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Prediction of Endurance Performance and Repeated Sprint Ability Based on Critical Velocity in Soccer Players Depending on their Playing Position

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A B S T R A C T

Tests and regular monitoring of the athlete's' performance is an important aspect of a successful training program. However, the methods of conducting tests are challenging, particularly in team sports. The present study is an attempt to predict endurance performance and repeated sprint ability based on critical velocity (CV) and anaerobic distance capacity (ADC) in soccer players according to their playing position. The current research used a causal ex post facto design. 60 players from the same team (Ilam, Iran) participating in 3-5 regular practice sessions a week, with an age range of 16-20 years participated in this study as volunteers. They are divided in 6 playing positions (Fullback, Center Back, Defending/Holding Midfielder (CDM), Midfielder Offensive, Winger and Striker) presenting homogeneous level, experience, volume and intensity of training. Body composition, 400m and 1600m running tests and Running-Based Anaerobic Sprint Test (RAST) were measured. CV and ADC were measured using 400m and 1600m running time data. Linear regression test was used to predict the relationship between the variables and one-way analysis of variance (ANOVA) was used to determine the differences between the players in different positions. Results of the linear regression model showed that CV and ADC ha significantly impact maximum, minimum, average power, aerobic and anaerobic performance in irrespective of the playing position. Regardless of the game positional role. CV of Fullback had an effect on the minimum, average power and decremental index, and the ADC variable in the Center Back position had an effect on the minimum power. However, CV and ADC variables had a significant effect on the prediction of aerobic and anaerobic performance in all six game positions. The results of the one-way ANOVA statistical test showed that there was a significant difference between the different positions only in the deceleration index factor (p=0.015), and the results of the Bonferroni test showed that this difference was between the Midfielder Offensive and winger groups (p=0.012). This study has shown relevant information for coaching about the use of C.V and ADC in order to propose new keys and ways of planning training sessions.

Keywords: *Critical velocity, anaerobic capacity, football, running speed, physical performance.*

1. Introduction

Tests and regular monitoring of athletes' performance is an important aspect of a successful training program. However, methods of conducting tests are challenging, particularly in team sports. Several obstacles have been reported including the large number of player's involved, limited time, and the lack of resources and specialized physiological tests available to coaches(1). Numerous researchers analyzed various aspects of football, and especially how help the players reach their peak performance and ability (2). One important variables for measuring performance in football is physical fitness. Oxygen consumption in the muscles is an important determinant of aerobic performance and critical velocity (CV). CV is derived from the concept of critical power. The concept of critical power was first defined by Monod and Scherrer (1965). Critical power tests include a series of strenuous exercises on small muscle groups with different exercise intensities. Critical power parameters and anaerobic work capacity are obtained from the linear relationship between work (the parameter determined by power and time) and lag time. The parameters of CV and anaerobic distance capacity (ADC) are equal to the parameters of anaerobic work capacity (3, 4). CV is the ability to maintain maximum running speed without fatigue, and ADC is the distance covered by anaerobic energy sources in the muscles (3, 4). The level of aerobic fitness of athletes can be predicted by CV and ADC. Cihan (2022) analyzed the relationship between CV and running profile during a match. In this study, the yo-yo intermittent recovery test level 1 was used to determine the maximum aerobic speed and the 30-meter speed test to evaluate the maximum sprint speed (MSS). The results of the study showed that CV is a significant predictor of high-intensity running, maximal running speed and total running distance during the match(5). Ari et al. (2021) also investigated the prediction of anaerobic speed running test and 800 meters performance by CV parameters in amateur soccer players and reported no significant correlation between CV and RAST test parameters, but ADC and parameters RAST test were significantly correlated. CV and ADC had a correlation with the maximum speed of 800 meters, but they did not have a correlation with the average speed of 800 meters. Among the parameters of the RAST test, only the fatigue index predicted the 800 m running time (6). It seems that if the relationship and the possible effects of CV and ADC on aerobic and anaerobic activities are determined, football players' preparation program can be organized based on the CV and ADC parameters. Therefore, choosing the right training method is of particular significance. Accordingly, for the efficient organization of teams, it is necessary to develop the abilities of each player according to his playing position to outperform the opponent. On this basis, the players in the field practice special skills according to their playing position (7). In most of the studies, football players have been divided into four groups: striker, midfielder, defender and goalkeeper (8). According to some studies, forwards are faster than other players. They also perform more speed repetitions at longer distances during the match (9). It has also been reported that forwards and defenders have better power compared to midfielders but less power compared to young players (7). Many studies have reported players have different characteristics according to their position (i.e. add here one studies). However, a careful examination of the previous studies indicates that none of them have addressed CV and ADC based on the position of the player. Considering the importance of CV and its role in the modern football game and the fact that it varies across the players, positions, competitions, leagues and different countries and the lack of information on this matter, the purpose of the present study is to predict endurance performance and repeated-sprint ability based on CV in amateur football players according to their playing position.

