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CARDIORESPIRATORY POWER AND FORCE-VELOCITY CHARACTERISTICS IN ROAD CYCLING: THE EFFECT OF AGING AND UNDERLYING PHYSIOLOGICAL MECHANISMS

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Abstract

Introduction: Although a considerable amount of research is available describing the physiological characteristics of competitive adolescent and senior level cyclists, research describing the same characteristics in master level cyclists is rare.

Aim of this study was to compare cardiorespiratory power and force-velocity characteristics between two groups, one of master and one of senior level cyclists in an attempt to examine the effect of aging on these parameters.

Methods: Eighteen master (43.25±5.37 y) and 13 senior level male road cyclists (28.78±4.95 y) were examined for anthropometric characteristics, body composition, and they performed the anaerobic force-velocity test and a graded exercise test to determine maximal oxygen consumption and anaerobic threshold.

Results: Maximal heart rate (accordingly 176.9±13.8 bpm vs. 189.1±8.3 bpm) and heart rate at anaerobic threshold (157±13.9 bpm vs. 170.5±8.3 bpm) were the only parameters that differed significantly (P<0.001).

Conclusions: Based on these results, it was concluded that optimal training could attenuate the decline of physiological parameters in cyclists until the beginning of the 5th decade of human life. In addition, considering the variability of heart rate values (either maximal or at anaerobic threshold), i.e. wider range of scores in master than in senior level participants, it was suggested the need for individualized data, especially in master level road cyclists.

Key words: *anaerobic power, force-velocity relationship, maximal oxygen uptake, sport*

Introduction

While there is an increase in the prevalence of inactivity in western societies, a rise of the number of those participating in cycling as physical activity and furthermore the engagement of previously sedentary adults in road cycling as a competitive sport activity have been noticed and posed demands for new area of scientific research, the older athlete. Master level athletes are typically 35-40 years of age or older, although this age cutoff varies significantly by sport [1]. During cycling, they are subjected to similar physiological demands as their younger counterparts. According to Mujika and Padilla [2], male professional road cycling competitions last between one hour (e.g. the time trial in the World Championships) and 100 hours (e.g. the Tour de France). Although, road cycling is a sport event relying predominantly on aerobic metabolism, other health-related (e.g. body composition) and sport-related fitness parameters (e.g. anaerobic power) play a crucial role for performance, too.

Cardiorespiratory power and body composition are main parameters of health-related fitness, i.e. optimal values in these parameters are associated with health benefits, and depending on the sport, they may constitute sport-related fitness, i.e. there is a direct relationship between them and sport performance. Moreover, anaerobic power and force-velocity characteristics influence sport performance, and muscular strength is a component of health-related fitness, too. The aforementioned health-related and/or sport-related fitness parameters decline with age; aging results in changes in fiber type with a swift towards a higher percentage of type I fibers, decrease in heart function and aerobic capacity, elevated nutritional needs, degenerative joint disease and orthopedic conditions related to decreases in flexibility [3]. Moreover, the decline in maximal oxygen uptake is attributed to both central and peripheral adaptations, primarily reductions in maximal heart rate and lean body mass [4]. However, the age when all these changes occur remain unclear.

On the one hand, it was suggested that endurance athletes would have greater decline in cardiorespiratory power due with aging due to higher values at baseline. Endurance-trained adult runners appeared to undergo greater absolute rates of decline in maximal oxygen consumption with advancing age compared with healthy sedentary adults, due to higher $\dot{V}O_2$max at baseline and a marked age-related decline in exercise training volume and intensity [5]. On the other hand, it was possible to achieve high values in aerobic capacity by elderly athletes. The success of the master athletes and of previously sedentary elderly who undertake well-designed, carefully administered training programs provide dramatic evidence that age-associated atrophy, weakness and fatigability can be slowed, but not halted [6]. Studies on the aging effect on performance in endurance events revealed controversial findings, too. Performance in cycling showed greater decline with age than in running, swimming and walking [7], while decline in performance was less pronounced in cycling than in swimming in a comparison of triathlon's events [8].

