Stručni rad

EVALUACIJA BIOLOŠKE ZRELOSTI U SPORTU

UDK 796.012:612

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Apstrakt: Cilj rada usmeren je na prikaz različitih metoda za procenu biološke zrelosti kojima se mogu definisati razlike između hronološkog uzrasta i biološke zrelosti kod mladih sportista. Biološko sazrevanje je nelinearan proces, odvija se na svim organskim nivoima različito od protoka vremena nakon rođenja. Sa tog stanovišta javlja se potreba utvrđivanja razlika u brzini biološkog sazrevanja u okviru hronološkog perioda. Definisanje biološke zrelosti sportista ima višedimenzionalni značaj, procena zrelosti mladih u poređenju sa hronološkim uzrastom ima implikativnu vrednost, selekcija i predikcija sportskog postignuća na individualnom nivou od presudnog je značaja za planiranje i programiranje trenaznog procesa. Povratne informacije procene zrelosti imaju funkciju u prevenciji i sprečavanju povređivanja sportista koji kasne u razvoju od svojih vršnjaka. Sportisti koji su napredni u odnosu na svoju hronološku generaciju, u mlađim selekcijama rano dosežu plato sportske performanse što se može negativno odraziti na uspeh u seniorskom periodu. U radu su prikazane osnovne metode procene biološke zrelosti koje se koriste u dijagnostici mladih sportista. Biološka zrelost može se odrediti metodom radiografije, antropometrijskih mera i polnih pokazatelja.

Ključne reči: *radiografija, polni pokazatelji zrelosti, maksimalna brzina rasta, mladi sportisti*

UVOD

Razvoj čoveka je složen i diskontinuiran proces koji se odvija pod uticajem spoljnjih i unutrašnjih faktora. Uticaj genetskog potencijala, geografskog područja, rase, pola, socijalnog statusa, ishrane, životnih navika i patoloških stanja može uticati na dinamiku i kvalitet razvoja čoveka (Ehrlich, 2000). Sa ontogenetskog aspekta čovek je pod jakim uticajima zakonitosti prirode koje determinišu redosled, pravac i smer razvoja uz tri fundamentalne komponente: diferenciranja tkiva, funkcionalnog sazrevanja i rasta (Ugarković, 2001). Tokom vremena čovek prolazi razvojne etape koje su antropološki jasno

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definisane. Trajanje svake etape određeno je vremenskim intervalom, mada postoje individualne razlike u brzini razvoja.

Zrelost mladih sportista se može posmatrati hronološki i biološki. Hronološka zrelost je posmatrani period od rođenja do zadate vremenske odrednice (Prieto, 2005). Životna dob posmatrana hronološki podrazumeva upotrebu astroloških parametara kako bi se odredila starost. Takav pristup jednostrano posmatra razvoj čoveka, ne uzimajući u obzir brojne uticaje koji mogu dovesti u zabludu kada se sagledava biološki potencijal organskih sistema. Napredak u razvoju je zasnovan na fiziološkim karakteristikama ljudskog organizma, nivo biološke i hronološke zrelosti često može da se ne poklapa, posebno u periodu pre adolescencije i adolescencije (Choen, 1979). Biološka zrelost je definisana po modelu funkcionalnog, morfološkog, anatomskog i biohemijskog statusa organizma koji je karakterističan za određeno hronološko razdoblje, disbalans biološke i hronološke zrelosti sagledan je u brzini promena koje karakterišu razvojne etape. Neke osobe brže sazrevaju i ranije dosežu biološke parametre koji su karakteristični za populaciju koja je na višem hronološkom razdoblju. U literaturi se navode tri grupe biološke zrelosti u odnosu na hronološku starost: mladi koji kasne u biološkom razvoju za svojim vršnjacima, oni koji sazrevaju u skladu sa hronološkom odrednicom i grupa u kojoj su osobe dosegle viši nivo biološke zrelosti (aksceleranti) u odnosu na hronološki uzrast (Avsiyevich, 2016). Razlike bioloških parametara mogu biti latentne, ali sa morfološkog i antropometrijskog aspekta jasno se uočavaju među grupama. U funkcionalnim obeležjima primetan je veći prirast snage kod aksceleranata kao posledica višeg stepena sazrevanja muskulature što se odražava na bolje performanse motoričkih sposobnosti i superiornost u sportskom izvođenju (Avsiyevich, 2016). U primarne somatske indikatore na osnovu kojih se vrši biološka procena zrelosti kategoriju se mere osifikacije hrskavice, primarno i sekundarno polno sazrevanje, zubna zrelost, morfološki status, biohemijski i hormonski markeri (Beunen et al., 2006).

Procena biološke zrelosti mladih sportista važan je segment dijagnostike, posmatrani fenomen individualnog razvoja čoveka predstavlja potrebu da se definišu i utvrde biološke osnove svakog pojedinca. Uspešnost u sportskoj aktivnosti u većini sportova dominantno je povezana sa morfološkom strukturom, antropometrijskim karakteristikama i motoričkim sposobnostima (Jakovljević et al., 2016). Razlike u biološkom potencijalu unutar iste generacije sportista se upravo u tim pojedinostima diferenciraju što može biti diskriminatorni faktor za postizanje sportskih rezultata. Kada se utvrde veća odstupanja biološke zrelosti od hronološkog standarda bioloških markera potrebno je primeniti adekvatan pristup u trenažnom radu. Akceleracija trenutno doprinosi boljim sportskim rezultatima u mlađim selekcijama, ali zbog dodežanja maksimalnog razvojnog nivoa seniorski učinak je doveden u pitanje. Treneri često selektuju igrače koji su rođeni u prvoj polovini godine ili koji su biološki zreliji kako bi ostvarili uspeh na takmičenju (Müller, 2017). Neretko se dešava da sportisti koji se razvijaju u skladu sa svojim uzrastom ili oni koji kasne u razvoju, u seniorskom uzrastu ostvare bolji sportski rezultat u odnosu na

