Effectiveness of foot protectors and forearm guards in Taekwondo

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B Data Collection
C Statistical Analysis
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Abstract

Background and Study Aim: In this study, we evaluated the effectiveness of forearm guards and foot protectors; the forearm and the foot are the main impact targets for kicks in Taekwondo.

Material/Methods: We used guards for the forearm (70 g, 16 mm thick) and protectors for the foot dorsum (50 g, 6 mm thick) that were produced from a foam material (Daedo®). One load cell (Cas Coop®) was fixed on the tip of a swing that performed a pendulum movement. A prosthetic foot was mounted in front of the load cell to mimic the kicking foot. The forearm prosthesis was produced from a hard foam that had natural anthropometric characteristics. Specially designed sensor systems (Tekscan®, F-Socket system) were mounted on the forearm prosthesis and the prosthetic foot. Using this set-up, the impact on the bare sensors and the impact with both guards mounted on the sensors were measured. The impact parameters recorded were the maximal force, mean force, impulse, maximal pressure, mean pressure and integral pressure.

Results: While the total impact force on the load cells without protection was 127.5±1.18 kg, the forearm guard and foot protection decreased the total impact force to 107.25±0.52 kg. In addition, the difference between the foot and forearm maximal impact force increased – with protection. For the measured force and pressure parameters, the foot protection had no absorbing effect, in contrast to the forearm guard.

Conclusions: Forearm guards used in Taekwondo are more effective than foot protectors.

Key words: Taekwondo • guards • impact • foot protector

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Background

Taekwondo is a popular martial art sport and has been accredited as an Olympic event since the Olympic Games of Sydney in the year 2000. The wide acceptance of Taekwondo is partly based on the variability of technical movement patterns, including the front kick, roundhouse kick, side kick, back kick, swing kick, hook kick, back spinning hook kick and axe kick [1]. Scoring is achieved by techniques executed mainly with the lower extremities, and kicking with the dorsum and lower parts of the foot is preferred [2]. To earn a point, the athlete has to execute an officially accepted kicking technique in a standard manner, producing an impact that has to exceed a threshold value. However, the athlete cannot score extra points by further increasing the kick impact [2,3].

Injury rates are unexpectedly low in Taekwondo [4]. While 54% of injuries occur during matches, 36% are related to training incidents. The lower extremities are more frequently involved (46.5%) than the upper extremities (18%) [5]. The significant majority of these injuries (82%) are soft tissue traumas, such as sprains and strains [6].

Factors that are related to injury prevention are the characteristics of the match, training grounds and equipment

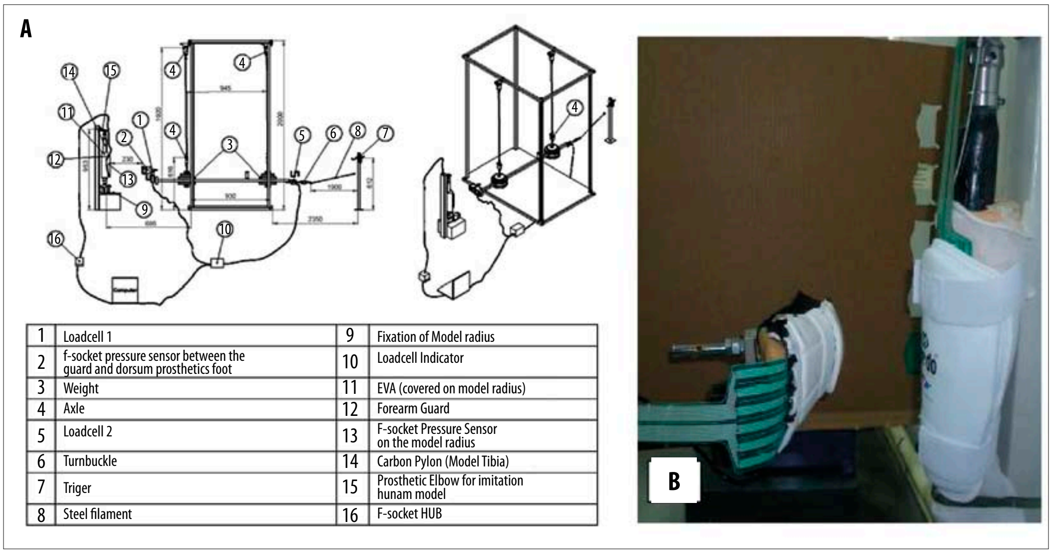

Figure 1. Experimental setup. (**A**) The pendulum movement system. (**B**) Foot and forearm guards with sensors.

and the technical abilities and fitness level of the athlete. However, much more importantly, the obligatory use of protective guards for the head, chest, groins, forearms, shins and feet during matches result in a major reduction of serious injuries [7].

