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# Designing and Manufacturing a New Volleyball and Comparison of Kinetic Components with Other Volleyballs

**Ehsan Fakhri Mirzanag *, Mohsen Baraghamadi**
Department. of Sport Biomechanics, Faculty of Educational Sciences and Psychology, University of Mohaghegh Ardabili, Ardabil, Iran
E-mail: ehsanfakhri6454@gmail.com, barghamadi@uma.ac.ir
*Corresponding author

**Hediyeh Koohi**
Department. of English Language Teaching, Faculty of Literature and Humanities, University of Mohaghegh Ardabili, Ardabil, Iran.
E-mail: Hediyehkoohi2001@gmail.com

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**Abstract:** Sports equipment is widely available in the international market. The market's focus is on the design of sports equipment to prevent injury, and all equipment must be designed to enable performance without causing injury. The purpose of this study is to design and manufacture a new volleyball and comparison of kinetic components with other volleyballs. The present study is applied and developmental type. We used four full-size Federation International Volleyball (FIVB), official volleyballs (V200W MIKASA made in Japan, FOX volleyball, model Spain, made in the United States, BETA, and new volleyballs made in Iran) to determine the biomechanical components, such as stiffness and Ground Reaction Force (GRF) on that ball. Ground reaction force variables and stiffness of all samples were recorded by a force plate device (sampling rate: 1000 Hz) and Shore C (Newton's per meter N/m), respectively. There was a significant difference in all groups between stiffness ($P<0.001$), vertical ground reaction force (vGRF) ($P<0.001$), and impulse ($P=0.012$), also the LSD Post Hoc test showed that stiffness, vGRF, and impulse in new volleyball and MIKASA volleyball were less than BETA and FOX volleyballs. The results indicate that the biomechanical components of the new volleyball with MIKASA were similar. Therefore, the new volleyball design appears to be suitable for an official competition. Nonetheless, more clinical studies are needed to evaluate the kinetic and kinematic parameters of using new volleyball.

**Keywords:** Ground Reaction Force, Kinetic, Technology

**Biographical notes: Ehsan Fakhri Mirzanag** is PhD student of biomechanics and a lecturer at the University of Mohaghegh Ardabili. His current research focuses on mechanical properties characterization of sport tools in order to improve the performance of athletes. **Mohsen Baraghamadi** is an Assistant Professor of the Department of Sport Biomechanics at the University of Mohaghegh Ardabil. His research interests include Kinematics, kinetics, and nonlinear dynamics. **Hediyeh Koohi** is a bachelor student of English language teaching. Her current research focuses on technology, computer programming, and nanomechanics.