2. Methods and Materials

2.1. Study Design and Participants

The current research used a causal ex post facto design. 60 players from the same team (Ilam, Iran) participating in 3-5 regular practice sessions a week, with an age range of 16-20 years participated in this study as volunteers. They are divided in 6 playing positions (Fullback, Center Back, Defending/Holding Midfielder (CDM), Midfielder offensive, Winger and Striker) presenting homogeneous level, experience, volume and intensity of training. All the participants were familiarized with the research protocol. Then, they completed the general information questionnaire and signed their written consent to voluntarily participate in

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this study. The participants maintained regular contact with the researcher during the research program. During the tests, they were fully taken care of and they were asked not to make any changes in their diet and lifestyle. Having at least three training sessions per week, not smoking, not changing the diet during the study, and also not taking any supplements during the research were the inclusion criteria, and the exclusion criterion included limitation in performing the tests (neurological, muscular, skeletal problems) during the study. In the briefing session, the participants were asked to refrain from heavy physical activities at least 48 hours before the tests and to use all their power during the tests.

2.2. *Test day schedule*

After determining the height and weight as well as body composition assessment, the participants first warmed up for 15 minutes by performing stretching and stretching movements, then the 400 meters running test was performed. On the second day, the RAST test was performed, and on the third day, the 1600 meters running test was held, and the records were registered in hundredths of a second.

2.3. *Testing procedure*

The RSA test used in this research is the RAST field test, whose validity and reliability have been confirmed. This test consists of six repetitions of sprinting with full power at a distance of 35 meters with a rest interval of 10 seconds. Before the test, the participants did light stretching and stretching exercises for 10 minutes to warm up. For a favorable conclusion in the RSA test, the players were asked to avoid dividing energy between repetitions and perform each activity with their maximum effort. In order to increase their motivation in applying maximum effort during the activity, their recorded time in each repetition was announced to them. The speed drop index was calculated according to the following formula:

$$\text{decremental index} = \frac{\text{Number of repetitions x Speed activities optimal time}}{\text{Speed activities total time}} \times 100$$

The 400 and 1600 meters testing procedure

With a tape measure of 400 and 1600 meters and after the command, the participants covered the specified distance at full strength.

Calculating the CV index

The following three formulas were used to calculate the CV index.

1) Average speed mathematical model (Lin - TD) [6] D=ADC+CV×t

The second distance (more) in meters minus the first distance (less) divided by the second time in seconds (greater distance) minus the first time (less distance)

2) Linear velocity mathematical model (Lin – V) [6] $V = ADC(\frac{1}{t}) + CV$

3) Non-linear velocity mathematical model (Lin – V) [6] $t = ADC/(V - CV)$

Descriptive statistics (mean and standard deviation) were used to describe the condition of the samples and the Kolmograph-Smirnov (KS) test was used to check the normality of the statistical data and regression analysis and one-way analysis of variance as inferential statistics were utilized to determine the difference between different posts at the significance level of $p \leq 0.05$.

3. Findings and Results

Table 1 presents the mean and standard deviation related to the participants' morphological characteristics.