Aging resulted on changes in body composition and mechanical characteristics, too. Percentage body fat increased slightly throughout adult life [9], while the major reason for the increase in fat mass in older persons appeared to be weight gain rather a true age-related increase in percentage body fat [10]. Changes in body composition could have impact indirectly on the force-velocity relationship, regarding the association between fat free mass and muscle strength. Particularly, the force-velocity relationship in human muscles altered with age due to the reduction in muscular strength and power caused by a loss of skeletal muscle mass and changes in muscle architecture [11].

Investigations of physiological characteristics have been already conducted in junior cyclists (*N*=132, aged 16.8±0.6 years (y); [12]) and on masters-level cyclists (*N*=32, aged 35-73 y; [13]). Differences between professional and elite cyclists (*N*=50, aged 23-25 y; [14]), as well as between professional, amateur and young cyclists (*N*=72, aged 18-26 y; [15]) have been studied. Although a considerable amount of research is available describing the physiological characteristics of competitive young-adult cyclists, research describing these same characteristics in master level cyclists is rare [13]. To the best of our knowledge, only one study was conducted on physiological differences between master (*N*=12, aged 65.1 y) and senior level road cyclists (*N*=12, aged 24.8 y; [16]).

To sum up, what was known until now about this topic the following remarks should be stated: master level road cyclists (aged 65.1 y) had much lower aerobic and anaerobic power than their 40-y younger counterparts, as well as less decrease of velocity than of force [16]; there were significant differences between three master level groups (aged 35-45 y, 45-54 y and 55-73 y) regarding aerobic power, which was inversely proportional to the age [13]. Therefore, aim of our study was to compare cardiorespiratory power and force-velocity characteristics between two groups, one of the master and one of senior level cyclists, presenting relatively small chronological difference (approximately 14.5 y), in an attempt to examine the effect of aging on these parameters and to provide reference fitness data. The research hypotheses that aerobic and anaerobic power was lower, theoretical maximal force and velocity was lower with a more pronounced difference in force, percentage of body fat was higher and muscle mass was lower (with corresponding changes in somatotype, i.e. higher endomorphy, lower mesomorphy and ectomorphy) in master than in senior level road cyclists, were examined.

Materials and methods

Participants and procedures

Eighteen master (43.25±5.37 y), older than 35 y, and 13 senior level male road cyclists (28.78±4.95 y), younger than 35 y with similar weekly training volumes (11.8±2.4 h and 11.4±2.6 h respectively), volunteered for this study. The cut-off point of 35 y was employed to distinguish master from senior level cyclists in accordance with previous studies [1,13,16]. The athletes were members of competitive sport clubs and had taken part in at least one competition during the six months prior testing. They visited our laboratory once, were informed about the protocols and provided oral informed consent. First, anthropometric and body composition data were obtained followed by a guided 15-min warm-up. Then force-velocity test was performed and after a 15-min break graded exercise test was taken place.

Protocols and equipment

Height and body mass were measured using a stadiometer (SECA, Leicester, UK) and an electronic scale (HD-351, Tanita, Illinois, USA), respectively. Percent of body fat was calculated from the sum of 10 skinfolds using a skinfold caliper (Harpenden, West Sussex, UK), based on the formula proposed by Parizkova [17]. Body circumferences were measured using a measuring tape, and humerus and femur biepicondylar breadths were assessed by caliper (Anthropometer 01291, Lafayette, USA). The anthropometric Heath-Carter method of somatotyping was employed for the quantification of shape and composition of the human body, expressed in a three-number rating representing endomorphy (relative fatness), mesomorphy (relative musculo-skeletal robustness), and ectomorphy (relative linearity or slenderness) [18].

The force-velocity test was employed to assess maximal anaerobic power, theoretical maximal velocity and force – this test employed various applied braking forces that elicit different pedalling velocities in order to derive maximal power [19,20]. With respect to other anaerobic tests, this test had the advantage that provided information not only about maximal anaerobic power, but also about the constituents of power, i.e. force and velocity. Seat height was adjusted to each participant's satisfaction, and toe clips with straps were used to prevent the feet from slipping off the pedals. Participants were instructed before the tests that they should pedal as fast as possible. The participants performed five supramaximal pedal sprints, each lasting 7 sec, against incremental braking force, on a cycle ergometer (Ergomedics 874, Monark, Sweden). During each sprint, participants were encouraged to reach their maximal velocity as soon as possible. This value of peak velocity was recorded and was used to calculate the force-velocity relationship. The warm-up activity, which was conducted before the test, included stretching exercises, steady-paced cycling, and short submaximal sprints. Minimal warming-up and learning experience was necessary in order to perform a true maximal sprint. The recovery period between each exercise bout was 5 minutes. The test began against a braking force of 29.4 N. In every subsequent sprint, 9.8 N was added.