Research paper

## 1 INTRODUCTION

Volleyball is a sport that is regarded as one of the most popular in the world [1]. The International Volleyball Federation estimates that 500 million people play volleyball worldwide [2]. To interact with a ball, players must move their body's position and orientation [3]. The result of this interaction depends on the mechanical components of the ball and its kinematic parameters during contact. Collisions of low-to-high velocity are common during serve reception or after an attack [4]. Volleyballs are used in training and competition in various brands and models. A player's contact force with a particular ball could be affected by differences in the coefficient of restitution (COR) between balls. As a result, comprehending the mechanical behavior of various balls during collisions can be advantageous for coaches and athletes [4]. Balls' mechanical properties may have an impact on injuries [4]. When a ball collides with an object, it exerts force on and radiates energy to various tissues such as skin, muscles, tendons, ligaments, and bones [4]. It is possible that the amount of force transferred could result in tissue damage, including injuries like bruises and contusions of muscles, finger ligament sprains, or tendon tears [5]. Head mass and ball size are factors that impact linear and angular head acceleration and contact time, respectively, according to Queen et al.'s 2003 study, while ball inflation pressure has little effect on the impact characteristics. These findings suggest that children should only use the balls of their age. The likelihood of injury among players with smaller heads is a significant indicator, but not as important as it appears in younger people [6]. The forces involved in volleyball collisions must be considered to investigate the causes of injury and determine the design of the ball to ensure safety. On the other hand, in many team sports, participants use a piece of sporting equipment to interact with a ball [7]. In such sports, the ball is an important piece of equipment in the game and generates feedback to players. For this reason, the bounce of the ball has a remarkable effect on the way the game is played [8]. Several factors influence the bounce of the ball: internal factors such as surface texture, internal structure, and pressure; and external factors such as temperature and aerodynamic drag [9]. Previous studies have investigated the effects of varying surface designs on the aerodynamic changes surrounding balls (e.g. volleyballs and soccer balls) flying in the air [10-14]. For example, Hong et al. 2020. Examined the Aerodynamic force of the new volleyball for use in the 2020 Tokyo Olympics. The results indicate that during a float serve, the flight path may vary depending on the type of volleyball and its orientation [15]. However, few reports have explored the effects of materials on the kinetic components in volleyball studies. Biomechanical parameters, such as the vertical ground reaction force (vGRF) and its passive and active peaks, are crucial for analyzing and preventing musculoskeletal injuries [16]. According to reports, increased impact vGRF during sport activity can cause changes in the kinetic and kinematic chain [17-18], which could result in increased stress on other limb structures [19-20]. Volleyballs can exhibit significant morphological changes upon contact, and the resulting energy loss cannot be measured directly [21]. Knudson and Bahamonde 2001 examined biomechanical data collected during object contact, particularly data that included the maximal velocity. However, estimations based on these data may be incorrect because of inappropriate calculations [22]. In addition, nonlinear responses, relative velocity, and energy loss of the ball present significant challenges [23]. Therefore, instead of estimating forces, this study employed force plates to measure directly the relevant forces. Priceet al. 2008, reported that the viscoelastic material properties of the outer panels significantly affected ball impact characteristics, with outer panel materials exhibiting higher levels of viscous damping resulting in higher losses of kinetic energy [24]. The MVA200 (Mikasa Corp., Japan) is now the official volleyball of competitions. Many manufacturers invested in research to develop a similar ball. The Conti Company (Continental Chemical Industries Co., Ltd., Taiwan), one of the well-known manufacturers, provided the prototype balls for this study. In this study, the Type A ball was a prototype designed to imitate official balls, and the Type B ball was a modified version of the type A ball for specific training. Currently, information regarding the dynamics of volleyballs of varying materials and weights is rare, necessitating specific research [21]. So, this study aimed to design and manufacture a new volleyball and compare it with other volleyballs in terms of biomechanical variables. We hypothesized that the kinetics parameter in the new volleyball would be smaller than in other volleyballs.

## 2 PROCEDURE FOR PAPER SUBMISSION

### 2.1. The Manufacturing Process of a New Volleyball

#### 2.1.1. Cutting the Panels

The first step in making a volleyball was to cut the panels that would be used to make the volleyball. The panels are made of synthetic leather, which is a durable and water-resistant material. The panels were cut into shapes that were then sewn together to form the volleyball.

#### 2.1.2. Adding the Bladder

After the panels had been cut, the next step was to add the bladder. The bladder is the inner part of the volleyball that holds the air. It is made of latex and was inserted into the volleyball through a small hole. Once the bladder was in place, the hole was sealed to prevent air from escaping. To maintain the strength and proper spherical shape of the new ball bladder, it was first gauged and kept inside the shelf for 24 hours to ensure that it did not have a puncture. The bladder was made with a special textile instead of rubber to create the second layer of the new volleyball. The attachment of the textile at the joints to the outer surface of the bladder segments guarantees adequate attachment of the fabric, while an adhesive layer is not necessary. Although wear of the woven fabric occurs, this wear provides an appearance to the ball which was comparable to e.g. This appearance is perceived as attractive in particular competes. Accordingly, the choice of a denim outer layer shows that the use of the sports ball enhances the value of the ball[1]. Finally, the newly designed ball textile bladder was made with pu panel synthetic leather [21] [2].

#### 2.1.3. Adding the Graphics

Once the new volleyball had been assembled and the bladder was in place, the next step was to add the graphics.

### 2.2. Inclusion and Exclusion Criteria

The present research's inclusion criteria included samples of size V5 volleyballs (the competition's official size) weighing between 265-270 grams with an internal air pressure of 4psi, a diameter of 60±66 bounce from a one-meter height resisting against the test of 2000 blows at the speed of 50km/h inside the impact tester for 12 hours with no deformity (“Fig. 1”).

**Fig. 1** Sports ball impact testing machine.

Finally, we used four full-size Federation International Volleyball (FIVB), official volleyballs (V200W MIKASA made in Japan, FOX volleyball, model Spain, made in the United States, BETA, and new volleyballs made in Iran) to determine the biomechanical components, for example, stiffness and ground reaction force (GRF) on that ball.