akscelerante koji su taj uspeh imali na takmičenjima mlađih kategorija. Nivo biološke zrelosti sportista prilikom selekcije, posebno tokom trenažnog procesa treba uzeti u obzir i uvažavati pri donošenju odluka. Takođe, određivanje pozicije u timu kod ekipnih sportova koje se zasnivaju na trenutnim telesnim karakteristikama i fizičkim sposobnostima, može da dovode do rane specijalizacije čime se jednostrano razvijaju veštine. Sportisti čija je biološka zrelost u skladu sa hronološkim uzrastom, posebno u periodu puberteta, mogu doživeti emocionalne krize, anksiozna stanja koja su izazvana neuspehom na takmičenjima sa drugim ekipama u kojima su vršnjaci, biološki zreliji, ostvarili bolji uspeh. Neophodna je edukacija mladih igrača kako bi oni razumeli biološke procese sazrevanja i značaj razvojne biologije čoveka u trenažnom procesu. U proceni biološke zrelosti izdvajaju se tri grupe metoda, zasnovane na proceni skeletne zrelosti, polne razvijenosti i proporcionalnog odnosa određenih dimenzija delova tela. Sazrevanje skeleta je pouzdan parametar kojim se može proceniti biološka zrelost i izvršiti predikcija konačne visine što je za selekciju u nekim sportovima od velike važnosti (Baxter-Jones, 2005). Skeletna zrelost se procenjuje na osnovu rendgenskog snimka zglobova, udaljenost proksimalnog okrajka kosti od medijalnog ili distalnog okrajka definiše razvojnu etapu okoštavanja skeleta na osnovu koje se utvrđuje biološka zrelost. Polni pokazatelji koji mogu odrediti stepen telesne zrelosti posmatraju se kroz primarne i sekundarne karakteristike muškaraca i žena. Polni parametri su, kod muškaraca, razvijenost genitalija dok se kod žena posmatra razvijenost grudi, takođe zrelost se procenjuje i na osnovu facijalne, pubične i akselarne maljavosti, perioda prve menarhe i frekvencije glasa (Malina et al., 2015). Procena biološke zrelosti koja se zasniva na brzini rasta i proporcionalnim dimenzijama delova tela (sedeća visina, dužina donjih ekstremiteta i dr.) ukazuju da brzina telesnog rasta, koja je nelinearna pruža informacije o zrelosti (Loyd et al., 2014).

METODE ZA PROCENU BIOLOŠKE ZRELOSTI

Kompleksnost metoda za procenu biološke zrelosti ogleda se u tehnikama koje se koriste. Invazivnost tehnika može uticati na pristanak sportista da se podvrgnu testiranju. Zahtevnost određenih metoda podrazumeva rendgenska zračenja ili preglede intimnih delova tela. S druge strane nivo validnosti dobijenih podataka i značaj povratnih informacija utiče na odabir odgovarajuće metode za procenu biološke zrelosti. Kada se procenjuje zrelost kod dece, metodama koje imaju osetljiv karakter po ličnost ispitanika neophodno je dobiti saglasnost ispitanika, roditelja, dok se za istraživačke i naučne provere mora pribaviti i saglasnost etičke komisije (Puri, 2009).

Radiografija

Radiografija je metod koji se koristi u medicini za snimanje unutrašnjih organa. Rendgenski uređaj ima elektromagnetna svojstva, vrši diferencijaciju mekih i čvrstih tkiva, rendgenski zraci u procesu snimanja identifikuju koštane strukture koje se prikazuju na radiogramu (rendgenskom snimku). Radiografija

je invazivna tehnika u meri propuštanja X zraka kroz tkiva, uz nivo zračenja koji ne ostavlja posledice. Tretiranjem koštano-zglobnih lokacija rendgenskim zracima dobijaju se podaci o dimenzijama, strukturi i rastojanju kostiju na osnovu kojih se vrši analiza biološke zrelosti (Bešenski i Škegro, 2012). Procena biološke zrelosti radiografskom metodom zasnovana je na stepenu osifikacije hrskavice i približavanju proksimalnih i distalnih epifiza kostiju. Sazrevanje skeleta je pod dejstvom endokrinološkog sistema, brzina promena koje pogađaju koštani sistem određuju nivo zrelosti (Rai et al., 2012). Potpuno okoštavanje zglobnih sistema u ljudskom telu označava završetak telesnog rasta. Skeletno sazrevanje ima individualni karakter, skeletni status može se znatno razlikovati unutar istog hronološkog uzrasta (Beunen et al., 2006).

Savremena dijagnostika radiografskom metodom podrazumeva upotrebu specijalizovanih kompjuterskih programa koji detektuju i analiziraju parametre sa radiograma, takav pristup omogućava dobijanje preciznih rezultata koji ne zavise od subjektivne procene stručnjaka. U naučnoj praksi upotrebljava se različit pristup u izračunavanju biološkog uzrasta koji se određuje prema koštanoj zrelosti. Od 1896. godine vrši se procena na osnovu snimka leve šake ispitanika (Hojreh et al., 2018). Greulich–Pyle tehnika procenjuje koštanu zrelost na osnovu Todovog atlasa koji čini zbirku od 100 radiografskih snimaka za svaki hronološki uzrast od rođenja do 19. godine života (Todd, 1937). Prosečna vrednost veličine i rasporeda kostiju leve šake koje su sadržane u Todovom atlasu predstavljaju vrednost koja se upoređuje sa parametrima radiograma ispitanika (Roche et al., 1975). Fels tehnika određuje zrelost skeleta na osnovu promera kostiju radijusa, ulne, karpalnih, metakarpalnih kostiju i kostiju prstiju (Nahhas et al., 2013). Tanner-Whitehouse tehnika je tokom vremena prošla kroz tri verzije dok nije ustanovljena najnovija Tanner-Whitehouse III tehnika (Tanner et al., 2001). Dijagnostika koštane zrelosti vrši se na osnovu pojedinačne procene 20 kostiju leve šake čija je skala formirana na velikom uzorku dece sa različitih kontinenata (Beunen et al., 2006). Kompjuterska dijagnostika skeleta, automatizovan pristup u određivanju rezultata omogućava pouzdan i jednostavan način da se proceni biološka zrelost u odnosu na hronološki uzrast. BoneXpert je alat koji omogućava multidimenzionalno modelovanje za procenu skeletne zrelosti zasnovanu na rekonstrukciji 15 kostiju leve šake. BoneXpert procenjuje zrelost kostiju na osnovu Greulich–Pyle i Tanner-Whitehouse III tehnike (Thodberg et al., 2009). Na Slici 1 prikazani su referentni podaci dva različita pristupa u proceni zrelosti skeleta, kao i standardna odstupanja uz Bone health index (BHI).

Savremene tendencije u dijagnostici biološke zrelosti koja je zasnovana na skeletnom sazrevanju usmerene su na validaciju procena magnetne rezonance i ultrazvučne procedure, imajući u vidu razvoj dijagnostičkih uređaja u medicini (Hojreh et al., 2017; Mughal et al., 2014). Radiografskom metodom se može dati pretpostavka o konačnoj visini ispitanika uz pomoć prediktivnih formula za oba pola (Gilsanz & Ratib, 2005).

