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Widad Kadhim Majeed
College of Physical Education and Sport Sciences for Women, University of Baghdad, wedad@copew.uobaghdad.edu.iq

Huda Shihab Jari
College of Physical Education and Sport Sciences for Women, University of Baghdad, huda@copew.uobaghdad.edu.iq

Maryam Abdul Jabbar Khudair
College of Physical Education and Sport Sciences for Women, University of Baghdad, mariam.abd1204a@copew.uobaghdad.edu.iq

Özgür Eken
Faculty of Sports Sciences, Department of Physical Education and Sports Teaching, ÿlnönü University, Türkiye, ozgur.eken@inonu.edu.tr

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ORIGINAL STUDY

The Instantaneous Push Force Indicator and Its Relationship to Lower Limb Explosive Power and Selected Biomechanical Variables of the Salto forward tucked

Widad Kadhim Majeed [a,*], Huda Shihab Jari [a], Maryam Abdul Jabbar Khudair [a], Özgür Eken [b]

[a] College of Physical Education and Sport Sciences for Women, University of Baghdad
[b] Faculty of Sports Sciences, Department of Physical Education and Sports Teaching, İnönü University, Türkiye

Abstract

The scarcity of studies examining this relationship makes it difficult to provide accurate and scientifically grounded data regarding its significance. This research aims to bridge this academic gap by analyzing the dynamic relationship between these variables. The research problem lies in the observed difficulty athletes face in performing the tucked front somersault on the floor exercise mat. This difficulty may stem from deficits in the explosive muscular power of the legs and insufficient instantaneous push-off force required to achieve the necessary elevation to complete the skill. Additionally, the coach's neglect of the importance of these variables—as well as the biomechanical factors that influence the movement—may contribute to the problem. To shed light on the factors influencing athletes' performance, the research problem was formulated as follows: *What is the relationship between the instantaneous push-off index, the explosive power of the legs, and selected biomechanical variables related to the tucked front somersault skill performed on the men's floor exercise mat?* The researchers hypothesized that there is no statistically significant relationship between the instantaneous push-off index and the explosive power of the legs. They also hypothesized no significant relationship between the instantaneous push-off index and biomechanical variables. A descriptive methodology was adopted with a purposive sample of six male athletes from Al-Thawra Club in Kirkuk, aged 14–18, representing 60% of the 10-athlete population. Explosive power and instantaneous push-off were measured using a Foot Scan device, while biomechanical variables were assessed via motion analysis software. The results revealed a significant relationship between push-off index and explosive power, emphasizing the importance of targeted training programs to enhance both. and this achieves one of the sustainable development goals of the United Nations in Iraq which is (Quality Education)

Keywords: Biomechanical variables, Instantaneous push force indicator, Lower limb explosive power

1. Introduction

The tucked front flip on the floor exercise mat is considered one of the fundamental and complex skills in gymnastics. It requires high athletic performance in strength and coordination between jumping and rotational movements. This skill combines power, flexibility, motor control, and aerial dynamics, demanding precise synchronization between strength and movement execution. Due to the necessity of achieving sufficient body elevation while maintaining ideal rotational speed for accurate completion before landing, this skill presents a significant performance challenge. The quality of execution depends on the interaction of various physical and biomechanical factors, such as lower limb explosive power, instantaneous force during take-off, and joint

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* Corresponding author.
E-mail addresses: wedad@copew.uobaghdad.edu.iq (W. K. Majeed), huda@copew.uobaghdad.edu.iq (H. S. Jari), mariam.abd1204a@copew.uobaghdad.edu.iq (M. A. J. Khudair), ozgur.eken@inonu.edu.tr (O. Eken).

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positioning (knee, hip, ankle) throughout different phases of movement, which directly affect vertical lift and the athlete's control over rotational speed.

To enhance the technical performance of this skill, professionals in the field must identify weaknesses in execution phases through motion analysis and their relationship with relevant kinematic variables, then work to address these through appropriate corrective strategies. As the literature states, "motion analysis is among the most valid sciences in evaluation and direction" (Mahjoub, 1986, p.17).

Modern motion analysis software can obtain a wealth of data to correct performance errors or reinforce effective techniques. (Al-Zwainy et al., 2024).