### 2.3. Quality Control

In the next step was quality control. New volleyball and other samples were inspected to ensure that they meet the required standards for size, weight, and shape. If any defects are found, the volleyballs sample was discarded and a new sample was in its place. In the next step to make sure there were no punctures, all the samples inside the device were placed on shelves for 24 hours.

#### 2.3.1. Circumference Recording

After the impact test was finished, an advanced caliper was used to measure the circumference of the sample volleyballs that were healthy. The measurement method consisted of measuring various points of the volleyballs removed from the impact tester in 12 efforts (“Fig. 2”). The circumference of the sample volleyballs that were not standard-sized according to FIVB were excluded from this stud.

**Fig. 2** A caliper to measure the circumference of samples.

#### 2.3.2. Bounce Recording

The bounce of the volleyballs was examined using an advanced bounce machine, model Juiyi, manufactured in China (“Fig. 3”). The approach for measuring the balls’ bouncing top became that all samples were thrown from a top of one meter in 5 efforts with a mean jump of 60±66 cm, consistent with the FIVB. Photoelectric sensor measurement was done, and this machine used the PLC as the electric-controlled system. With such advanced technology, it features strong availability, convenient utility, wide adaptability, high reliability, strong anti-disturbance, simple program design, etc.

[1] https://data.epo.org/publication-server/rest/v1.2/patents/EP1709998NWB1/document.pdf

[2] EUROPEAN PATENT SPECIFICATION, EP 3 528 906 B1

Drop height and rebound height were displayed on the touch screen, accuracy was 1mm (“Fig. 3”).

**Fig. 3** Bounce test tool.

**2.3.3. Weight and Pressure Recording**

The weight of the samples was determined by a digital scale manufactured in Tehran, Kala Iran (model EB 9003). Also, a digital pressure gauge from MIKASA was utilized to measure the pressure of the balls. (“Fig. 4”).


**Fig. 4** A used Pressure gauge.

**2.3.4. Ground Reaction Force Recording**

Three-dimensional GRFs were recorded using a force plate (Bertec Corporation, Columbus, 4060–07 Model, OH, United States) sampled at 1000 Hz. Kinetic data were recorded during the dropping of a sample of volleyballs on the force plate from a height of one meter (defined as the interval from ground contact (vertical GRF > 10 N) to ground Separated (vertical GRF < 10 N). Kinetic data were filtered using a third-order low-pass Butterworth filter with a cutoff frequency of 50 Hz. Figure 5 illustrates the grand averages from the vGRF. The vertical force recorded during the dropping of a sample of volleyballs provided the volleyball contact time, active peak (defined as the highest peak after the impact peak), and the impact peak (defined as the first peak in the vertical force). The time to peak was computed from ground contact to the time of impact peak. The vertical impulse was calculated by extracting the area under the vertical force curve. If no impact peak was present, the highest tangential angle within the first 100 ms during the collision of a sample of volleyballs with a force plate was used to determine the impact peak [25].

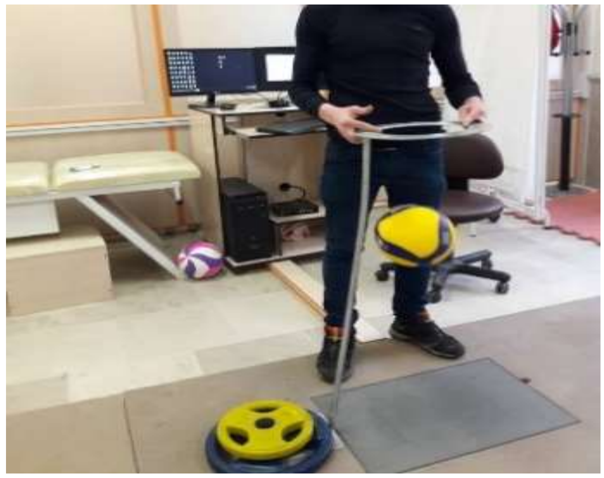

**Fig. 5** Recording the GRFS using a device designed to reduce the measurement error.

Impulse was calculated for all axes based on the trapezoid integration method [26] as follows:

$$\text{Impulse} = \Delta t(\left(\frac{F1 + Fn}{2}\right) + \sum_{i=2}^{n-1} Fi)$$

In this equation, delta t is the time period for which the impulse was calculated, F1 and Fn are reaction forces at the first and the last frame.