A graded exercise test on a cycle ergometer (Ergomedics 828, Monark, Sweden), in which initial workload was 1.5 $W \cdot kg^{-1}$ and it increased by 20 W every minute until exhaustion [20], was performed. A ramp protocol was employed elsewhere with increases of 25 W every minute [14]. A gas analyzer (Fitmate Pro, Cosmed, Italy) recorded minute ventilation and oxygen uptake. During the test, a cadence of 80 revolutions per minute was maintained through two means: visual contact with the monitor embodied in the cycle reporting cadence and audio signal of a metronome set at 80 beats per minute. Anaerobic threshold was identified from ventilatory threshold, i.e. the relationship between minute ventilation and oxygen uptake. Blood sample was taken 5 min after termination of the test and lactate concentration was analyzed (Accutrend, Roche, Germany). Lactate concentration was employed as a criterion of $\dot{V}O_2max$ achievement (accepted values >9 $mmol \cdot L^{-1}$). Predicted maximal heart rate ($HR_{max, predicted}$) was calculated by the formula $HR_{max, predicted} = 208 - 0.7 \cdot age$ [21] and it was employed as a criterion of $\dot{V}O_2max$ achievement, as well as an index of motivation level.

Statistical and data analysis

All data are presented as mean±standard deviation. Data sets were checked for normality using the Shapiro-Wilks normality test and visual inspection. Student t-test was employed to examine the differences between age groups. Pearson moment correlation coefficient was used to examine the association between age and physiological parameters. For each participant in force-velocity test an individual linear regression (least squares method) was determined between peak pedaling frequency and breaking force for each of the five sprints (five data points for each force-velocity relationship). The theoretical maximal force (F_0) and velocity (V_0) corresponded to the intercepts with the force and velocity axes in the force – velocity graph. Maximal anaerobic power (P_{max}) was determined at an optimal force and optimal velocity of 0.5 F_0 and 0.5 V_0 and was calculated as $P_{max} = 0.25 \cdot F_0 \cdot V_0$. The duration of every flywheel revolution in force-velocity test was measured with the help of electronic sensor and power output of every revolution was computed by specialized software [22]. Regarding the taxing of human energy transfer systems during the test, maximal anaerobic power was considered a descriptor of short-term power that relied mainly upon adenosine triphosphate-creatine phosphate (alactic anaerobic system). The quotient of anaerobic maximal power by aerobic maximal power ($P_{max, anaerobic} / P_{max, aerobic}$) was calculated as a descriptor of the bioenergetic profile. Significance level was set at alpha=0.05. Statistical analyses were performed using SPSS v17.0.

Results

The values of physiological parameters of each group were depicted in Table 1. The comparison between the two age groups with respect to these variables revealed a significant difference only for maximal heart rate (t=2.83, P<0.001) and heart rate at the anaerobic threshold (t=3.11, P<0.001). These heart rate indices were significantly associated with age (r=-0.66, P<0.001 and r=-0.69, P<0.001 respectively). Regarding aerobic power, there was a weak negative non-significant association between age and $\dot{V}O_2max$ (r=-0.11, P=0.57), $\dot{V}O_2thr$ (r=-0.18, P=0.36), and $\dot{V}O_2thr/\dot{V}O_2max$ (r=-0.2, P=0.29) with respect to anaerobic power, there was weak non-significant association between age and anaerobic P_{max} (r=0.14, P=0.49), F_0 (r=0.11, P=0.6), and v_0 (r=0.04, P=0.84), while regarding age and bioenergetic profile ($P_{max, anaerobic}/P_{max, aerobic}$) there was an also weak non-significant association (r=0.12, P=0.55).

Discussion

Anthropometry, body composition and somatotype

With respect to body mass, stature, body mass index, percentage of body fat, fat mass and fat free mass, there was no significant difference between master and senior level road cyclists. Somatotype of both groups was endomorphic mesomorph. The findings regarding anthropometric characteristics came to terms with existing data. In a comparison between master (N=12, aged 65.1 y) and senior athletes (N=12, aged 24.8 y), both groups had a similar body mass (74.5 kg vs. 73.5 kg) and height (1.73 m vs. 1.77 m [16].