Researchers have emphasized modern imaging and analysis technologies to detect mechanical errors in movement trajectories accurately (Shaker and Kadhem, 2021).

The instantaneous force indicator is critical in determining athletic performance in this skill, as it reflects the lower limb's ability to generate maximal force quickly. This ability is influenced by various mechanical factors, both internal and external, which can positively or negatively affect performance. Understanding these aspects helps reinforce positive elements and reduce negative ones in the mechanical path of the movement. There is a strong link between fulfilling biomechanical conditions and successful performance in gymnastics, which fundamentally relies on joint angles during skill execution.

Despite the acknowledged importance of the relationship between the instantaneous force indicator, lower limb explosive power, and key biomechanical variables in various floor skills and other gymnastics techniques, there remains a lack of in-depth understanding of how these physical and biomechanical factors influence motor performance. The limited number of studies investigating this relationship makes it difficult to provide accurate scientific data regarding its significance. Shedding light on these relationships could aid coaches in understanding the connection between these variables and the execution of the tucked front somersault skill, enhancing athletes' ability to perform other complex gymnastics movements.

A deeper understanding of these interactions would enable coaches to design more effective training programs, grounded in objective standards, to evaluate and improve athletes' technical performance. Therefore, this study aims to fill existing knowledge gaps in the scientific literature regarding the dynamic relationship between the studied variables and the motor performance of male gymnasts. The ultimate goal is to develop more effective training models that improve technical execution and athletic achievement.

Based on their experience in biomechanics and gymnastics, the researchers observed that many athletes struggle to perform the tucked front flip on the floor mat. These difficulties may be attributed to deficiencies in lower limb explosive power, weak instantaneous force needed for vertical elevation, and the lack of coach attention to the significance of these variables, especially those biomechanical factors that directly influence the skill.

Although the skill requires high explosive power and effective push-off ability, studies exploring the relationship between the instantaneous force indicator and joint angles and performance outcomes (such as height and rotational speed) remain limited, particularly in applied gymnastics contexts.

To highlight the factors affecting athletes' performance, the research problem is framed in the following question:

> *What is the relationship between the instantaneous force, lower limb explosive power, and selected biomechanical variables of the tucked front flip on the floor exercise mat?*

Improving floor exercise skills' complexity and technical quality while minimizing performance deductions has driven professionals to apply motion analysis to examine influential variables and develop corrective solutions that enhance athlete performance.

1.1. Research objective

- To identify the correlation between the instantaneous force indicator, lower limb explosive power, and selected biomechanical variables of the tucked front flip on the floor exercise mat among male gymnasts.

1.2. Research hypotheses

- There is no statistically significant relationship between the instantaneous force indicator and lower limb explosive power.
- There is no statistically significant relationship between the instantaneous force indicator and selected biomechanical variables of the tucked front flip on the floor exercise mat among male gymnasts aged 14–18.

2. Methodology and procedures

2.1. Research method

The researchers adopted the descriptive method with a correlational approach, which is appropriate

Table 1. Statistical indicators showing the values of the arithmetic mean and coefficient of variation.

No.	Sample Characteristics	Measurement unit	Statistical Parameters		
			AM	SD	Coefficient of variation
1	Age	Year	16.30	1.37	7.41 %
2	Height	cm	167.30	3.39	2.03%
3	Body Mass	Kg	63	2.85	4.53 %
4	Training Age	Year	5.50	2.88	18.21%
5	Leg Length	cm	91.33	7.42	8.13 %

for the nature of the research problem and its objectives.

2.2. *Research population and sample*

The research population was intentionally selected and consisted of (10) gymnasts from Al-Thawra Club in Kirkuk, aged between 14–18 years.

The research sample was also intentionally selected from athletes proficient in performing the skill. The sample consisted of (6) gymnasts, representing (60%) of the total research population.

As shown in Table 1, the characteristics of the research sample include age, height, body mass, training age, and leg length.

Based the Table 1 shows that the variables **(age, height, body mass, training age, and leg length**) have low coefficients of variation, all below 30%, This indicates the homogeneity of the sample, meaning that individuals in this sample are similar in these physical characteristics.

