

Ergometrijski test – jučer i danas. Iz povijesti svjetske i hrvatske kardiologije

Exercise test – Yesterday and Today. From the History of the World and Croatian Cardiology

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SAŽETAK: Test opterećenja ili ergometrijski test nezaobilazna je neinvazivna metoda u dijagnostici koronarne bolesti već desetljećima. Unatoč razvoju drugih suvremenih i sofisticiranih neinvazivnih i invazivnih metoda dijagnosticiranja koronarne bolesti, do današnjih dana ergometrija ne gubi svoje mjesto već je, u pravilu, prva karika u dijagnosticiranju koronarne bolesti srca. U radu je prikazan povijesni razvoj ergometrijskog testa u svijetu i Hrvatskoj.

SUMMARY: The exercise test has for decades been an unavoidable non-invasive method in the diagnosis of coronary artery disease. Despite the development of other modern and sophisticated non-invasive and invasive methods for coronary artery disease diagnosis, the exercise test has not lost its place to this day and is usually the first line in the diagnosis of coronary artery disease. This paper gives an overview of the historical development of exercise testing in the world and in Croatia.

KLJUČNE RIJEČI: test opterećenja, ergometrija, povijest, koronarna bolest srca.

KEYWORDS: exercise test, ergometry, history, coronary artery disease.

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Test opterećenja ili ergometrijski test nezaobilazna je neinvazivna metoda u dijagnostici koronarne bolesti srca (KBS) već desetljećima. Unatoč razvoju drugih suvremenih i sofisticiranih neinvazivnih i invazivnih metoda dijagnosticiranja KBS-a, do današnjih dana ergometrija ne gubi svoje mjesto, već je, u pravilu, prva karika u dijagnosticiranju stabilne KBS, praćenju i evaluaciji potencijalne rezidualne ishemijske koronarne bolesti nakon preboljelog infarkta, perkutanih intervencija i/ili kirurške revaskularizacije miokarda, kao i u objektiviziranju funkcionalnog kapaciteta pojedinog bolesnika. Njezina je prednost u tome što je široko dostupna, jednostavna za izvođenje te pouzdana metoda glede sigurnosti testiranog pacijenta ili bolesnika. Procijenjena specifičnost (mogućnost prepoznavanja normalnih ispitanika) ergometrijskog testiranja na razini je 85 – 90 %, a osjetljivost (mogućnost otkrivanja koronarne bolesti) 60 – 70 %¹⁻³.

Povijesno, početci razvoja današnjeg suvremenog ergometrijskog testiranja sežu i stotinjak godina u prošlost. Još je 1918. godine Bousfield u članku objavljenom u časopisu *Lancet* opisao promjene u elektrokardiogramu (EKG) koronar-

The exercise test has for decades been an unavoidable non-invasive method in the diagnosis of coronary artery disease (CAD). Despite the development of other modern and sophisticated non-invasive and invasive methods for CAD diagnosis, the exercise test has not lost its place to this day and is usually the first step in the diagnosis of stable CAD, monitoring and evaluation of potential residual ischemia in coronary patients after a previous infarction, percutaneous interventions, and/or surgical myocardial revascularization and the objectivization of the functional capacity of individual patients. The advantage of the stress test is that it is a widely accessible, simple to perform, and reliable method especially in relation to the safety of the tested patients. The estimated specificity (ability to recognize normal subjects) of the exercise test is 85-90%, and the sensitivity (ability to discover coronary disease) is 60-70%¹⁻³.

Historically, the beginnings of the development of modern exercise testing reach about a hundred years into the past. Already in 1918, Bousfield published a paper in the *Lancet* journal describing changes in the electrocardiogram

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nog bolesnika s napadajem anginoznog bola u obliku denivelacije ST-segmenta u trima standardnim EKG odvodima^{2,4}. Godine 1928. Feil i Siegel^{2,5} također su opisali promjene u ST-segmentu i T-valu u bolesnika s poznatom anginom pectoris nakon izlaganja tjelesnoj aktivnosti (uzastopno posjedanje i ustajanje) i izazivanja bolova u prsima, kao i njihovu regresiju nakon prestanka aktivnosti ili davanja nitroglicerinskoga pripravka. Master i Oppenheimer^{2,6} vjerojatno su prvi opisali test opterećenja 1929. godine, ali su monitorirali samo kretanje arterijskoga tlaka i frekvencije srca dok tada još nisu dokraja prepoznali potencijalnu vrijednost EKG-a u detekciji ishemije. Dvanaest godina poslije Master i Jaffe⁷ pokazali su korist od analize EKG promjena prije i nakon opterećenja u detekciji ishemije miokarda. Godine 1931. Wood i Wolferth^{2,8} također opisuju EKG promjene vezane za ishemiju izazvanu naporom te ističu korist od izlaganja tjelesnom naporu u detekciji ishemije, ali također navode da je takvo testiranje odviše opasno provoditi u bolesnika s poznatom KBS.