Slika 1. Prikaz rezultata procene biološke zrelosti skeleta u BoneXpert programu (<https://www.bonexpert.com/products/bonexpert-server>)

Antropometrijska metoda

Antropometrijski parametri tela imaju prediktivnu funkciju u određivanju biološke zrelosti mladih. Metod je utemeljen na fenomenu maksimalne brzine rasta (eng. Peak height velocity) koji predstavlja somatsku odrednicu, tačku približavanja potpunoj zrelosti (Tanner et al., 1966). Topografski posmatrano brzina rasta delova tela se ne odvija linearno u svim regijama. Nauka je potvrdila da je moguće na osnovu određenih telesnih proporcija utvrditi tačku u kojoj se biološki razvoj trenutno odvija (Moore et al., 2015). Antropometrijska procena biološke zrelosti je neinvanzivna metoda, obuhvata nekoliko telesnih varijabli, visinu tela, sedeću visinu, dužinu nogu i masu tela, takođe je neophodno definisati pol i hronološki uzrast ispitanika (Gil et al., 2013). Protokol predviđa da se izvrše dva merenja, mere koje se koriste predstavljaju srednju vrednost, ako se razlika dobijenih rezultata između prvog i drugog merenja razlikuje 4 mm za visinu/dužinu i 0.4 kg u proceni mase neophodno je ponovo izvršiti merenje (Sherar et al., 2005). Preciznost dobijenih mera važna je u predikciji, minimalna odstupanja mogu znatno uticati na konačnu procenu biološke zrelosti.

Regresionim analizama nekoliko različitih longitudinalnih studija, koje su obuhvatale kontinuirana merenja mladih od 8 do 16 godina starosti, dobijeni su prediktivni parametri za dve različite formule, zasebno za ženski i muški pol (Mirwald et al., 2002.; Kozić & Malina, 2018.; Moore et al., 2015):

1. Muški pol:

Biološka zrelost (godine) = $-9.236 + ((0.0002708 \times (\text{dužina noge} \times \text{sedeća visina})) + (-0.001663 \times (\text{godine života} \times \text{dužina donjeg ekstremiteta})) + (0.007216 \times (\text{godine života} \times \text{sedeća visina})) + (0.02292 \times ((\text{masa tela} / \text{visina tela}) \times 100))$, ili

Biološka zrelost (godine) = $-7.999994 + (0.0036124 \times (\text{godine života} \times \text{visina tela}))$

2. Ženski pol:

Biološka zrelost (godine) = $- 9.376 + ((0.0001882 \times (\text{dužina noge} \times \text{sedeća visina})) + (0.0022 \times (\text{godine života} \times \text{dužina donjeg ekstremiteta})) + (0.005841 \times (\text{godine života} \times \text{sedeća visina})) + (- 0.02658 \times (\text{godine života} \times \text{masa tela})) + (0.07693 \times ((\text{masa tela} / \text{visina tela}) \times 100))$, ili

Biološka zrelost (godine) = $-7.709133 + (0.0042232 \times (\text{godine života} \times \text{visina tela}))$

Antropometrijska metoda široko je prihvaćena kao jednostavna dijagnostička procedura za procenu biološke zrelosti adolescenata oba pola. Takođe, pomoću ove metode može se izvršiti procena konačne visine ispitanika (Sherar et al., 2005).

Metod polnih karakteristika

Sazrevanje primarnih i sekundarnih polnih karakteristika odvija se mehanizmom biološkog razvoja do potpune reproduktivne funkcionalnosti. Polni pokazatelji predstavljaju metodu koja je korišćena u mnogim istraživanjima, kojom je vršena procena biološke zrelosti sportista, odnosno stepena diferencijacije od hronološke dobi (Brooks-Gunn et al., 1987; Susman et al., 2010; Malina et al., 2007; Baxter-Jones et al., 1995). Razvijenost grudi i pubičnih dlaka kod devojaka, kao i razvijenost genitalija i telesne maljavosti kod dečaka određuje stepen biološke zrelosti. Poređenjem dobijenih mera sa vrednostima koje su karakteristične za određeni hronološki uzrast mogu se doneti zaključci koji ukazuju na to da li ispitanik odstupa i koliko od svoje uzrasne kohorte. Takođe, kod devojaka se može respektivno uzeti u obzir ranije dobijanje menarhe što se tumači kao brže biološko sazrevanje, s tim da to može biti posledica i drugih faktora, pa se taj vid predikcije uzima kao dopunski parametar (Marshall & De Limongi, 1976).

Metod polnih karakteristika zahteva angažovanje stručnjaka medicinske struke koji jedini mogu realizovati pregled i dati konačan sud o stepenu zrelosti (Malina et al., 2004). Pregled obuhvata palpatorno ispitivanje kao i fotografisanje ciljanih delova tela kako bi se formirala arhiva. Prema Tanerovoj klasifikaciji postoji pet faza (TS1-TS5) polnog sazrevanja, pregled podrazumeva određivanje polne faze razvoja penisa, testisa, pubičnih dlaka i dojki (Tanner, 1962). Tehnika po Taneru umanjene je dijagnostičke osetljivosti, raspon unutar faza nije preciznije određen, dva deteta mogu biti u istoj fazi, ali jedno bliže početku razvojne faze, dok drugo na samom završetku polnog razvoja u istoj fazi (Llojd, 2014). Glavni nedostatak ove metode leži u činjenici da se ona može primenjivati samo u periodu puberteta, kao i da se ne može utvrditi dinamika sazrevanja. Preporuke stručnjaka su usmerene na sagledavanje više polnih karakteristika istovremeno, kako bi procena bila potkrepljena sa više argumenata koji opisuju biološku zrelost. Ocenjivanje se vrši davanjem broja godina iznad ili ispod uzrasne klase u kojoj se nalazi ispitanik, obično do tri godine. Takođe ispitanik može dobiti nulu što označava da se razvija u skladu sa svojim

hronološkim uzrastom. Najčešći znak biološke zrelosti kod dečaka je volumen testisa dok kod devojaka obim grudi i pubična maljavost (Johnston et al., 1980).

ZAKLJUČAK

Utvrđivanje kvaliteta i brzine biološkog razvoja mladih sportista svakako treba uvrstiti u predmet trenažnog procesa, bez obzira da li se radi o selekciji igrača za vrhunske domete ili amaterski sport. Sa takmičarskog aspekta neophodno je sagledati sve efekte i nedostatke koji proizilaze od odstupanja biološke zrelosti u odnosu na hronološki uzrast. Nagli razvoj, heterogenost trenažne grupe po pitanju mnogih antropoloških dimenzija nameće dodatnu odgovornost trenera. Neminovno je prilagođavanje sadržaja, inteziteta i obima trenažnih celina. Poseban disbalans je primetan kod dece koja ranije sazrevaju i kod dece koja kasne u razvoju. Osetljivost muskulature može dovesti do povreda tokom treninga ako se zanemari mogućnost postojanja telesnih razlika u istoj uzrasnoj grupi. Dugoročno planiranje sportskog veka sportista uslovljeno je potencijalom biološkog razvoja.