Maximal aerobic power

The level of motivation in the two groups was assumed to be comparable during the incremental aerobic test as both attained similar percentage of predicted

Table 1. Anthropometric and physiological characteristics of master and senior level road cyclists.

	Masters (N=18)	Seniors (N=13)
Anthropometric characteristics		
Age (y)	43.25±5.37*	28.78±4.95
Body mass (kg)	75.12±3.47	75.02±5.85
Stature (m)	1.76±0.047	1.78±0.043
BMI ($kg·m^{-2}$)	24.31±1.51	23.67±2
Body composition		
Body fat (%)	16.01±4.35	17.35±5.08
Fat mass (kg)	12.05±3.42	13.19±4.69
Fat-free mass (kg)	63.07±4.04	61.83±3.97
Somatotype		
Endomor phy	3.14±1.16	3.85±1.77
Mesomorphy	5.39±1.18	5.12±0.6
Ectomorphy	1.91±0.98	2.35±1.01
Cardiorespiratory indices		
$\dot{V}O_2max$ ($mL·min^{-1}·kg^{-1}$)	58.46±7.02	56.71±7.61
$\dot{V}O_{2threshold}$ ($mL·min^{-1}·kg^{-1}$)	42.17±7.48	41.81±6.87
$\dot{V}O_{2threshold}$/ $\dot{V}O_2max$ (%)	71.98±6.48	73.49±4.39
HR_{max} (bpm)	176.9±13.8*	189.1±8.3
HR_{max} /HRmax,predicted (%)	99.49±6.87	100.63±3.56
$HR_{threshold}$ (bpm)	157±13.9*	170.5±8.3
$HR_{threshold}$/ HR_{max} (%)	88.75±3.88	90.18±2.79
P_{max} ($W·kg^{-1}$)	4.69±0.58	4.66±0.82
$P_{threshold}$ ($W·kg^{-1}$)	3.66±0.68	3.75±0.8
$P_{threshold}$/ P_{max} (%)	77.68±7.28	80.42±8.73
Lactate ($mmol·L^{-1}$)	10.39±3.41	9.05±1.94
Anaerobic power and force-velocity characteristics		
Pmax (W)	1084.4±225.36	985.6±152.86
Pmax ($W·kg^{-1}$)	14.53±3.06	13.25±2.37
V_0 (rpm)	214.4±14.03	215.69±16.91
F_0 (N)	202.6±41	183.3±29.2
Bioenergetic profile		
$P_{max, anaerobic}$/$P_{max, aerobic}$	3.01±0.45	2.86±0.47

*P<0.001; BMI is body mass index, $\dot{V}O_2$ oxygen uptake, HR heart rate, bpm beats per minute, P power, V_0 theoretical maximal velocity, F_0 theoretical maximal force; max denotes maximal value and threshold the corresponding value at anaerobic threshold

maximal heart rate close to 100% (HR_{max}/$HR_{max, predicted}$) and lactate concentration in the end of the test close to 10 $mmol·L^{-1}$. Maximal oxygen uptake of master and senior level cyclists (58.46±7.02 $mL·min^{-1}·kg^{-1}$ and 56.71±7.61 $mL·min^{-1}·kg^{-1}$ respectively) was found lower than that of younger cyclists (61.9-69.4 $mL·min^{-1}·kg^{-1}$; N=132, aged 16.8±0.6 y, body mass 66.3±6.7 kg, stature 1.77±0.06 m; [12]), the Irish Olympic Road Cycling Squad (66.2 $mL·min^{-1}·kg^{-1}$; N=6, aged 21 y, body mass 71.2 kg, stature 1.756 m; [23]) or professional male cyclists (75.6 $mL·min^{-1}·kg^{-1}$; N=8, aged 27 y, body mass 65.5 kg; [24]). The level of anaerobic threshold was similar in master and senior level cyclists (71.98±6.48% vs. 73.49±4.39% of $\dot{V}O_2max$), but lower than professional cyclists (83.7% of $\dot{V}O_2max$; [14]).