Table 1

Mean and standard deviation related to the participants' morphological characteristics

Athletes' position Variable	Fullback	Center Back	Defending/Holding Midfielder (CDM)	Midfielder offensive	Winger	Striker	Total
Age (in years)	18.6±1.26	18.4±1.1	17.2±1.4	18.3±1.25	18.2±1.1	18.3±1.2	18.66±1.25
Weight (in kg)	176±7	175±6	175±7	175±5	172±6	174±4	174.9±5.73
Height (in cm)	72.2±10.2	70.9±7	65.2±7	70.9±4.4	64.4±3.5	68.8±3	68.73±6.71
Fat percentage	12.77±3.5	12.3±2.8	10.2±3.5	12.8±2.4	10.7±3	12.9±2.13	11.94±3.02

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Table 2 reports the mean and standard deviation related to the RAST test variables by playing position.

Table 2

Mean and standard deviation related to the RAST test variables by position

Athletes' position Variable	Fullback	Center Back	Defending/Holding Midfielder (CDM)	Midfielder offensive	Winger	Striker	Total
Maximum power	493±82	481±115	466±81	484±69	484±76	477±92	481±84
Minimum power	328±71	333±86	323±63	352±34	307±57	339±83	330±66
Average power	404±73	407±93	398±74	424±53	390±62	406±89	405±73
Fatigue index	4.55±.9	4.12±1.52	4.06±1.8	3.73±1.4	4.99±1.5	3.86±.7	4.22±1.4
Decremental index	0.93±0.015	0.942±0.019	0.943±0.024	0.954±0.01	0.924±0.022	0.942±0.018	0.940±0.02

Table 3 displays the mean and standard deviation related to the variable of time (by second, hour) and speed in 400 and 1600 meters running separately for each playing position.

Table 3

Mean and standard deviation of the variable of time (by second, hour) and speed in 400 and 1600 meters running by playing position

Athletes' position Variable	Fullback	Center Back	Defending/Holding Midfielder (CDM)	Midfielder offensive	Winger	Striker	Total
Time 400 m (by second)	67.2±4.91	70.6±4.11	65.6±4.19	69.9±6.19	65.4±3.47	68.8±4.68	67.9±4.9
Time 400 m (by hour)	0.018±0.0013	0.019±0.0011	0.018±0.0011	0.019±0.0017	0.018±0.0009	0.019±0.0013	0.019±0.0013
Speed 400 m (m/s)	21.53±1.6	20.46±1.24	22.03±1.34	20.74±1.82	22.07±1.13	21.01±1.4	21.31±1.51
Time 1600 m (by second)	451.9±46.47	443.2±33.5	408.1±42.56	438.1±44.18	447.2±41.05	429.7±33.66	436.36±41.43
Time 1600 m (by hour)	0.125±0.012	0.123±0.009	0.113±0.011	0.121±0.012	0.124±0.011	0.119±0.009	0.121±0.011
Speed 1600 m (m/s)	12.87±1.36	13.07±1.13	14.25±1.45	13.28±1.46	12.98±1.22	13.48±1.07	13.32±1.32

Table 4 presents the means and standard deviations for the CV and ADV variables separately for each model and the participants' playing position.

Table 4

Means and standard deviations related to the CV and ADV variables by model according to the participants' playing position

Athletes' position Variable	Fullback	Center Back	Defending/Holding Midfielder (CDM)	Midfielder offensive	Winger	Striker	Total
CV1	11.36±1.34	11.67±1.08	12.76±1.45	11.90±1.57	11.43±1.25	12.06±1.16	11.86±1.35
ADC1	0.189±0.022	0.17±0.01	0.17±0.021	0.17±0.04	0.19±0.026	0.17±0.027	0.17±0.026
CV2	11.36±1.34	11.67±1.08	12.76±1.45	11.90±1.57	11.43±1.25	12.06±1.16	11.86±1.35
ADC2	0.189±0.022	0.17±0.01	0.17±0.021	0.17±0.04	0.19±0.026	0.17±0.027	0.17±0.026
CV3	11.36±1.34	11.67±1.08	12.76±1.45	11.90±1.57	11.43±1.25	12.06±1.16	11.86±1.35
ADC3	0.189±0.022	0.17±0.01	0.17±0.021	0.17±0.04	0.19±0.026	0.17±0.027	0.17±0.026

As shown in Table 5, the results are the same for all three models. To investigate the reason for the same value in all three models, we further studied all three formulas and examined their mathematical proof.