Kada se procenjuje biološka zrelost poželjno je koristiti metode koje su neinvazivne i koje ne mogu kod ispitanika izazvati nelagodu. S tim u vezi najpoželjnije je primenjivati Antropometrijsku metodu koja je zasnovana na merama longitudinalne dimenzionalnosti skeleta, jednostavna je za primenu i zastupa sve etičke principe. Za potrebe preciznijeg utvrđivanja poželjnije je procenu biološke zrelosti izvršiti radiografijom koja je invazivna u manjem stepenu, ali zauzvrat pruža visok nivo prediktivne procene. Polne karakteristike se mogu upotrebljavati u naučnim studijama i u situacijama kada nije moguće postupiti drugačije.

Pored metoda procene biološke zrelosti koje su pomenute u ovom radu mogu se koristiti i metode usmerene na brzinu i kvalitet razvoja zuba (izradom ortopana), kao i glasovnih karakteristika (specifičnosti glasovnih mutacija). Važni kriterijumi prilikom odabira metode su uzrasna grupa (predpubertet ili pubertet), kategorija ispitanika (deca selektovana za vrhunski sport ili rekreativno-razvojni sport), oprema i ljudski resursi, materijalni status kluba i sl. Svakako, metode se mogu kombinovati, posebno ako se vrše istraživanja u naučne svrhe, deskriptivne ili epidemiološke studije.

Utvrđivanje prevalence bioloških razlika u odnosu na hronološke parametre predstavlja početak istraživanja za naučne potrebe. Istraživačke linije je neophodno usmeriti na traženje uzroka dinamike pokretanja mehanizama biološkog razvoja, uticaja spoljnih i unutrašnjih faktora. Takođe, saznanja o karakteristikama i sposobnostima dece koja su biološki naprednija ili zaostaju od svojih vršnjaka doprinela bi formiranju adekvatnih trenažnih tretmana koji bi podsticajno delovali sa umanjenim rizikom od nastanka povreda. Dobijeni rezultati adekvatnim dijagnostičkim metodama za procenu biološke zrelosti, mogu doprineti kreiranju takmičarskog okruženja koje je zasnovano na biološkim kvalitetima u odnosu na hronološku kategorizaciju sportista.

LITERATURA

1. Avsiyevich, V., Plakhuta, G., & Fyodorov, A. (2016). The Importance of Biological Age in the Control System of Training Process of Young Men in Powerlifting. *Research journal of pharmaceutical, biological and chemical sciences*, 7(5), 945–954.
2. Baxter-Jones, A. D. G., Eisenmann, J. C., & Sherar, L. B. (2005). Controlling for Maturation in Pediatric Exercise Science. *Human Kinetics Journals*, 17(1), 18–30.
3. Baxter-Jones, A. D. G., Helms, P., Maffulli, N., Baines-Preece, J. C., & Preece, M. (1995). Growth and development of male gymnasts, swimmers, soccer and tennis players: a longitudinal study. *Annals of human biology*, 22(5), 381–394.
4. Beunen, G. P., Rogol, A. D., & Malina R. M. (2006). Indicators of biological maturation and secular changes in biological maturation, *Food and Nutrition Bulletin*, 27(4), 244–256.
5. Bešenski, N. i Škegro, N. (2012). *Radiografska tehnika skeleta*. Beograd: Data Status.
6. Brooks-Gunn, J., Warren, M. P., Rosso, J., & Gargiulo, J. (1987). Validity of Self- Report Measures of Girls' Pubertal Status. *Child development*, 58(3), 829–841.
7. Bonexpert: BoneXpert Server, <https://www.bonexpert.com/products/bonexpert-server> (Pristupljeno: 31.12.2018. godine.)
8. Frank, R. A., & Cohen, D. J. (1979). Psychosocial concomitants of biological maturation in preadolescence. *The American Journal of Psychiatry*, 136(12), 1518–1524.
9. Erlich, P. R. (2000). *Human Natures – Genes, Cultures, and the Human Prospect*. Waschitong: Island Press.
10. Gilsanz, V., & Ratib, O. (2005). *Hand bone age – A digital atlas of skeletal maturity*. New York: Springer-Verlag.
11. Gil, S. M., Badiola, A., Bidaurreazaga-Letona, I., Zabala-Lili, J., & Gravina, L. (2013). Relationship between the relative age effect and anthropometry, maturity and performance in young soccer players. *Journal of Sports Sciences*, 32(5), 479–486.
12. Hojreh, A., Gamper, J., Schmook, M. T., Weber, M., Prayer, D., Herold, C. J., & Noebauer-Huhmann, I. M. (2018). Hand MRI and the Greulich-Pyle atlas in skeletal age estimation in adolescents. *Skeletal Radiology*, 47(7), 963–971.
13. Jakovljević, S., Macura, M., Mandić, R., Janković, N., Pajić, Z., & Erculj, F. (2016). Biological Maturity Status and Motor Performance in Fourteen-Year-old Basketball Players. *International journal morphology*, 34(2), 637–643.
14. Johnston, F. E., Roche, A. F., & Susanne, C. (1980). *Human Physical*

- Growth and Maturation - Methodologies and Factors. New York: Plenum Press.
15. Koziet, S. M., & Malina, R. M. (2018). Modified maturity offset prediction equations: validation in independent longitudinal samples of boys and girls. *Sports medicine*, 48(1), 221–236.
 16. Lloyd, R. S, Oliver, J. L, Faigenbaum, A. D., Myer, G. D., & De Ste Croix, M. B. (2014). Chronological age vs. biological maturation: Implications for exercise programming in youth. *Journal Strength Cond Res*28(5), 1454–1464.
 17. Malina, R. M., Ribeiro, B., Aroso, J., & Cumming, S. P. (2007). Characteristics of youth soccer players aged 13–15 years classified by skill level. *British Journal of Sports Medicine*, 41(5), 290–295.
 18. Malina, R. M, Bouchard, C., & Bar-Or, O. (2004). *Growth, Maturation, and Physical Activity*. Champaign, IL: Human Kinetics.
 19. Malina, R. M., Rogol, A. D., Cumming, S. P., Coelho e Silva, M. J., & Figueiredo, A. J. (2015). Biological maturation of youth athletes: assessment and implications. *British Journal of Sports Medicine*, 49(13), 852–859.
 20. Marshall, W. A., & De Limongi, Y. (1976). Skeletal maturity and the prediction of age at menarche. *Annals of Human Biology*, 3(3), 235–243.
 21. Mirwald, R. L., Baxter-Jones, A. D., Bailey, D. A., & Beunen, G. P. (2002). An assessment of maturity from anthropometric measurements. *Medicine & science in sports & exercise*, 34(4), 689–694.
 22. Moore, S. A., McKay, H. A., Macdonald, H., Nettlefold, L., Baxter-Jones, A. D., Cameron, N., & Brasher, P. M. (2015). Enhancing a Somatic Maturity Prediction Model. *Medicine & Science in Sports & Exercise*, 47(8), 1755–1764.
 23. Mughal, A. M., Hassan, N., & Ahmed, A. (2014). Bone Age Assessment Methods: A Critical Review. *Pakistan Journal of Medical Sciences*, 30(1), 211–215.
 24. Müller, L., Hildebrandt, C., & Raschner, C. (2017). The Role of a Relative Age Effect in the 7th International Children's Winter Games 2016 and the Influence of Biological Maturity Status on Selection. *Journal of Sports Science and Medicine*, 16(2), 195–202.
 25. Nahhas, R. W., Sherwood, R. J., Chumlea, W. C., & Duren, D. L. (2013). An update of the statistical methods underlying the FELS method of skeletal maturity assessment. *Annals of Human Biology*, 40(6), 505–514.
 26. Prieto, J. L., Barbería, E., Ortega, R., & Magaña, C. (2005). Evaluation of chronological age based on third molar development in the Spanish population. *International Journal of Legal Medicine*, 119(6), 349–354.
 27. Puri, K. S., Suresh, K. R., Gogtay, N. J., & Thatte, U. M. (2009). Declaration of Helsinki, 2008: Implications for stakeholders in research.

