისწინებულ იქნას სხვადასხვა სახის სპორტული აქტივობები.

COMBINED PHARMACOLOGICAL THERAPY INCLUDING SEVERAL ANTIARRHYTHMIC AGENTS FOR TREATMENT OF DIFFERENT DISORDERS OF CARDIAC RHYTHM

Kapustnick Yu., Lutsenko R., Sydorenko A.

Poltava State Medical University, Department of Experimental and Clinical Pharmacology, Clinical Immunology and Allergology, Ukraine

In widespread clinical practice, there is often a need for treatment of cardiac arrhythmias with simultaneous administration of antiarrhythmic agents of I or III classes in accordance with Vaughan Williams classification together with antiarrhythmic preparations of II or IV classes (β-blocker adrenergic drugs and calcium channel blocker agents). In severe and stable cardiac arrhythmias combined therapy on the bases of two antiarrhythmic agents, including preparations of I and III classes should be used [12,13,15].

However, at the same time it is necessary to understand well the goals, possible effects and dangers of such combined treatment. The main principle of any combined therapy lines in simultaneous action on different pathological mechanisms, which are the reason of development of cardiac arrhythmia. It allowes to reduce doses of antiarrhythmic agents [2,8].

Under antianginal and hypotensive therapy the combined tratment is often used even during beginning of the illness. However, antiarrhythmic therapy is performed according to other principle. Because only one antiarrhythmic preparation must be used for treatment of arrhythmias in most cases because all antiarrhythmic agents have fairly similar side effects that leads to exacerbation of their side effects that can be under combined therapy [2].

The requirement of combined therapy including the several antiarrhythmic agents for treatment of different disorders of cardiac rhythm arises in the following situations:

1. Monotherapy with administration of only one antiarrhythmic agent is effective. However, a therapeutic dose of the drug causes side effects that requires its correcting. In this case, the complete cancellation of the drug is possible with its replacement by other antiarrhythmic agent, which is effective and well-tolerated, Nevertheless, the possibility of such choice might not be available, because other drugs are not tolerated or ineffective [4,5].

For example, a patient with paroxysmal atrial fibrillation uses amiodarone in daily dose 400 mg with the most complete antiarrhythmic effect (compared to other agents). However, under administration of amiodarone in daily dose 400-600 mg and more in the sunny period of the year such side action as photosensitization can be development. This undesirable effect can be eliminated by reducing the daily dose of amiodarone to 200 mg. In this case amiodarone in the dose 200 mg during the morning must be administered for strengthening of antiarrhythmic effect together with one agent from antiarrhythmic preparation of IC subclass, which must be administered in half daily dose (allapinin 25-50 mg/day or ethacizin 75 mg/day).

2. The effect of antiarrhythmic agent is not complete, but it is impossible to in rease its dose to maximal, because can be development undesirable effects. Sometimes these side effects occur after administration of antiarrhythmic drug in moderate dose. For example, amiodarone was given in the daily dose 300 mg. This dose was sufficient to eliminate paroxysms of atrial fibrillation. In this case other antiarrhythmic agents are not effective. However, after administration of amiodarone in daily dose 300 mg night brady-depended supraventricular extrasystolic arrhythmia occurred. This disorder of cardiac rhythm is poorly tolerated by patient. Besides, supraventricular extrasystolic arrhythmia can be transform in atrial fibrillation. [6,8]. That is why for preventive maintenance of such undesirable effects of amiodarone should be administered the decreased dose of this preparation and additional administration of allapinin in the evening orally in single dose 12,5-25 mg (1/2-1 tablet).

3. Antiarrhythmic monotherapy is effective. However, after administration of one antiarrhythmic agent undesirable side effects are developed. That is why the cancellation of the first antiarrhythmic agent is required. For instance, antiarrhythmic agent of IA subclass quinidine was given orally in dose 200 mg trice a day. But marked sinus tachycardia due to its vagolytic influence developed due to administration of this preparation. Quinidine decreases tonicity of pneumogastric nerve due to cholinolytic action on pacemaker cells in atrioventricular node. For suppression of sinus tachycardia, it is required to cancel quinidine and administration of β-blocker agent or calcium channel blocker drug for example verapamil.

4. All possible antiarrhythmic agents as monotherapy are not effective. In this case the combination of the two ineffective drugs may be effective.

5. A patient has several types of cardiac rhythm disorders, each of which is sensitive to one antiarrhythmic agent only. For example, two variants of paroxysmal tachycardia occurred periodically: 1) verapamil-sensitive reciprocal sinus tachycardia; 2) paroxysmal atrial fibrillation. Bolus administration of 4 ml 0,25% solution (10 mg) of verapamil intravenously is required for suppression of first disorder of cardiac rhythm. Administra-