2.3. *Data collection tools and devices used in the research*

- Arabic and Foreign References and Resources
- Internet Information Network
- Two Sony video recording cameras with a frame rate of 240 fps, each mounted on a tripod (2 tripods in total)
- One Foot Scan device with its accessories
- One HP laptop computer
- Medical scale for measuring body mass
- Metal measuring tape
- Number board used to indicate the athlete's number and the attempt performed

3. Tests used

1. **Test of explosive power of the legs** (Al-Fadhli and Alwan, 2007)

- **Test name:** Explosive Power Test of the Legs
- **Tools used:** Gymnastics hall, Foot Scan platform, high-speed video camera (240 fps) with tripod stand, electronic calculator
- **Performance procedure:**
  The athlete performs the test by initiating the movement with a one-step approach, followed by a vertical two-footed jump onto the Foot Scan platform. While in the air, the athlete executes a tucked front somersault, aiming to achieve the maximum possible vertical height and the longest vertical distance during the jump.
- **Scoring method:**
  Each subject performs two consecutive trials. The best of the two attempts is recorded as the final result. The evaluation is based on the athlete's body mass, the vertical distance achieved during the jump, and the push-off time. Explosive power of the legs is then calculated by analyzing the movement using Kinovea software, which determines the push-off duration from the moment the approach begins until the landing after the vertical jump. The achieved distance is measured in meters and decimal fractions of a meter.

  Explosive power is computed according to the equation provided by Al-Fadhli and Alwan (2007).

$$\text{Explosive Power of the Legs} = \frac{\text{Athlete's Mass} \times (\text{Distance})^2}{(\text{Time})^3}$$

- Mass = The athlete's body mass
- Time = The duration of performance from the moment of take-off to the moment of landing
- Distance = The vertical distance covered by the athlete from the moment of leaving the platform to the highest point reached by the body's center of mass

3.1. *Unit of measurement*

The unit used to express the result of the above formula is the watt (W).

1. Method for Measuring the Biomechanical Variables of the Skill:

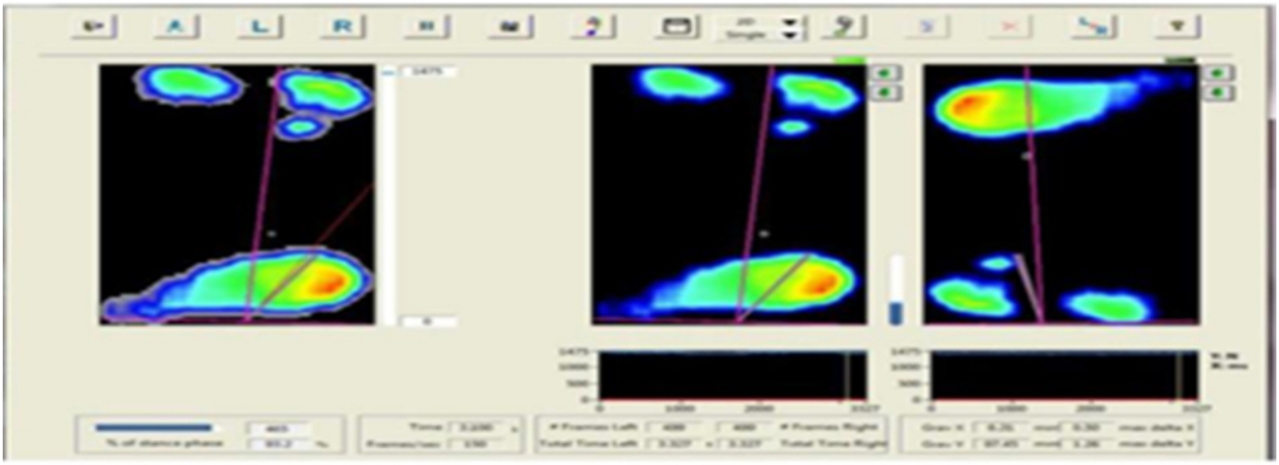

Fig. 1. Shows the angular measurements and the interface of the Foot Scan device.

- Instantaneous push force was measured using a Foot Scan device.
- Biomechanical variables were measured by capturing video of the skill performance and analyzing it using the motion analysis software Kinovea.