- Journal of postgraduate medicine, 55(2), 131–134.
28. Rai, V., Saha, S., Yadav, G., Tripathi, A. M., & Grover, K. (2014). Dental and Skeletal Maturity- A Biological Indicator of Chronologic Age. *Journal of Clinical and Diagnostic Research*, 8(9), 60–64.
 29. Roche, A. F., Wainer, H., & Thissen, D. (1975). *Skeletal maturity: the knee joint as a biological indicator*. New York: Plenum Press.
 30. Sherar, L. B., Mirwald, R. L., Baxter-Jones, A. D., & Thomis, M. (2005). Prediction of adult height using maturity-based cumulative height velocity curves. *The Journal of Pediatrics*, 147(4), 508–514.
 31. Susman, E. J., Houts, R. M., Steinberg, L., Belsky, J., Cauffman, E., DeHart, G., et al. (2010). Longitudinal Development of Secondary Sexual Characteristics in Girls and Boys Between Ages 9½ and 15½ Years. *Archives Pediatric Adolescent Medicine*, 164(2), 166–173.
 32. Tanner, J. M. (1962). *Growth at Adolescence* (2nd ed.). Oxford: Blackwell.
 33. Tanner, J. M., Whitehouse, R. H., & Takishi, M. (1966). Standards from birth to maturity for height, weight, height velocity, and weight velocity: British children, 1965. I. *Archives of Disease in Childhood*, 41(219), 454–471.
 34. Tanner, J. M., Healy, M. J. R., Goldstein, H., & Cameron, N. (2001). *Assessment of skeletal maturity and prediction of adult height (TW3 method)*, 3rd ed. London: Saunders.
 35. Thodberg, H. H., Kreiborg, S., Juul, A., & Pedersen, K.D. (2009). The BoneXpert Method for Automated Determination of Skeletal Maturity, *IEEE Transactions on Medical Imaging*, 28(1), 52–66.
 36. Todd, T. W. (1937). *Atlas of skeletal maturation*. St Louis: Mosby.
 37. Ugarković, D. (2001). *Osnovi sportske medicine*. Beograd: Viša košarkaška škola.

Professional paper

THE EVALUATION OF BIOLOGICAL MATURITY IN SPORT

UDK 796.012:612

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Abstract: The aim of the paper is to present various methods for the evaluation of biological maturity which can define the differences between chronological age and biological maturity in young athletes. Biological maturation is a non-linear process, taking place at all organic levels, differing from the flow of time after birth. From this point of view, there is a need to determine the differences in the rate of biological maturation within the chronological period. Defining the biological maturity of athletes has a multidimensional significance, the evaluation of youth's maturity in comparison with the chronological age has an implicit value, the selection and prediction of sports achievement at the individual level is crucial for the planning and programming of the training process. Maturity evaluation feedback has a function in preventing and restraining injuries of athletes who are behind their peers. Athletes who are advanced in comparison to their chronological generation, in younger selections, reach a plateau of sports performance early, which can negatively affect success in the senior period. The paper presents the basic methods of evaluation of biological matrices used in the diagnosis of young athletes. Biological maturity can be determined by means of radiography, anthropometric measurements, and sex-based indicators.

Keywords: *radiography, sex-based indicators of maturity, peak height velocity, young athletes*

INTRODUCTION

Human development is a complex and discontinuous process that takes place under the influence of external and internal factors. The influence of genetic potential, geographical area, race, sex, social status, nutrition, lifestyle and pathological conditions can influence the dynamics and quality of human development (Ehrlich, 2000). From ontogenetic point of view, one is strongly influenced by the laws of nature which determine the order, orientation and

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direction of development with three fundamental components, tissue differentiation, functional maturation and growth (Ugarković, 2001). Over time, man goes through developmental stages that are anthropologically clearly defined. The duration of each stage is determined by a time interval, although there are individual differences in the speed of development.

The maturity of young athletes can be observed chronologically and biologically. Chronological maturity is the observed period from birth to a given point in time (Prieto, 2005). Chronologically observed age involves the use of astrological parameters for determining the age. Such an approach perceives human development unilaterally, without taking into account numerous influences that can lead to misconception when considering the biological potential of systems of organs. Developmental progress is based on the physiological characteristics of the human organism, the level of biological and chronological maturity can often not coincide, especially in the period of pre-adolescence and adolescence (Choen, 1979). Biological maturity is defined according to the model of functional, morphological, anatomical and biochemical status of the organism, characteristic for a given chronological period, the imbalance of the biological and chronological maturity is seen in the rate of changes that characterize developmental phases. Some people mature faster and are quicker to reach biological parameters that are characteristic of the population that is at the higher chronological age. Literature lists three groups of biological maturity in relation to chronological age, the young who are behind their peers in terms of biological development, those who mature in line with the chronological determiner and a group of people who have reached a higher level of biological maturity (accelerants) compared to their chronological age (Avsiyevich, 2016). The differences of biological parameters may be latent, but from the morphological and anthropometric aspect they are clearly observed between the groups. In terms of functional features, a higher increase in power in accelerants is noticeable as a result of a higher degree of muscle maturation, which reflects on better performance of motor skills and superiority in sports performance (Avsiyevich, 2016). Primary somatic indicators that the biological assessment of maturity is based on include measures of cartilage ossification, primary and secondary sexual maturation, dental maturity, morphological status, biochemical hormone markers (Beunen et al., 2006).