**2.3.5. Stiffness Recording**

To determine the Shore hardness, scale C of specimens and articles made of medium hardness rubber according to ASTM D-2240 standard were used. It is used in types of materials such as medium-hardness rubber and plastics, gypsum, plaster, and others [27]. Therefore, in the next step, the stiffness of the samples was measured using a Shore C (model VLX C4 made in China), (“Fig. 6”). For ZERO calibration of the Shore C stiffness tester, we kept the stiffness tester vertically so that the indenter was in the air and the indication in the display should have '0’. Otherwise, we pressed the 'ZERO' key to make the instrument display '0'. All the samples were cut into 10 cm, and the stiffness of the samples was recorded by applying continuous force and without shock by repeating the effort 5 times using the Shore C device.

**Fig. 6** Shore C stiffness tester.

### 2.4. Statistical Analysis

The standard distribution of the data was confirmed by the Shapiro-Wilk test. A one-way analysis of variance (one-way ANOVA) was used to conduct statistical analyses, along with LSD post hoc tests used for intergroup and between-group comparisons. Statistical Package for Social Sciences (SPSS) version 26 was utilized in all analyses with a significant level of P< 0.05.

## 3 DISCUSSIONS

The study was conducted to design and manufacture a new volleyball and compare its biomechanical properties to other types of volleyballs. One of the essential variables derived from the force-time curve is Impulse [28], biomechanically, the impulse variable covers a large portion of the surface below the force-time curve, therefore, it is expected to have a significant effect on all variables derived from the force-time curve [28]. To optimize athletic performance and prevent injury, biomechanics researchers must consider the importance of each of these variables on impulse, but as far as we know, volleyballs have not been researched in the literature. According to our findings, new and MIKASA volleyball have a lower impulse than BETA and FOX volleyball. Furthermore, the LSD Post Hoc test demonstrates that the new and the MIKASA volleyball had no significant difference in impulse. As a result, the impulse to create a new volleyball with MIKASA and FOX was similar. The impact force on modern soccer balls was examined by Kuizumi et al. 2014, which was used to measure the impulsive force during impact. The maximum impulsive force in the Cafusa sample was the lowest, while Jabulani's impulsive force was the highest among all balls tested at each speed .The flexibility of the surface material and structural characteristics of each ball may be related to these results [29]. Furthermore, according to our findings, new and MIKASA volleyballs have a lower stiffness and vGRF compared to 35BETA and FOX volleyballs. To enhance ball design for safety, it appears that understanding these mechanisms is essential. It was reported that ball types that have a higher peak impact force do not always lose a significant amount of kinetic energy [30]. Internal pressure and stiffness are among the factors that affect the amount of kinetic energy lost and peak force exerted during impact [30]. For example, the increase in stiffness can lead to an increase in impact force, but it can also reduce deformation, resulting in a lower loss of kinetic energy. Examining each variable's role in impact injuries could be valuable if we explore the different combinations of kinetic energy lost and peak impact force for various volleyballs [31]. Additionally, several injuries related to sports activity have been linked to vGRF parameters [31-32]. According to James et al. 2004, dropping cricket balls on the seam had lower impact forces than dropping them perpendicular to the seam [33]. The analysis of different volleyball collision mechanics was investigated by Chiu et al. 2018 at a range of incident velocities. These data indicate that each volleyball type has a distinct behavior during collisions; as a result, the material and speed of the ball have a direct effect on the interaction. The kinetic energy lost was unrelated to peak impact force; of the two ball types with the highest peak impact force, one had the highest and the other the lowest kinetic energy lost. To examine the role of each of these variables in collision injuries, it may be useful to examine the various combinations of kinetic energy lost and peak impact force [34]. In this regard, the findings of the present study demonstrate a significant difference between BETA and FOX volleyballs. However, there was no significant difference between new with MIKASA volleyball, therefore stiffness and vGRF of new with MIKASA volleyball were similar. Many other research projects on volleyballs is related to fluid dynamics and aerodynamic properties of the ball for example Shan Ho et al. 2015 studied to investigate mechanical factors associated with the development of volleyball training. The results indicated that different volleyballs of the same size, weight, and internal air pressure have dissimilar mechanical features and implied that slight adjustments to ball structure can cause substantial changes in the specific characteristics. In addition, the weight increased the momentum lost, which could cause the ball to bounce unexpectedly [35]. Some limitations need to be discussed in this study. First, we included volleyballs as a sample, which is why the outcomes of this study are specific to the population under investigation. As a result, they cannot be transferred to other sports balls. There is a need for more research in this area. Second, kinematic data was not recorded in this study and this biomechanical component's response to different volleyball conditions is unknown to us. Future research should focus on this. Finally, our study has not prospectively recorded injury rates. Future studies should realize this.