Preteča kasnijem razvoju modernih ergometrijskih protokola bio je jednostavni Masterov „two-step“ test kao i etabliranje Masterovih EKG kriterija u detekciji ishemije miokarda⁹. Temelji današnjega ergometrijskog testiranja postavljene su sredinom 50-ih godina prošlog stoljeća, kada je Bruce¹⁰ opisao test opterećenja na pokretnom sagu. Današnji različiti protokoli ergometrijskog testiranja na pokretnom sagu izvedeni su i imaju temelj u principima koje je 1956. godine postavio Bruce¹⁰. Osim modificiranog Bruceova protokola, važno je spomenuti i simptomima ograničeni (engl. *symptom limited*), submaksimalni Naughtonov ergometrijski protokol koji se u praksi pokazao jednako vrijedan u detekciji ishemijskih promjena u koronarnih bolesnika¹¹.

Godine 1954. Olaf Astrand i Irma Rhyning izradili su nomogram za određivanje maksimalnog aerobnog kapaciteta u step-testu¹² i 1960. godine na biciklu koji se široko primjenjuje u sportskoj medicini i testiranju bolesnika¹³.

Nadalje, 1969. godine objavljeno je više radova vezanih za uporabu računala u analizi oscilacija ST-T-segmenta¹⁴. Ubrzo potom objavljeno je nekoliko izvještaja vezanih za korelaciju detektiranih ishemijskih EKG promjena na ergometrijskom testu s nalazom koronarne angiografije^{15,16}.

Prema dostupnim podacima¹⁷⁻²⁵, prvi izvještaji vezani za razvoj i standardizaciju ergometrijskih testiranja kardioloških bolesnika u Hrvatskoj datiraju s kraja 60-ih godina prošlog stoljeća^{17,18} (slika 1 A i B). Naime, tih je godina u kardiološkom rehabilitacijskom centru Thalassoterapiji u Opatiji tim liječnika pod vodstvom fiziologa prof. dr. sc. Krunoslava Turkulina intenzivno radio na standardizaciji i implementaciji tada inovativne dijagnostičke metode ne samo u Hrvatskoj nego i na prostorima cijele bivše države. U dokumentu „Ergometrija u kardiologiji i pulmologiji“ objavljenom 1971. godine¹⁹ (slika 2 A i B) kojemu je prethodio stručni sastanak u organizaciji Kardiološkog društva Jugoslavije održan u Opatiji, prvi put su detaljno opisani; potrebna tehnička oprema, tipovi testa opterećenja, uvjeti ispitivanja, indikacije i kontraindikacije za testiranje, EKG promjene i klinička primjena testa opterećenja. U predgovoru te publikacije tadašnji direktor opatijske Thalassoterapije i predsjednik Kardiološkog društva bivše države prof. dr. Čedomil Plavišić navodi da „razvoj tehnologije, elektronike i automacije dovodi do korjenitih promjena u cjelokupnoj kliničkoj medicini – naročito na polju dijagnostike. I pored spoznaje da je pravilno ocjenjivanje osnova svakog liječenja i rehabilitacije, metode još nisu ujednačene,

(ECG) of a coronary patients with an anginous pain attack demonstrated as a denivelation of the ST-segment in three standard ECG leads^{2,4}. In 1928, Feil and Siegel^{2,5} also described changes in ST-segment and T-wave in patients with known angina pectoris after exposure to physical activity (repeatedly sitting and standing up) as well as the presence of chest pain and its regression after cessation of the activity or the administration of nitroglycerine medication. Master and Oppenheimer^{2,6} were probably the first to describe an exercise test in 1929, but they only monitored changes in blood pressure and heart frequency, not yet fully recognizing the potential value of ECG in the detection of ischemia. Twelve years later, Master and Jaffe⁷ demonstrated the usefulness of analyzing ECG changes before and after exertion for the detection of myocardial ischemia. In 1931, Wood and Wolferth^{2,8} also described ECG changes associated with ischemia caused by exertion and stressed the usefulness of exposure to physical exertion in the detection of ischemia, while also noting that such tests are too dangerous to perform in patients with diagnosed CAD.

The predecessor for the later development of modern ergometric protocols was Master's simple "two-step" test and the establishment of Master's ECG criteria in the detection of myocardial ischemia⁹. The basics of modern exercise testing were laid down during the 1950s, when Bruce¹⁰ described the treadmill exercise test. Today, the different protocols for treadmill testing are developed and based on the principles set by Bruce in 1956¹⁰. In addition to the modified Bruce protocol, it is important to mention the symptom-limited, submaximal Naught protocol, which has in practice shown itself to be equally valuable in the detection of ischemic changes in coronary patients¹¹.