The assessment of the biological maturity of young athletes is an important segment of diagnostics, the observed phenomenon of individual human development represents the need to define and determine the biological basis of each individual. Performance in sports activity in most sports is predominantly related to morphological structure, anthropometric characteristics and motor skills (Jakovljević et al., 2016). Differences in biological potential within the same generation of athletes are precisely differentiated in these details, which can present a discriminatory factor for achieving sports results. In cases of greater biological maturity variations than the chronological standard of biological markers, an adequate approach in training should be applied. Acceleration currently contributes to better sports results in younger categories,

but due to the achievement of the maximum developmental level, the performance in senior categories is under question. Coaches often select players who were born in the first half of the year or who are biologically more mature in order to achieve success in a competition (Müller, 2017). It often happens that athletes who develop in accordance with their age or those who are late in developing, achieve better sports results in the senior age group than accelerants who experienced success in competitions for younger categories. For the purpose of selection, the level of biological maturity of athletes, especially during the training process, should be taken into account and appreciated when making decisions. Also, determining the position in the team, in case of team sports, based on current physical characteristics and physical abilities can lead to early specialization which leads to unilateral development of skills. Athletes whose biological maturity is consistent with chronological age, especially during adolescence, can experience emotional crises, anxiety states caused by failure in competitions against other teams where biologically more mature peers have achieved better results. It is necessary to educate young players so that they understand the biological processes of maturation and the significance of human developmental biology in the training process. The biological maturity assessment comprises three sets of methods, based on the estimation of skeletal maturity, sexual development and the proportional relation of certain dimensions of body parts. Skeletal maturation is a reliable parameter for the evaluation of biological maturity and prediction of the peak height which is important for selection in some sports (Baxter-Jones, 2005). Skeletal maturity is assessed on the basis of an X-ray image of the joints, the distance of the proximal bone edge from the medial or distal margin defines a development stage of skeletal ossification on the basis of which biological maturity is determined. Sex-based indicators that can determine the degree of physical maturity are observed through the primary and secondary characteristics of men and women. In men, sex-based are the development of genitals, while in women maturity is observed through the development of breasts, facial, pubic and axillary hair, menarche, and vocal frequency (Malina et al., 2015). An estimate of biological maturity based on the growth rate and proportional dimensions of the body parts (sitting height, length of the lower extremities, etc.) indicate that the rate of physical growth, which is non-linear, provides information concerning maturity (Loyd et al., 2014).

METHODS FOR BIOLOGICAL ASSESSMENT

The complexity of methods for assessing biological maturity is reflected in the techniques used. The invasiveness of techniques may influence an athlete's consent to undergo testing. Certain methods involve x-ray radiation or intimate examinations. On the other hand, the level of validity of the obtained data and the importance of feedback influences the selection of an appropriate method for assessing biological maturity. When assessing maturity in children, methods that may affect the personality of the respondents require a consent of the respondents or their parents, while for the research and scientific checks the consent of an ethics committee must be obtained (Puri, 2009).

Radiography

Radiography is a method used in medicine to observe internal organs. The X-ray device has electromagnetic properties, it performs differentiation of soft and hard tissues, and during the process, X-rays identify the bone structures that are displayed on the radiogram (X-ray). Radiography is an invasive technique because X-rays penetrate the tissues, exposing them to non-harmful radiation. By treating bone and joint sites with X-rays provides data on the dimensions, structure and distance between the bones based on which the biological maturity analysis is performed (Bešenski i Škegro, 2012). The assessment of biological maturity by means of radiography is based on the degree of cartilage ossification and the approximation of proximal and distal bone epiphyses. The maturation of the skeleton is affected by the endocrine system, the rate of changes affecting the skeletal system determines the level of maturity (Rai et al., 2012). Complete ossification of joints in the human body signifies the completion of physical growth. Skeletal maturation has an individual character, as the skeletal status can vary significantly within the same chronological age (Beunen et al., 2006).

Modern diagnostics by radiographic method involves the use of specialized computer programs that detect and analyze parameters from radiographs, and such an approach allows obtaining precise results that are independent of the subjective assessment of the expert. In scientific practice, a different approach is used in the calculation of biological age, which is determined by bone maturity. Since 1896, assessment has been made based on the footage of the left hand of the respondent (Hojreh et al., 2018). The Greulich-Pyle technique estimates bone maturation based on Todd's Atlas, which makes a collection of 100 radiographic images for each chronological age from birth to the age of 19 (Todd, 1937). The average value of the size and arrangement of the bones of the left hand contained in Todd's Atlas represent a value that is compared with the parameters of radiographs of subjects (Roche et al., 1975). The FELS technique determines the skeletal maturity based on the diameter of the radius, ulna, carpals, metacarpals and finger bones (Nahhas et al., 2013). The *Tanner-Whitehouse* technique had three versions over time before the latest *Tanner-Whitehouse III* technique was established (Tanner et al., 2001). Bone maturity diagnostics is done on the basis of an individual estimate of 20 bones of the left hand whose scale was based on a large sample of children from different continents (Beunen et al., 2006). Computer Skeletal Diagnostics, an automated approach to determining results provides a reliable and easy way to evaluate biological maturity in relation to chronological age. *BoneXpert* is a multidimensional modeling tool for assessing skeletal maturity based on the reconstruction of 15 bones of the left hand. *BoneXpert* estimates bone maturity based on the *Greulich-Pyle* and *Tanner-Whitehouse III* technique (Thodberg et al., 2009). Figure 1 shows the reference data in two different approaches to skeletal maturity estimation, as well as standard deviations with the *Bone Health Index* (BHI).

Figure 1. Results of the skeletal biological maturity assessment in the BoneXpert program (<https://www.bonexpert.com/products/bonexpert-server>)

Modern tendencies in the diagnostics of biological maturity based on skeletal maturation are directed at the validation of MRI and ultrasound assessments, bearing in mind the development of diagnostic medical equipment (Hojreh et al., 2017; Mughal et al., 2014). The radiographic method can provide an assumption about the final height of the examinee with the help of predictive formulas for both sexes (Gilsanz & Ratib, 2005).

Anthropometric method

Anthropometric parameters of the body have a predictive function in determining the biological maturity of young people. The method is based on the phenomenon of peak height velocity, which represents a somatic determinant, the point of approaching complete maturity (Tanner et al., 1966). Topographically observed, the growth rate of different body parts does not occur linearly in all areas. Science has confirmed that it is possible, on the basis of certain body proportions, to determine the point in which biological development is currently taking place (Moore et al., 2015). Anthropometric assessment of biological maturity is a non-invasive method, covering several body variables, body height, sitting height, leg length and body mass. It is also necessary to define the sex and chronological age of the respondents (Gil et al., 2013). The protocol involves two measurements, the measures used are the mean, if the difference between the obtained results between the first and the second measurement is 4 mm in height / length and 0.4 kg in mass assessment, it is necessary to conduct re-measuring (Sherar et al., 2005). The accuracy of the obtained measures is important for prediction, so even the smallest deviations can significantly affect the final assessment of biological maturity.