In the first equation (mathematical model of average speed), the distance traveled in terms of time has been mentioned; if the distance is divided by time in the equation, the second equation (mathematical model of linear speed) is obtained, which constitutes the first part of the equation.

$$D = ADC + CV \times t$$

Now, we divide the above equation into t:

$$D/t = (ADC + CV \times t)/\mathrm{t}$$

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Distance is divided into time thus forming the second equation:

$$V = ADC(\frac{1}{t}) + CV$$

Now, in the second equation, if we put CV next to v, we will have:

$$V - CV = ADC(\frac{1}{t})$$

Then, t*v-cv; therefore,

$$(V - CV)t = ADC$$

Now, if we want to find *t*, we divide ADC by V-CV, which forms the third equation (mathematical mode of non-linear speed):

Given the fact that all three mathematical models are ultimately similar and due to the same numerical value in all three models, only one table is reported representing all three models.

Table 5

Linear regression model to investigate the effect of CV variable on RAST test variables by playing position

Athletes' position / Variable	Fullback		Center Back		Defending/Holding Midfielder (CDM)		Midfielder offensive		Winger		Striker		Total	
	p	t	p	t	p	t	p	t	p	t	p	t	p	t
Maximum power	0.12	1.77	0.06	2. 2	0.78	0.27	0.2	1.4	0.76	0.32	0.48	0.71	0.013	2.56
Minimum power	0.02	2.97	0.054	2.31	0.26	1.22	0.47	0.75	0.47	0.75	0.63	0.49	0.019	2.42
Average power	0.03	2.66	0.07	2.13	0.46	0.76	0.25	1.24	0.41	0.87	0.55	0.62	0.009	2.71
Fatigue index	0.87	0.159	0.16	1.56	0.57	-0.58	0.18	1.49	0.8	-0.25	0.26	1.2	0.11	1.6
Decremental index	0.018	3.05	0.79	-0.27	0.17	1.52	0.2	-1.4	0.14	1.66	0.87	-0.16	0.44	-0.76

Table 6

Linear regression model to investigate the effect of ADC variable on RAST test variables by playing position

Athletes' position / Variable	Fullback		Center Back		Defending/Holding Midfielder (CDM)		Midfielder offensive		Winger		Striker		Total	
	p	t	p	t	p	t	p	t	p	t	p	t	p	t
Maximum power	0.22	1.35	0.18	1.48	0.89	-0.14	0.33	1.04	0.91	0.12	0.23	1.3	0.035	2.16
Minimum power	0.06	2.15	0.049	2.37	0.4	0.9	0.34	1.01	0.81	0.24	0.35	0.99	0.05	1.96
Average power	0.08	1.97	0.09	1.9	0.8	0.27	0.32	1.06	0.72	0.36	0.33	1.03	0.04	2.01
Fatigue index	0.88	0.16	0.83	-0.21	0.34	-1.02	0.47	0.76	0.93	-0.08	0.14	1.67	0.19	1.3
Decremental index	0.09	1.93	0.11	1.79	0.27	1.17	0.72	-0.36	0.46	0.78	0.74	-0.33	0.81	-0.24

Table 7

Linear regression model to investigate the effect of CV and ADC variable on 400m and1600m test by playing position

Athletes' position / Variable	Fullback		Center Back		Defending/Holding Midfielder (CDM)		Midfielder offensive		Winger		Striker		Total	
	p	t	p	t	p	t	p	t	p	t	p	t	p	t
CV – 400 m	0.0001	-11.99	0.0001	-16.12	0.0001	-21.38	0.0001	-9.71	0.0001	-13.6	0.0001	-11.28	0.0001	-34.29
ADC – 400m	0.0001	-10.73	0.0001	-9.21	0.0001	-17.97	0.0001	-12.88	0.0001	-15.6	0.0001	-13.17	0.0001	-36.83
CV – 1600 m	0.0001	-18.85	0.0001	-20.49	0.0001	-20.19	0.0001	-21.98	0.0001	-12.79	0.0001	-28.45	0.0001	-44.45
ADC – 1600m	0.04	-2.42	0.09	-1.9	0.26	-1.21	0.007	-3.73	0.21	-1.35	0.0001	-8.9	0.0001	-6.32

The results of the linear regression model showed that CV and ADC ha significantly affect maximum, minimum, average power, aerobic and anaerobic performance in irrespective of the playing position regardless of the game post.