Olaf Astrand and Irma Rhyning created a nomogram for determining the maximum aerobic capacity in the step test¹² in 1954 and one for the bicycle test in 1960, which is widely applied in sports medicine and testing of patients¹³.

By 1969, numerous papers were published on the use of computers in analyzing ST-T segment oscillations¹⁴. Soon after, several reports were published on the correlation of detected ischemic ECG changes in exercise tests with the results of coronary angiography^{15,16}.

According to available data¹⁷⁻²⁵, the first reports related to the development and standardization of exercise tests for cardiac patients in Croatia date from the end of the 1960s^{17,18} (Figure 1A and 1B). During this period, a team of doctors in the Thalassoterapia Cardiological Rehabilitation Center in Opatija under the leadership of the physiologist Prof. Krunoslav Turkulin intensively worked on the standardization and implementation of a diagnostic method that was innovative at the time not only in Croatia but in the whole region. The document "Ergometrija u kardiologiji i pulmologiji" (Ergometry in cardiology and pulmonology) published in 1971¹⁹ (Figure 2A and 2B), which was preceded by a meeting of experts organized by the Yugoslavian Cardiology Society held in Opatija, was the first to describe the required technical gear, types of tests and exertions, test conditions, indications and contraindications for testing, ECG changes, and the clinical application of the exercise test. In the foreword of this document, the current director of the Thalassoterapia in Opatija and the president of the Yugoslavian Cardiology Society, Prof. Čedomil Plavišić, stated that "the development of technology, electronics, and automation have led to deep-rooted changes in clinical medicine as whole – especially in the field of diagnostics. Even

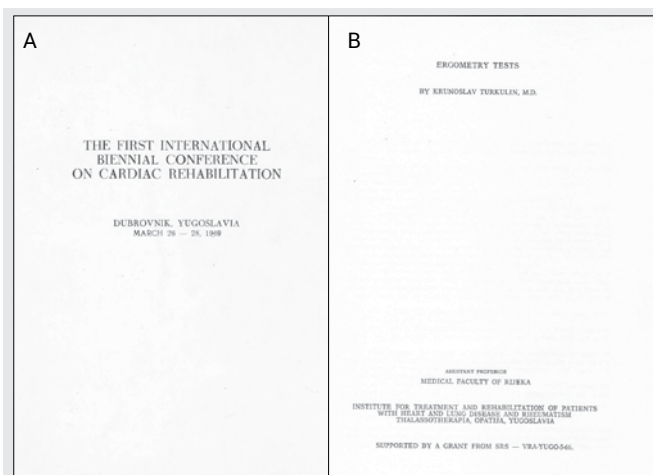


FIGURE 1. A) Cover page of the conference book „The first international biennial conference on cardiac rehabilitation“. Dubrovnik, 1969. (co-organizers Thalassotherapia, Opatija and New York University Medical Center), **B)** front page of the article by Turkulin K. „Ergometry tests“.

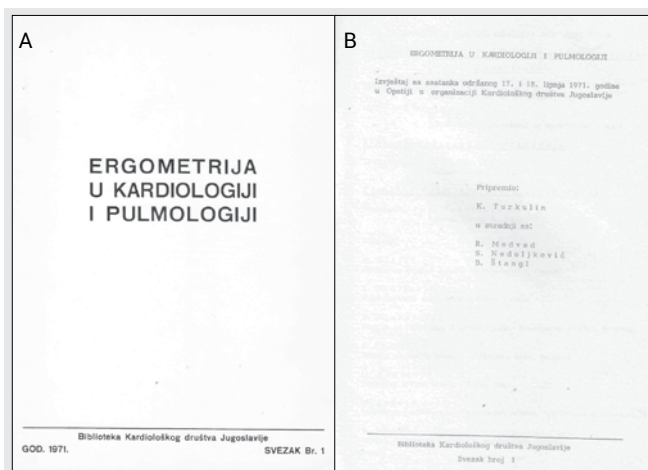


FIGURE 2. A) Cover and **B)** front page of the publication by Turkulin K, Medved R, Nedeljković S, Štangel B. [Ergometry in cardiology and pulmology]. Library of the Yugoslavian Society of Cardiology, 1971.

to su naročito pitanja terminologije, izbor aparatura, metoda i ujednačeno tumačenje rezultata.“ Tri godine poslije, integralni tekst¹⁹ je u skraćenom obliku ponovno objavljen zbog iskazanog interesa struke, a „prethodni svezak bio je rasprodan“²⁰.