Regression analyses in several different longitudinal studies, which encompassed continuous measurements of young people aged 8 to 16, provided predictive parameters for two different formulas, separately for female and male sex (Mirwald et al., 2002.; Koziat & Malina, 2018.; Moore et al., 2015):

1. Males:

Biological maturity (years) = $-9.236 + ((0.0002708 \times (\text{length of leg} \times \text{sitting height})) + (-0.001663 \times (\text{age} \times \text{length of lower limb})) + (0.007216 \times (\text{age} \times \text{sitting height})) + (0.02292 \times ((\text{body weight} / \text{body height}) \times 100)))$, or

Biological maturity (years) = $-7.999994 + (0.0036124 \times (\text{age} \times \text{body height}))$

2. Females:

Biological maturity (years) = $-9.376 + ((0.0001882 \times (\text{length of leg} \times \text{sitting height})) + (0.0022 \times (\text{age} \times \text{length of lower limb})) + (0.005841 \times (\text{age} \times \text{sitting height})) + (-0.02658 \times (\text{age} \times \text{body weight})) + (0.07693 \times (\text{body weight} / \text{body height} \times 100)))$, or

Biological maturity (years) = $-7.709133 + (0.0042232 \times (\text{age} \times \text{body height}))$

The anthropometric method is widely accepted as a simple diagnostic procedure for assessing the biological maturity of adolescents of both sexes. Also, this method can be used to estimate the final height of the respondent (Sherar et al., 2005).

Sex-based characteristics method

Maturation of primary and secondary sex-based characteristics takes place through the mechanism of biological development until complete reproductive functionality. Sex-based indicators represent a method used in many studies for the assessment of the biological maturity of athletes, that is, the degree of differentiation from their chronological age (Brooks-Gunn et al., 1987; Susman et al., 2010; Malina et al., 2007; Baxter-Jones et al., 1995). The development of breasts and pubic hair in girls, as well as the development of genitals and body hair in boys determines the degree of biological maturity. Comparing the obtained measures with the values that are characteristic of a particular chronological age can lead to conclusions that indicate whether the respondent deviates from their age cohort and to what extent. Also, in girls, it is possible to take into account earlier menarche which is interpreted as faster biological maturation, but this may be due to other factors, so this type of prediction is taken only as an additional parameter (Marshall & De Limongi, 1976).

The method of sex-based characteristics requires the engagement of medical professionals who are the only ones who can carry out examination and have a final say on the degree of maturity (Malina et al., 2004). The examination involves palpatory examination as well as photographing target body parts in order to form an archive. According to Tanner's classification, there are five phases (TS1-TS5) of full maturation. The examination involves determining the sex-based development stage of the penis, testicles, pubic hair and breasts (Tanner, 1962). Tanner's diagnostic technique has a reduced sensitivity, the range of the stages is not precisely specified, two children can fall into the same stage, but one closer to the beginning of the development stage and the other at the end of sex development in the same stage (Lloyd, 2014). The main disadvantage of this method lies in the fact that it can be applied only in the period of puberty, and that the dynamics of maturation can't be determined. Experts recommend looking at multiple sex-based characteristics at the same time, so that the assessment is supported by multiple arguments describing

biological maturity. Evaluation is done by allocating the number of years above or below the respondent's age category, usually up to 3 years. The respondent can also get zero, which means that he develops according to his chronological age. The most common sign of biological maturity in a boy is the volume of testicles while in girls, it's breast circumference and the appearance of pubic hair (Johnston et al., 1980).

CONCLUSION

Determining the quality and speed of the biological development of young athletes should definitely be included in the training process, regardless of whether it is the selection of players for top-level ranges or amateur sport. From the competitive aspect it is necessary to look at all the effects and disadvantages that result from the deviation of biological maturity from chronological age. Rapid development, the heterogeneity of the training group, in terms of many anthropological dimensions, imposes additional responsibility on coaches. They inevitably need to customize the content, intensity and volume of training units. Particular imbalance is observed in children who mature earlier and those who are late in development. The sensitivity of musculature can lead to injuries during training if the possibility of having physical differences in the same age group is ignored. Long-term planning athletes' sports life is conditioned by the potential of biological development.

When biological maturity is assessed, it is desirable to use methods that are non-invasive and which can't cause discomfort to the respondents. In this regard, it is most desirable to apply the anthropometric method that is based on the longitudinal dimension of the skeleton. It is simple to apply and it represents all ethical principles. For the purposes of more precise determination, it is more desirable to evaluate biological maturity by means of radiography, which is invasive to a lesser extent, but in turn provides a high level of predictive assessments. Sex-based features can be used in scientific studies and in situations where it is not possible to act differently.

In addition to the biological maturity assessment methods outlined in this paper, methods based on tooth development rate and quality (by developing an orthopan), as well as voice characteristics (the specificity of voice mutations) can be used. The important criteria when choosing the method are the age group (pre-puberty or puberty), the categories of respondents (children selected for top-level sports or recreational development), equipment and human resources, the material status of the club. Certainly methods can be combined, especially if research is done for scientific purposes, descriptive or epidemiological studies.

Determining the prevalence of biological differences in relation to chronological parameters is the beginning of research for scientific purposes. It is necessary to focus the research lines on looking for the causes of the dynamics of the initiation of biological development mechanisms, the influence of external and internal factors. Also, the knowledge about the characteristics and abilities of children who are biologically advanced or behind their peers will contribute

to the formation of adequate training treatments that would be stimulating and have a reduced risk of injuries. The obtained results, with adequate diagnostic methods for assessing biological maturity, can contribute to the creation of a competitive environment that is based on biological qualities in relation to the chronological categorization of athletes.