In a comparison between senior and master athletes [16], the maximal aerobic power was 35% lower (323 W vs. 210 W) and the maximal oxygen uptake was 34.7% lower (58.4 $mL·min^{-1}·kg^{-1}$ vs. 37.6 $mL·min^{-1}·kg^{-1}$) in the latter group. The discrepancy between the findings of this study and of the present one could be explained by the chronological difference between the employed groups (40 y vs. 14.5 y accordingly). However, in a comparison between three master level groups (N=32;

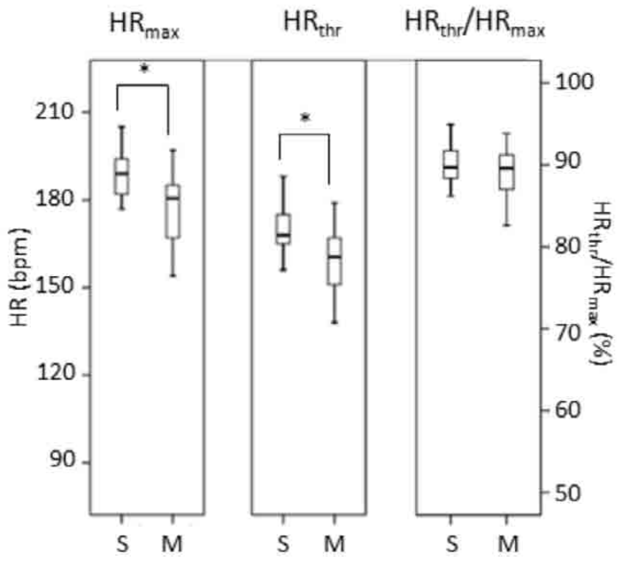

Fig. 1. *Maximal heart rate (HRmax), heart rate at threshold (HR_{thr}), both expressed in beats per minute (bpm), and HR_{thr} to HR_{max} ratio (HR_{thr}/HRmax) of senior (S) and master level participants (M), *P<0.001*

35-45 y, 45-54 y, 55-73 y; [13]) maximal oxygen uptake and absolute peak power output were significantly lower among participants 55-73 y (45.9±4.6 mL·min^{-1}·kg^{-1} and 324±51 W, respectively) with respect to the 45-54 y group (54.2±6.6 mL·min^{-1}·kg^{-1} and 392±36 W, respectively), and both were significantly less compared with the 35-44 y group (60.7±5.1 mL·min^{-1}·kg^{-1} and 434±32 W, respectively). Putting together our findings and those of the two aforementioned studies it was indicated that cardiorespiratory power, either expressed as oxygen consumption or as mechanical power, could be maintained in competitive levels until the beginning of the 5th decade and then a considerable decrease would take place.

Considering the close relationship between cardiorespiratory power and cycling performance, these findings came to terms with the effect of age on performance. With regard to the USA records in 40 km time trial, in the 35 y age group record was only 0.5% higher than the national record, in 40 y 1.8%, in 45 y 5%, in 50 y 6.3%, in 55 y 9.2% and in 60 y 10.8% [1], indicating that a considerable decline of performance took place between 40 y and 45 y.

The decline of maximal heart rate (HR_{max}) with aging was in accordance with previous data, where HR_{max} was significantly greater in both the 35-44 y and 45-54 y age groups compared with the 55-73 y group [13]. In addition to the decline of HR_{max} and heart rate at the threshold ($HR_{threshold}$) with aging, the effect of age on the variability of these parameters though statistically non-significant was remarkable. Both groups had a similar variation of chronological age. Notwithstanding, standard deviation of HR_{max} was 13.8 bpm in master level cyclists and 8.3 bpm in their senior counterpart, while the respective values of $HR_{threshold}$ were 13.9 bpm and 8.3 bpm (Figure 1). Thus, it was indicated that with the advancing of age variability of HR_{max} and $HR_{threshold}$ increased. Theoretically, it would be expected that with aging, considering the decline of these heart rate indices (shown by Peiffer et al. [13], as well as by our study) and the decreased range of individual HR, variability in these indices should decrease. Nonetheless, this inconsistency could be attributed to different training stimuli and mechanisms of adaptation to training.