The extracted biomechanical variables included:

1. Ground reaction force at take-off (foot strike force)
2. Instantaneous force at take-off
3. Ground contact time during the push phase
4. Duration of the somersault
5. Angular velocity of the center of mass (COM)
6. Horizontal distance of the somersault
7. Knee joint angle during push-off
8. Hip joint angle during push-off
9. Vertical height of the center of mass (COM) during flight

The Foot Scan program Fig. 1 is used in medical and sports fields to analyze walking, standing, and jumping by measuring the pressure distribution on the sole of the foot during movement or while stationary. This data is displayed in the form of a heat map.

4. Field procedures

4.1. Pilot study

The pilot study was conducted on two athletes from the research population but not included in the main experiment. It took place at 4:00 PM on Thursday, October 24, 2024, in the Artistic Gymnastics Hall at Al-Thawra Club, Kirkuk. The purpose of the pilot study was to assess the suitability of the devices and tools for the research tests, verify the functionality of the video cameras, and determine their final placement and distances. This ensured clear footage of the athletes during skill execution and the accuracy of the collected data.

4.2. Main experiment

The main video recording session was conducted at 4:00 PM on Sunday, October 27, 2024, in the Artistic Gymnastics Hall at Al-Thawra Club, Kirkuk. The researchers used two video cameras, each mounted on a tripod and fixed at a height of 1.65 meters from the lens to the ground and at a distance of 10.80 meters from the center of the movement and the force measurement platform. One camera was positioned frontally and the other laterally, allowing for comprehensive coverage of the athlete's movement from the approach phase to landing after the vertical jump.

The video recording was synchronized with the athlete's performance to simultaneously capture the skill execution, explosive power, and instantaneous force indicators.

Afterward, the researchers analyzed the skill using Kinovea software to extract the biomechanical variables related to the studied skill.

5. Results and discussion

Table 2 presents the means and standard deviations of the research variables (Explosive Power, Ground Reaction Force at Take-off, Instantaneous Push Force at Take-off, Ground Contact Time during Push Phase, Flip Duration, Angular Velocity of the Center of Mass (COM), Vertical Height of the COM during Flight, Horizontal Distance of the Flip, Knee Joint Angle during Push-off, and Hip Joint Angle during Push-off).

Table 2. Shows the arithmetic means and standard deviations of the research variables.

Variables	Unit of Measurement	Mean	Standard Deviation
Explosive Power	Meter	1.84	0.049
Ground Reaction Force at Take-off	Newton (N)	4462.60	11.425
Instantaneous Push Force at Take-off	Newton (N)	1359.59	29.74
Ground Contact Time during Push Phase	Second (s)	0.547	0.061
Somersault Duration	Second (s)	0.945	0.035
Angular Velocity of the Center of Mass (COM)	Degrees/Second (°/s)	156.14	3.20
Vertical Height of the COG during Flight	Centimeter (cm)	1.56	0.078
Horizontal Distance of the Somersault	Centimeter (cm)	34.44	3.28
Knee Joint Angle during Push-off	Degree (°)	166.13	2.97
Hip Joint Angle during Push-off	Degree (°)	173.34	2.80

Table 3. Shows the correlation coefficients between Explosive Power and the variables of the Instantaneous Force Indicator.

Variables	Calculated r Value	Percentage Error	Significance
Foot strike force at the moment of take-off	0.843	0.001	Significant
Instantaneous pushing force at the moment of take-off	0.755	0.002	Significant
Support time at the moment of push	0.765	0.001	Significant

Significant at a significance level of ≤ 0.05.

The mean values of these variables were respectively as follows:

(1.84, 4462.60, 1359.59, 0.547, 0.945, 156.14, 1.56, 34.44, 166.13, 173.34)

With standard deviations as follows:

(0.049, 11.425, 29.74, 0.061, 0.035, 3.20, 0.078, 3.28, 2.97, 2.80)

Table 3 Presents the correlation coefficients between Explosive Power and the variables of the Instantaneous Force Index. It is observed that there are statistically significant differences between them, as the error margins were respectively: (0.001, 0.002, 0.001). When compared to the significance level of 0.05, the differences were found to be statistically significant for all variables.

Table 4 presents the correlation coefficients between Ground Reaction Force at Take-off and the biomechanical variables of the tucked front flip skill. The error margins for these variables were respectively: (0.001, 0.001, 0.000, 0.001, 0.002, 0.000).

When compared to the significance level of 0.05, all differences were found to be statistically significant.