By comparing the positions of the players, it was found that the CV variable in the Fullback position had an effect

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on the minimum, average power and decremental index, and the ADC variable in the Center Back position had an effect on the minimum power.

However, CV and ADC variables had a significant effect on the prediction of aerobic and anaerobic performance in all six game positions. The results of the one-way ANOVA statistical test showed that there was a significant difference between the different positions only in the deceleration index factor (p=0.015), and the results of the Bonferroni test showed that this difference was between the Midfielder Offensive and winger groups (p=0.012). (no significant difference between the players based on their playing position for the time of 400 meters (p=0.06), the speed of 400 meters (p=0.07), the time of 1600 meters (p=0.198), the speed of 1600 meters (p=0.197) p), maximum power (p=0.9), minimum power (p=0.78), average power (p=0.95), fatigue index (p=0.33), CV (p = 0.20) and ADC (p = 0.14) in the factors under study).

4. Discussion and Conclusion

For the first time, the present study investigated the effect of CV and ADC variables on power parameters, deceleration index and fatigue index in football players according to their playing positions (Fullback, Center Back, Defending/Holding Midfielder (CDM), Midfielder Offensive, Winger and Striker). The results of the present study showed that CV and ADC factors are among the factors influencing the average power, minimum power and maximum power in football players, and also had a significant effect on the time parameter of running 400 and 1600 meters running in all players and across different playing positions. There are few studies in this field. As an instance, in line with the present study, Ari et al. (2021) showed that ADC had a significant relationship with RAST parameters; However, as against the results of the present study, CV was found to have no significant relationship with RAST test parameters (6). In general, they suggested that ADC predicts speed endurance and repeated sprint ability (RSA) in soccer players and can be used to improve speed endurance performance (6). Given the few studies in this regard, the reasons for this discrepancy in the findings are not clear. However, it has been shown that one of the parameters involved in aerobic endurance is CV. CV is the highest exercise intensity that is theoretically maintained without fatigue in long-term exercise (10, 11). Further, CV indicates the lowest exercise limit stimulating maximum oxygen consumption, but ADC is the distance covered through anaerobic energy sources in the muscles [3]. In fact, CV is closely related to maximal oxygen consumption and is an important indicator of maximal oxygen consumption (12). In similar studies, it has been reported that CV is related to maximum aerobic speed and maximum oxygen consumption (13, 14). It may be stated that the 800 m test is anaerobic and has a lesser role in the aerobic performance test (6). In professional soccer players, no relationship has been found in the RAST test with match performance such as maximum speed and total distance (15). Nevertheless, it has been shown in runners that the maximum aerobic speed and the maximum anaerobic speed determine the performance in 800 meters running (16). Also, it has been reported that CV is significantly related to both the onset of lactate accumulation and the steady state of lactate (17). In line with this, the researchers have shown that the average intensity of activity during a soccer match is around 85% of the maximum heart rate and the anaerobic threshold or lactate threshold in soccer players occurs at around 80-90% of the maximum heart rate (18).

Since football requires high aerobic energy, CV can be used as a means of determining the intensity of aerobic activity in football (5). In a study, Maida et al. (2023) investigated the effect of CV and ADC on speed, acceleration and agility in soccer players. The results showed that CV and ADC were not predictors of acceleration, speed and agility. In fact, ADC had no effect on high-intensity anaerobic activities such as agility and speed (19). Also, researchers found a high correlation between marathon running time and CV value; during marathon running, there is aerobic activity and energy is mainly provided by the aerobic system(20). On the other hand, in a study, a high correlation was observed between CV and anaerobic threshold and maximal aerobic velocity value (21). The results of the present study showed that CV and ADC can predict the 1600 meters sprint time. In line with the results of the present study, Ari et al.'s study, which involved 2400 meters running, showed that ADC and CV can predict the 2400 meters running time. In another study, a significant relationship was reported between CV and anaerobic threshold running speed(22). Anaerobic threshold

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indicates aerobic endurance. Both CV and anaerobic threshold are the most important factored involved in aerobic endurance (22).