Maximal anaerobic power and force-velocity characteristics

Even if there were no significant differences between the two age groups regarding anaerobic power, certain indications could be made based upon the results. Theoretical maximal velocity was in the same level (214.4±14.03 rpm vs. 215.69±16.91 rpm in master and senior level cyclists respectively). Maximal anaerobic power expressed either in absolute or with respect to body mass values and theoretical maximal force were non-significantly higher in the master level group. Elsewhere, maximal anaerobic power was 42.7% lower in a master group than in a senior group of athletes (8.38 W·kg^{-1} vs. 14.82 W·kg^{-1}), theoretical maximal force 30.3% (138 N vs. 198 N) and theoretical maximal velocity 15.2% (183.1 rpm vs. 215.9 rpm; [16]). These values were lower than those of adolescent cyclists (14.4-16.7 W·kg^{-1}; [12]).

In a cross-sectional study of P_{max} of 195 males, P_{max} and rP_{max} were 417±24 W and 12.4±0.3 W·kg^{-1} respectively in age group 8-12 y, 1060±79 W and 15.9±0.5 W·kg^{-1} in 12-20 y, 1322±38 W and 17.4±0.4 W·kg^{-1} in 20-30 y, 1335±52 W and 16.9±0.4 W·kg^{-1} in 30-40 y, 1203±58 W and 15.5±0.6 W·kg^{-1} in 40-50 y, 1057±31 W and 13±0.3 W·kg^{-1} in 50-60 y, and 927±37 W and 12.1±0.3 W·kg^{-1} in 60-70 y [25]. In the same research, the adult groups which differed significantly from the 20-30 y one with respect to P_{max} were the 50-60 y and the 60-70 y, while regarding rP_{max} the corresponding groups were the 40-50 y, 50-60 y and 60-70 y. Based on our findings and in the light of previous investigations two points should be highlighted: first, anaerobic power could be maintained until the first half of the 5th decade and then an important decrease occurred, and second, force-velocity characteristics did not exhibit the same trend, there was a more "strong" profile until that age and then a gradual switch to "fast" profile occurred, partially explained by loss of fat free mass after this age.

Practical implication

The comparison of the fitness characteristics of master level cyclists with established senior level cyclist data should be avoided, because this may lead to inaccurate assessments of fitness [13], e.g. heart rate indices. It is not only the effect of age on heart rate values that should be considered in master level cyclists training, but also the effect of age on the variability of these values highlighting the need for individualized data. Moreover, knowledge about the changes of fitness characteristics over time could be crucial for coaches and fitness trainers in order to design optimal training programs and set realistic goals. Based on our findings, it was suggested that since master level road cyclists exhibited similar body composition, aerobic and anaerobic profile like their younger counterparts, coaches and fitness trainers should provide no age-specific suggestions regarding physical fitness training.

Limitations of the study and suggestions for future research

On the one hand, the cross-sectional design of this investigation [13,16] though applied to different participants, it had the advantage of a well-controlled research environment. On the other hand, longitudinal studies, although appeared the difficulty of applying the same methods over long time, could provide data about the same participants. Therefore, the combined use of cross-sectional and longitudinal study should be suggested for future research, in order to cover a long period and to be able to identify crucial "turn-points" across lifespan regarding physiological characteristics. Another drawback of this study was the number of cyclists who performed the tests. A small number of participants could be sufficient to reveal statistically significant differences in these characteristics in the case that the two groups differed too much in age. However, in the case that the chronological difference of the groups was not large enough, a bigger number of participants would be needed.

Conclusions

In conclusion, significant difference between master and senior level road cyclists was found only regarding maximal and threshold heart rate, and larger variability in these heart rate indices was indicated for the former group. The main findings revealed no significant difference with respect to anthropometric parameters, body composition, cardiorespiratory and anaerobic power. Based on these findings, it was concluded that master level cyclists could exhibit similar physiological characteristics like their senior counterparts. Although there was no significant difference regarding anaerobic power, it was suggested that there was a higher contribution of muscular strength to the outcome of anaerobic power in master level cyclists. In previous study [16] in which groups differed by more than 40 y, great differences between master and senior level groups were found in aerobic and anaerobic characteristics. What is novel is that these differences can be attenuated examining two groups that are closer in age like in our study. These findings could be employed in the field of performance optimization of master level road cyclists.

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A – Study Design
B – Data Collection
C – Statistical Analysis
D – Data Interpretation
E – Manuscript Preparation
F – Literature Search
G – Funds Collection