Table 5 presents the correlation coefficients between Instantaneous Push Force at Take-off and the biomechanical variables of the tucked front flip skill.

The error margins for these variables were respectively: (0.001, 0.001, 0.002, 0.001, 0.000, 0.000).

When compared to the significance level of 0.05, all the values indicate statistically significant relationships.

As for Table 6, it is evident that the correlation coefficients between Ground Contact Time during the Push Phase and the biomechanical variables of the tucked front flip skill showed statistically significant differences when compared to the significance level of 0.05. The error level for these variables were respectively: (0.001, 0.001, 0.000, 0.001, 0.000, 0.002).

6. Results discussion

From observing Table 3, a statistically significant correlation was found between explosive power of the lower limb and instantaneous push force. The researchers attribute this to the idea that athletes with strong leg muscles are able to perform jumping and push-off actions more effectively.

They further suggest that the significance of this correlation may be due to the relationship between explosive power and the skill-specific variables, which highlights the need for coaches to develop appropriate training solutions to improve vertical jump performance and the quality of take-off. This supports the recommendation that coaches diversify their training methods and use assistive tools, as previous research emphasized that varied training—whether with or without tools—stimulates motivation and encourages athletes to train, ultimately leading to better skill development (Azeez and Majeed, 2022).

According to the researchers, developing muscular strength in gymnasts allows them to overcome body weight resistance and raise their center of gravity according to the demands of the skill and its movement range. Moreover, enhanced muscular strength improves body control and coordination, which is essential for achieving the required vertical jump and upward body velocity. Since artistic gymnastics is an individual sport that relies heavily on the athlete's muscular abilities, this factor becomes vital for performing movements on gymnastic apparatuses (Saeed et al., 2019).

Table 4. Shows the correlation coefficients between Ground Reaction Force at Take-off and the biomechanical variables of the skill.

Variables	Calculated r Value	Percentage Error	Significance
Flip Duration	0.513	0.001	Significant
Angular Velocity of the Center of Mass (COM)	0.704	0.001	Significant
Vertical Height of the Center of Mass (COG) during Flight	0.832	0.000	Significant
Horizontal Distance of the Flip	0.547	0.001	Significant
Knee Joint Angle during Push-off	0.640	0.002	Significant
Hip Joint Angle during Push-off	0.733	0.000	Significant

Significant at a significance level of ≤ 0.05.

Table 5. Correlation coefficients between instantaneous push-off force at take-off and the biomechanical variables of the skill.

Variables	Calculated r Value	Significance level	Statistical significance
Flip Duration	0.511	0.001	Statistically significant
Angular Velocity of the Center of Mass (COM)	0.631	0.001	Statistically significant
Vertical Height of the Center of Mass (COG) during Flight	0.588	0.002	Statistically significant
Horizontal Distance of the Flip	0.854	0.001	Statistically significant
Knee Joint Angle during Push-off	0.778	0.000	Statistically significant
Hip Joint Angle during Push-off	0.817	0.000	Statistically significant

Significant at a significance level of ≤ 0.05.

Additionally, from Tables 4 to 6, there appears to be a significant correlation between the Instantaneous Force Indicator and the biomechanical variables of the tucked front flip, indicating that instantaneous force significantly affects the execution and success of the skill. Proper technical performance requires bilateral push-off with the legs and upward arm swing, followed by a downward swing to grasp the legs and tuck them toward the chest, which directly affects the vertical elevation of the body's center of gravity at take-off. This was confirmed by (Hasaballah and Gendy, 2006).

The researchers believe that the athletes' possession of explosive leg power was crucial for executing the skill and improving the push index, especially since a shorter execution time enhances the efficiency of force transmission during vertical jumping.

Increased angular velocity of the center of mass (COM) is attributed to the hip joint acting as a driver of rotational speed and body movement direction. Maintaining angular momentum is achieved by continuously bringing body segment masses closer to the center of mass, as influenced by the surrounding joints. (Abdel Hamid et al., 2020)

Other studies have shown that training in gymnastics significantly contributes to correct technical performance, which requires not only execution but also balance and precision to avoid falls (Al-Attar and Jari, 2023).

Regarding the knee joint angle during push-off, the relationship was highly significant. On the floor mat, the athlete exerts considerable force with the legs to enhance upward push, which involves greater flexion of the knee joint to generate more muscular power. This explains the significant correlation between ground reaction force and knee joint angle at take-off.