**Table 1** Mean and standard deviation of the weight (kg), deformation (cm), and bonce (cm) for all groups

| Parameter | BETA | FOX | NEW BALL | MIKASA | P-values |
|---|---|---|---|---|---|
| Weight | 268.00±.0.00 | 268.66±.0.57 | 268.66±0.57 | 268.66±0.57 | 0.330 |
| Deformation | 65.91±.0.792 | 65.73±0.753 | 66.90±0.796 | 64.78±0.750 | 0.850 |
| Bounce | 66.45±0.790 | 65.04±0.789 | 66.20±0.798 | 65.98±0.796 | 0.559 |

*Stand for significant difference p<0.05

## 4 FIGURES, TABLES, AND OTHER IMAGES

There was no significant difference between the four volleyball types in weight, deformation, and bonce. However, demographic characteristics of all types were similar (P>0.05, "Table 1").

There was a significant difference in all groups between stiffness, vertical ground reaction force (vGRF), and impulse (P<0.001), also the LSD Post Hoc test showed that stiffness, vGRF, and impulse in new volleyball and MIKASA volleyball were less than BETA and FOX volleyballs. Findings did not demonstrate any significant difference in time to peak ($TT_P$) among all groups (P>0.05, "Table 2").

**Table 2** Mean and standard deviation of the stiffness and ground reaction force for all groups

| Parameter | BETA | FOX | NEW BALL | MIKASA | P-values |
|---|---|---|---|---|---|
| Stiffness | 61.80±.1.78 | 61.40±.1.67 | 54.20±.0.83 | 53.80±.0.83 | 0.000* |
| vGRF | 620.35±.17.77 | 573.80±.10.78 | 525.57±.41.82 | 520.25±.5.98 | 0.000* |
| Impulse | 10.05±.1.53 | 8.07±.0.63 | 7.53±.1. 28 | 7.72±0.97 | 0.012* |
| $TT_p$ | 6.00±0.00 | 6.20±0.44 | 6.40 ±.0.54 | 6.20±0.44 | 0.532 |

*Stand for significant difference P<0.05

*vGRF; Vertical ground reaction force, TTp; Time to peck, kg; Kilogram, cm; Centimeter, NEWBALL; New volleyball

There was a significant difference between the stiffness and vGRF of the new volleyball with BETA and FOX volleyballs (P<0.001), However, there was no significant difference between the new volleyball with MIKASA, therefore stiffness and the vGRF of the new volleyball with MIKASA were similar. There was a significant difference between the impulse of the new volleyball with BETA volleyball, Also, the LSD Post Hoc test showed that the impulse of a new volleyball with FOX and MIKASA was not significantly different. Therefore, the impulse of the new ball with MIKASA and FOX volleyball was similar (P>0.05, "Table 3").

**Table 3** Statistically significant differences between all groups for biomechanical variable

| Variables | Row | Group | P-values |
|---|---|---|---|
| Stiffness | NEW Ball | BETA | <0.001* |
| | | FOX | <0.001* |
| | | MIKSA | 0.648 |
| | BETA | FOX | 0.648 |
| | | MIKSA | <0.001* |
| | FOX | MIKSA | <0.001* |
| vGRF | NEW Ball | BETA | <0.001* |
| | | FOX | 0.005 |
| | | MIKSA | 0.725 |
| | BETA | FOX | 0.007 |
| | | MIKSA | <0.001* |
| | FOX | MIKSA | 0.002 |
| Impulse | NEW Ball | BETA | 0.003 |
| | | FOX | 0.471 |
| | | MIKSA | 0.808 |
| | BETA | FOX | 0.016 |
| | | MIKSA | 0.006 |
| | FOX | MIKSA | 0.630 |

| | | | |
|---|---|---|---|
| $TT_P$ | NEW Ball | BETA | 0.150 |
| | | FOX | 0.461 |
| | | MIKSA | 0.461 |
| | BETA | FOX | 0.461 |
| | | MIKSA | 0.461 |
| | FOX | MIKSA | 0.100 |

*Stand for significant difference p<0.05

## 5 CONCLUSIONS

The results indicate that the biomechanical components of the new volleyball with MIKASA were similar. Therefore, the new volleyball design appears to be suitable for an official competition. Nonetheless, more clinical studies are needed to evaluate the kinetic and kinematic parameters of using new volleyball.

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