Nadalje, od 1971. godine skupina znanstvenika s Elektrotehničkog fakulteta u Ljubljani te liječnika iz opatijske Thalassotherapije počela je izrađivati program za računalnu analizu EKG opterećenja sa svrhom unapređenja, odnosno smanjenja dotadašnjih ograničenja analize ishemijskih EKG promjena^{21,22}. Zbog tih istraživanja prof. dr. Turkulin dobio je Kidričevu nagradu 1982. godine (*nagrada najviše razine za dostignuća na polju znanosti, dodjeljivala se od 1957. – 1991. godine u Sloveniji*). Poslije je na temelju rezultata toga projekta i istraživanja tvrtka Gorenje izradila računalo (MAE101) za analizu EKG-a u opterećenju.

Na temelju bogatog iskustva u rehabilitaciji i funkcionalnom ergometrijskom testiranju srčanih bolesnika, skupina autora 1980. godine izradila je „medicinske kriterije za određivanje tjelesnog oštećenja srčanih bolesnika“ čija je temeljna odrednica bilo ergometrijsko testiranje srčanih bolesnika²⁵.

Godine 1985. godine prof. dr. Krunoslav Turkulin iz Opatije prelazi na mjesto voditelja kardiološkog odjela Specijalne bolnice za medicinsku rehabilitaciju u Krapinskim Toplicama, gdje radi do umirovljenja 1997. godine. Prof. dr. Turkulin tijekom sljedećih godina znatno unapređuje rad kardiorehabilitacijskog odjela u Krapinskim Toplicama uvođenjem novih modaliteta tjelesnog treninga, novim dijagnostičkim tehnikama te osobito u nastavnim i znanstvenim pogledu. Tih godina bolnica postaje važan centar u neinvazivnoj kardiovaskularnoj dijagnostici, osobito ergometrijskom testiranju.

Zaključno, iako se danas rutinski i široko primjenjuje, ergometrijsko je testiranje, kao i većina novih dijagnostičkih ili terapijskih metoda, prošlo svoj „trnoviti“ razvojni put do pune afirmacije u kliničkoj praksi. Prema kazivanju samog prof. dr. Turkulina, u početcima razvoja i šire primjene ergometrijskog testa opterećenja u Hrvatskoj kao i intenzivnijega tjelesnog

with the knowledge that proper evaluation is the basis of all treatment and rehabilitation, the methods have not yet been standardized, especially in issues of terminology, device choices, methods, and consistent interpretation of results“. Three years later, the integral text¹⁹ was republished in an abbreviated version due to the interest shown by physicians in the field, and the “earlier publication was sold-out“²⁰.

Furthermore, since 1971 a group of scientists from the Faculty of Electrical Engineering in Ljubljana and the physicians from the Thalassotherapia in Opatija started developing a program for computer analysis of ECG during exertion with the goal of improving the analysis of ischemic ECG changes and reducing its limitations^{21,22}. Prof. Dr. Turkulin received the Kidrič award in 1982 for this research (*an award of the highest level for achievements in the field of science, awarded between 1957-1991 in Slovenia*). The Gorenje company later build a computer (MAE101) for the analysis of ECG during exertion based on the results of that project and research.

Based on their extensive experience in rehabilitation and functional exercise testing in cardiac patients, a group of authors created the “medical criteria for determining the physical damage in heart patients” in 1980, where the main determinant was exercise testing of cardiac patients²⁵.

In 1985, Prof. Dr. Krunoslav Turkulin from Opatija became the head of the Cardiology Department at the Special Hospital for Medical Rehabilitation in Krapinske Toplice, where he worked until his retirement in 1997. Prof. Dr. Turkulin significantly improved the work of the Cardiological Rehabilitation Department in Krapinske Toplice over the following years, introducing new modalities of physical training, new diagnostic techniques, and improvements in research and education. During those years, the hospital became an important center for non-invasive cardiovascular diagnostics and exercise testing in particular.

In conclusion, although exercise testing in widely and routinely applied today, it has, like most new diagnostic and treatment methods, gone through its own “thorny” path towards full affir-

treninga koronarnih bolesnika, bilo je nepovjerenja, pritajene skepse i otpora pojedinih suvremenika tog doba s jasnim stajalištem da „se time može ozbiljno naštetiti pacijentima“. Nasreću, to je vrijeme daleko iza nas i danas ova metoda postojano živi u rutinskoj kliničkoj praksi i zauzima nezaobilazno mjesto u dijagnostici i evaluaciji koronarne bolesti srca koja je jedan od vodećih uzroka obolijevanja i smrtnosti suvremenog svijeta.

mation in clinical practice. According to Dr. Turkulin himself, at the start of the development and wider application of exercise testing in Croatia and more intensive training for coronary patients was faced with suspicion, unvoiced skepticism, and resistance from individual peers at the time who clearly held the position that “this can seriously harm patients”. Fortunately, these times are behind us, and this method is now routinely applied in clinical practice and holds an irreplaceable position in the diagnosis and evaluation of coronary disease, which is one of the leading causes of illness and mortality in the modern world.

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