The researchers concluded that the athletes' muscular strength in the legs—evidenced by significant correlations with the push indicator and joint angles—suggests their training involved diverse and repeated exercises, driven by performance motivation. This aligns with existing research, which recommends that coaches implement non-traditional, varied, and equipment-supported training programs to foster competition and enjoyment during training (Haider and Kadhum, 2021).

This is also evident in the hip joint angle, which was positively influenced by the instantaneous force

Table 6. Presents the correlation coefficients between Ground Contact Time during Push Phase and the biomechanical variables of the skill.

Variables	Calculated r Value	Significance level	Statistical significance
Flip Duration	0.832	0.001	Statistically significant
Angular Velocity of the Center of Mass (COM)	0.794	0.001	Statistically significant
Vertical Height of the Center of Mass (COG) during Flight	0.534	0.000	Statistically significant
Horizontal Distance of the Flip	0.814	0.001	Statistically significant
Knee Joint Angle during Push-off	0.504	0.000	Statistically significant
Hip Joint Angle during Push-off	0.713	0.002	Statistically significant

Significant at a significance level of ≤ 0.05.

indicators, achieving values near the optimal range (115–120 degrees) for skill execution.

All the above findings confirm the critical importance of the Instantaneous force Indicators and its strong connection to skill performance. The most crucial factor in achieving movement goals is not what the athlete does while airborne, but what is done during the push phase when the body is still in contact with the ground, as emphasized by (El-Sheikh, 1986).

This further supports the recommendation by Hadi et al. (2023), which stressed the importance for coaches to focus on push force, flight time, vertical elevation of the center of mass, and ground reaction force, as they contribute significantly to technical execution and optimizing performance.

The researchers concluded that instantaneous push force and lower limb explosive power play a major and positive role in performing the repeated tucked front somersault on the floor exercise mat, in addition to certain biomechanical variables, particularly: Vertical COG height during flight, Angular velocity of the COM, Horizontal distance of the somersault, Hip joint angle, and others.

7. Conclusion

- The results showed a statistically significant relationship between the Instantaneous Push force Indicator and lower limb explosive power, confirming the importance of instantaneous push in enhancing the performance of the tucked front flip on the floor exercise mat.
- A significant correlation was also found between the Instantaneous Push Force Indecator and the biomechanical variables of the tucked front flip skill, indicating that instantaneous push plays a critical role in the execution and success of the skill, which fundamentally relies on effective bilateral leg push.
- The correlation analysis revealed that vertical height of the center of mass (COG) during flight, angular velocity of the COM, horizontal flip distance, and hip joint angle were the biomechanical variables most influenced by the Instantaneous Push Index during the execution of the studied skill.
- Additionally, the results showed a significant correlation between Ground Reaction Force at Take-off and the biomechanical variables, particularly with vertical COG height during flight and angular velocity of the COM, which recorded the strongest correlations.

7.1. Recommendations

- The researchers recommend using motion analysis techniques to evaluate gymnastic skills and identify athletes' strengths and weaknesses to improve their technical performance.
- They also recommend studying the relationship between explosive power and the performance of other skills such as back tucked flip or front/back handsprings.
- The use of force platforms during the take-off phase should be applied to analyze other gymnastics skills.
- Further research is needed to investigate the relationships between different variables affecting performance.

The authors formally declare that the content of this paper is the original work of themselves.

Conflicts of interest

None.

We confirm that all tables and figures in this article are ours and written by the researchers themselves.

Ethical approval

Not applicable.

Author's contributions

- All contributions of this study were done by the researchers Prof. Dr. Widad Kadhem and Prof. Dr. Huda Shihab: Writing the research, filming, and motion analysis.
- Asst. Lect. Maryam Abdul-Jabbar: Typing and formatting the manuscript, coordinating with the foreign researcher, collecting references, and editing them according to the journal's requirements.
- Foreign Researcher: Reviewed the paper and added scientific notes who get the main idea and work on writing and concluding also with number of experts, Prof. Dr. Noor Hatim in Statistics, Dhafaf Ibrahim in revision, Noor Riyadh in translating.

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Data availability

The authors confirm that the data supporting the findings of this study are available within the article [and/or] its supplementary materials.

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