REFERENCES

1. Avsiyevich, V., Plakhuta, G., & Fyodorov, A. (2016). The Importance of Biological Age in the Control System of Training Process of Young Men in Powerlifting. *Research journal of pharmaceutical, biological and chemical sciences*, 7(5), 945–954.
2. Baxter-Jones, A. D. G., Eisenmann, J. C., & Sherar, L. B. (2005). Controlling for Maturation in Pediatric Exercise Science. *Human Kinetics Journals*, 17(1), 18–30.
3. Baxter-Jones, A. D. G., Helms, P., Maffulli, N., Baines-Preece, J. C., & Preece, M. (1995). Growth and development of male gymnasts, swimmers, soccer and tennis players: a longitudinal study. *Annals of human biology*, 22(5), 381–394.
4. Beunen, G. P., Rogol, A. D., & Malina R. M. (2006). Indicators of biological maturation and secular changes in biological maturation, *Food and Nutrition Bulletin*, 27(4), 244–256.
5. Bešenski, N i Škegro, N. (2012). *Radiografska tehnika skeleta*. Beograd: Data Status.
6. Brooks-Gunn, J., Warren, M. P., Rosso, J., & Gargiulo, J. (1987). Validity of Self- Report Measures of Girls' Pubertal Status. *Child development*, 58(3), 829–841.
7. Bonexpert: *BoneXpert Server*,
<https://www.bonexpert.com/products/bonexpert-server> (Pristupljeno: 31.12.2018. godine)
8. Frank, R. A., & Cohen, D. J. (1979). Psychosocial concomitants of biological maturation in preadolescence. *The American Journal of Psychiatry*, 136(12), 1518–1524.
9. Erlich, P. R. (2000). *Human Natures – Genes, Cultures, and the Human Prospect*. Waschitong: Island Press.
10. Gilsanz, V., & Ratib, O. (2005). *Hand bone age – A digital atlas of skeletal maturity*. New York: Springer-Verlag.
11. Gil, S. M., Badiola, A., Bidaurreaga-Letona, I., Zabala-Lili, J., & Gravina, L. (2013). Relationship between the relative age effect and anthropometry, maturity and performance in young soccer players. *Journal of Sports Sciences*, 32(5), 479–486.
12. Hojreh, A., Gamper, J., Schmook, M. T., Weber, M., Prayer, D., Herold, C. J., & Noebauer-Huhmann, I. M. (2018). Hand MRI and the Greulich-Pyle

- atlas in skeletal age estimation in adolescents. *Skeletal Radiology*, 47(7), 963–971.
13. Jakovljević, S., Macura, M., Mandić, R., Janković, N., Pajić, Z., & Erculj, F. (2016). Biological Maturity Status and Motor Performance in Fourteen-Year-old Basketball Players. *International journal morphology*, 34(2), 637–643.
 14. Johnston, F. E., Roche, A. F., & Susanne, C. (1980). *Human Physical Growth and Maturation - Methodologies and Factors*. New York: Plenum Press.
 15. Koziat, S. M., & Malina, R. M. (2018). Modified maturity offset prediction equations: validation in independent longitudinal samples of boys and girls. *Sports medicine*, 48(1), 221–236.
 16. Lloyd, R. S., Oliver, J. L., Faigenbaum, A. D., Myer, G. D., & De Ste Croix, M. B. (2014). Chronological age vs. biological maturation: Implications for exercise programming in youth. *Journal Strength Cond Res* 28(5), 1454–1464.
 17. Malina, R. M., Ribeiro, B., Aroso, J., & Cumming, S. P. (2007). Characteristics of youth soccer players aged 13–15 years classified by skill level. *British Journal of Sports Medicine*, 41(5), 290–295.
 18. Malina, R. M., Bouchard, C., & Bar-Or, O. (2004). *Growth, Maturation, and Physical Activity*. Champaign, IL: Human Kinetics.
 19. Malina, R. M., Rogol, A. D., Cumming, S. P., Coelho e Silva, M. J., & Figueiredo, A. J. (2015). Biological maturation of youth athletes: assessment and implications. *British Journal of Sports Medicine*, 49(13), 852–859.
 20. Marshall, W. A., & De Limongi, Y. (1976). Skeletal maturity and the prediction of age at menarche. *Annals of Human Biology*, 3(3), 235–243.
 21. Mirwald, R. L., Baxter-Jones, A. D., Bailey, D. A., & Beunen, G. P. (2002). An assessment of maturity from anthropometric measurements. *Medicine & science in sports & exercise*, 34(4), 689–694.
 22. Moore, S. A., Mckay, H. A., Macdonald, H., Nettlefold, L., Baxter-Jones, A. D., Cameron, N., & Brasher, P. M. (2015). Enhancing a Somatic Maturity Prediction Model. *Medicine & Science in Sports & Exercise*, 47(8), 1755–1764.
 23. Mughal, A. M., Hassan, N., & Ahmed, A. (2014). Bone Age Assessment Methods: A Critical Review. *Pakistan Journal of Medical Sciences*, 30(1), 211–215.
 24. Müller, L., Hildebrandt, C., & Raschner, C. (2017). The Role of a Relative Age Effect in the 7th International Children's Winter Games 2016 and the Influence of Biological Maturity Status on Selection. *Journal of Sports Science and Medicine*, 16(2), 195–202.
 25. Nahhas, R. W., Sherwood, R. J., Chumlea, W. C., & Duren, D. L. (2013). An update of the statistical methods underlying the FELS method of skeletal maturity assessment. *Annals of Human Biology*, 40(6), 505–514.

26. Prieto, J. L., Barbería, E., Ortega, R., & Magaña, C. (2005). Evaluation of chronological age based on third molar development in the Spanish population. *International Journal of Legal Medicine*, 119(6), 349–354.
27. Puri, K. S., Suresh, K. R., Gogtay, N. J., & Thatte, U. M. (2009). Declaration of Helsinki, 2008: Implications for stakeholders in research. *Journal of postgraduate medicine*, 55(2), 131–134.
28. Rai, V., Saha, S., Yadav, G., Tripathi, A. M., & Grover, K. (2014). Dental and Skeletal Maturity - A Biological Indicator of Chronologic Age. *Journal of Clinical and Diagnostic Research*, 8(9), 60–64.
29. Roche, A. F., Wainer, H., & Thissen, D. (1975). *Skeletal maturity: the knee joint as a biological indicator*. New York: Plenum Press.
30. Sherar, L. B., Mirwald, R. L., Baxter-Jones, A. D., & Thomis, M. (2005). Prediction of adult height using maturity-based cumulative height velocity curves. *The Journal of Pediatrics*, 147(4), 508–514.
31. Susman, E. J., Houts, R. M., Steinberg, L., Belsky, J., Cauffman, E., DeHart, G., et al. (2010). Longitudinal Development of Secondary Sexual Characteristics in Girls and Boys Between Ages 9½ and 15½ Years. *Archives Pediatric Adolescent Medicine*, 164(2), 166–173.
32. Tanner, J. M. (1962). *Growth at Adolescence (2nd ed.)*. Oxford: Blackwell.
33. Tanner, J. M., Whitehouse, R. H., & Takishi, M. (1966). Standards from birth to maturity for height, weight, height velocity, and weight velocity: British children, 1965. I. *Archives of Disease in Childhood*, 41(219), 454–471.
34. Tanner, J. M., Healy, M. J. R., Goldstein, H., & Cameron, N. (2001). *Assessment of skeletal maturity and prediction of adult height (TW3 method)*, 3rd ed. London: Saunders.
35. Thodberg, H. H., Kreiborg, S., Juul, A., & Pedersen, K.D. (2009). The BoneXpert Method for Automated Determination of Skeletal Maturity, *IEEE Transactions on Medical Imaging*, 28(1), 52–66.
36. Todd, T. W. (1937). *Atlas of skeletal maturation*. St Louis: Mosby.
37. Ugarković, D. (2001). *Osnovi sportske medicine*. Beograd: Viša košarkaška škola.