The aim of this study was to evaluate the effectiveness of forearm guards and foot protectors; the forearm and foot are the main impact targets for kicks in Taekwondo.

Material and Methods

We used guards for the forearm (70 g, 16 mm thick) and protectors for the foot dorsum (50 g, 6 mm thick) that were produced from a foam material (Daedo®, approved by the World Taekwondo Federation and in accordance with EN 13277 norms).

We constructed a test platform integrated with the following measurement devices:

1. One load cell (Cas Coop®) was fixed on the tip of a swing which performed a pendulum movement (Figure 1A). A prosthetic foot was mounted in front of the load cell to mimic the kicking foot.
2. A second load cell (Cas Coop®) was fixed on the other end of the swing to guarantee identical pre-tension and movement trajectories of the swing.
3. The forearm prosthesis was produced from a hard foam that had natural anthropometric and structural characteristics. The outer surface of the prosthesis was further hardened by lamination with carbon fibers and covered with a special soft material. Similar methods have been used in the literature [8].

4. Specially designed sensor systems (Tekscan®, F-Socket system) were mounted on the forearm prosthesis and the prosthetic foot dorsum; the sport guards for the foot dorsum and the forearm (Daedo®) were then fixed on these sensors (Figure 1B).

Using this set-up, 10 impacts without the protective guards and then 20 impacts with both guards mounted on the sensors were performed. The maximal and minimal impact recordings were not used for the frequency distribution.

Results

Recordings of the load cell for the pre-tension showed that all measurements were performed under identical impact conditions. The results for the impact parameters recorded by the forearm and foot sensors are listed in Table 1.

While the total impact force on the load cells without guards was 127.5±1.18 kg, the forearm guard and foot protector decreased the total impact force to 107.25±0.52 kg (15.88% absorption). This absorption of the maximal impact force by the guards was accompanied by a change in distribution. Without protective guards, the distribution of the recorded maximal impact force between the foot and forearm was nearly equal (54.77% *vs.* 45.23%), but the difference between the foot and forearm maximal impact force (Figures 2, 3) increased by using the guards (67.11% *vs.* 32.89%).

While the recorded total impulse on the sensors without protection was 7.36 kg*sec, protection decreased the total impulse to 5.85 kg*sec, but this increase in absorption was only due to the forearm guard. Similarly, while the use of the foot protector did not change the integral pressure on the F-socket sensor of the foot dorsum (.067 kg/cm^2*sec *vs.* 068 kg/cm^2*sec), there was a

Table 1. Results of Impacts on bare and guarded forearm and foot sensors.

		Impact results from using Forearm guard and Feet protector		Impact results from without protector	
Impact Force (kg) (Loading from loadcell)	Mean±SD	107.25±.52		127.5±1.18	
Sensors results		Foot dorsum	Forearm	Foot dorsum	Forearm
Max. Force (kg)	Mean±SD	64.75±5.60	31.73±1.43	70.19±5.14	57.97±3.37
	%	67.11	32.89	54.77	45.23
Mean Force (kg)	Mean±SD	44.83±11.08	19.94±1.14	53.08±3.03	40.56±4.83
	%	69.21	30.79	56.69	43.31
Impuls (kg*sec)	Mean±SD	4.19±.30	1.76±.06	4.18±.13	3.18±.21
	%	70.42	29.58	56.79	43.21
Max. Pressure (kg/cm²)	Mean±SD	.91±.06	.40±.02	.93±.05	.91±.03
	%	69.47	30.53	50.54	49.46
Mean Pressure (kg/cm²)	Mean±SD	.73±.06	.30±.00	.80±.07	.71±.09
	%	70.87	29.13	52.98	47.02
Integral Pressure (kg/cm²**sec)	Mean±SD	.68±.004	.029±.004	.067±.007	.059±.003
	%	70.10	29.90	53.17	46.83

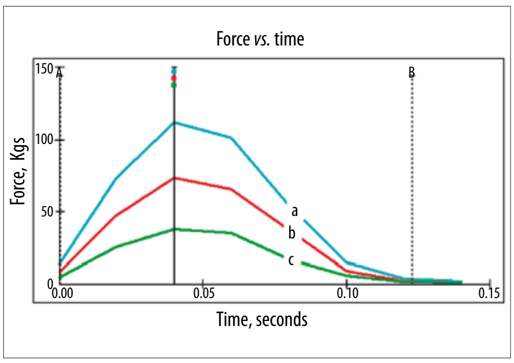

Figure 2. Distribution of total impact forces (a), on the dorsum of the foot (b) and forearm (c).

substantial drop on the forearm sensor with the forearm guard (.059 kg/cm²*sec *vs.* 029 kg/cm²*sec).