A significant aspect of the present study was that CV and ADC variables and their effect on sprint parameters and RAST test based on playing position were investigated for the first time. The results showed that in CV variable in the Fullback position had an effect on the minimum, average power and decremental index, and the ADC variable in the Center Back position had an effect on the minimum power. CV and ADC variables had a significant effect on the 400 and 1600m running time in all players and also in different playing positions. The reasons for these changes, why CV has an effect on power parameters in defenders but not in other positions, are unclear. Defenders and central midfielders have been shown to have better running performance at higher intensities compared to wing midfielders and forwards (23). Midfielders, defenders and forwards, respectively, have the highest aerobic threshold. Also, midfielders have the highest anaerobic threshold (2). Invaders have the lowest aerobic and anaerobic thresholds; but there is no difference in maximal oxygen consumption between players in different playing positions (2).

Footballers run different distances based on their playing position; midfielders run more, and forwards and then defenders are, respectively, next in terms of running distance(24). These results show that defenders probably have more high-intensity activity and, consequently, run less distance at higher intensities, which can affect the anaerobic capacity of these athletes (18). In a study, a difference in running economy was observed for center-back players and left and rightwing midfielders; however, in maximal oxygen consumption, lactate threshold, and anaerobic performance, there was no significant difference among defenders, midfielders, and forwards(25). CV has been reported to correlate with total running distance and low- and moderate-intensity running (5). But ADC is not correlated with running parameters during the race(5). ADC is the limited anaerobic energy resources in muscles, which indicates the distance traveled (20). CV and ADC are significant predictors of high-intensity running and maximum running speed parameters in soccer matches (5). In athletes, CV has been found to have a positive and significant relationship with maximum oxygen consumption and an inverse relationship with fatigue index(26). Furthermore, the results of the present study revealed that CV and ADC variables have no relationship with fatigue and deceleration indices. It has been reported that CV occurs at 84-91% of the peak oxygen consumption rate (VO2peak) and, in another study, it was observed at 88% of VO2peak [28]. Due to the limitations of the present study, it is not possible to specify the reason for these changes because it is possible that the CV in these athletes did not occur completely during the 400 m run. Previous studies indicate that there is no difference between CV and maximal lactate steady-state velocity [29]. In fact, CV is an indirect estimate of the maximum lactate in the steady state (27). Therefore, it can be generally stated that due to the limitation of the present study in estimating the maximum oxygen consumption, and in examination of endurance runs with longer distances and increasing sports activities to determine AC and ADC, as well as the existence of small number of studies on soccer players with contradictory findings, the reasons for the contradictory findings in the present and previous studies are unclear and requires further research in this regard.

The results showed that the CV variable in the Fullback position had an effect on the minimum, average power and the decremental index, and the ADC variable in the Center Back position had an effect on the minimum power. Also, CV and ADC variables had a significant effect on the prediction of aerobic and anaerobic performance in all six game positions. Overall, the results suggest that CV and ADC variables can predict aerobic and anaerobic performance in soccer. However, due to the limitations associated with the present study, future studies are needed.

Authors' Contributions

M. R. conceptualized the study, analyzed the data, and drafted the manuscript. R. A. contributed to the research design, data collection, and statistical analysis. N. R. assisted with the study design, interpretation of the results, and manuscript writing. All authors revised the manuscript and approved the final version for publication.

Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

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Transparency Statement

Data are available for research purposes upon reasonable request to the corresponding author.

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Declaration of Interest

The authors report no conflict of interest.

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Ethics Considerations

The study placed a high emphasis on ethical considerations. Informed consent obtained from all participants, ensuring they are fully aware of the nature of the study and their role in it. Confidentiality strictly maintained, with data anonymized to protect individual privacy. The study adhered to the ethical guidelines for research with human subjects as outlined in the Declaration of Helsinki. The present article is obtained from a master's thesis in Ilam University with code of ethics IR.ILAM.REC.1402.010 and has no sponsor.

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