Discussion

The maximal impact force of Taekwondo kicking techniques varies as a function of distance, height and velocity. Therefore, different research groups have reported varying figures for maximal impact forces: 382 N [9], 470 N [10], 620 N [11], 1280 N [12], 2103 N [13], (2003), 1994.03 N [14]; 1398-2040 N [15] and 5419–6400 N [16]. Li et al. (2005) reported a significant gender difference (2401 N *vs.* 2940 N) [17], and Pedzich et al. (2006) recorded much higher values with a distance step technique (7751–9015 N) [4]. In the present study we applied impact forces of approximately 1275 N, which corresponds to a medium range compared with the literature.

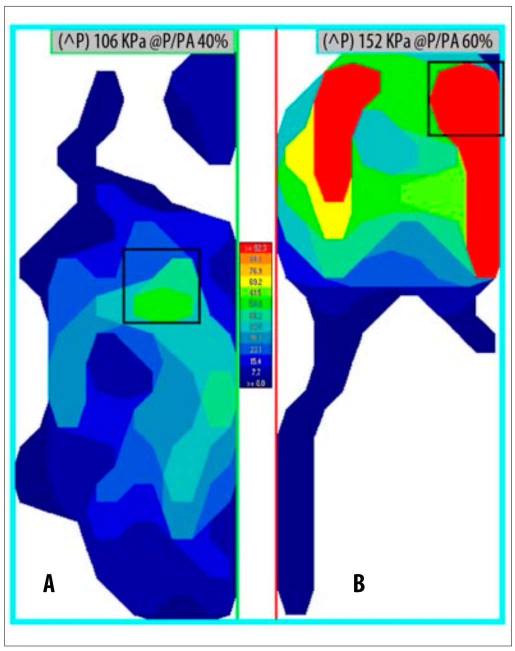

Figure 3. Impact force recording on the dorsum foot (**A**) and forearm (**B**).

Most of the scoring techniques (46%) in Taekwondo are performed with the dorsum of the foot [18]. The

The Integral/Impulse – as it is applied here provides an indication (calculated value) as to the amount of effect and/or influence of the pressure or force in relation to the amount of time that this load (pressure or force) is present and acting on the forearm and dorsal surface of the foot.

Impulse – is a concept of classical mechanics that is related to the amount of force multiplied by the time that this force is in effect. Impulse is also defined as the integral of force with respect to time.

The integral – is a concept of advanced mathematics (calculus) that is related to the area under a curve bounded by a horizontal and vertical axis, and a mathematical function of the relationship of the horizontal and vertical units

opponent has to block this action primarily by using the forearm, which is also essential for avoidance of head trauma [19]. This blocking defense distributes the resulting high impact forces among the attackers foot (and ankle) and the defenders forearm (and arm). In Taekwondo, impact and torsion traumas of the foot and ankle are frequently encountered. Therefore, special sport guards have to provide good protection by absorbing a significant amount of the impact forces [20].

The results of the present study show that the investigated guards diminish the impact forces to a greater extent for the forearm (without protection, the difference between impact forces was 21.68%, but with protection, it was 56.96%). This may be the direct result of the thinner structure of the foot protection. The greater effectiveness of the forearm guard is supported by the simplicity of the location, whereas joint mobility, proprioception and balance issues impede the use of better protection for the foot.

In a similar study, Tatar et al. (2010) compared classical polypropylene soccer shin guards with specially hardened carbon ones [21]. They reported that the carbon shin guards provided three times better protection. However, it is not possible to use rigid protective guards in martial sports, because such material properties increase the risk of dangerously harming the opponent. Therefore, the Taekwondo athlete should not exaggerate the kicking impact and to train according to the scoring threshold. For technical training, the use of sensors to measure impact forces at different body locations would be quite beneficial.

This point was also illustrated by the mean impact forces, but especially by the force and pressure parameters. For these parameters, the foot protection had no reducing effect, in contrast to the forearm guard. Whereas the impulse (Force*time) was reduced 45.65% with the forearm guard (from 3.18 kg*sec to 1.76 kg*sec), there was no change for the foot protector. Analogously, this also holds true for the pressure and integral (Force*Time/Area) pressure values. In this context, not only the impact on the dorsum of the foot, but also the translation of forces to the ankle bears the potential for serious injuries. Only an effective kicking technique with the lowest possible force production will provide the best scoring with minimal injury risk [22].

Although in the testing setup, the ankle and the elbow mobility were not integrated, the prosthetic material for the foot and forearm resembled natural conditions as much as possible. Unfortunately, there are no studies on Taekwondo for comparison.

Naturally, the properties of guards and related protective material are important for the prevention of injuries in Taekwondo and other martial sports. However, the results of this study show that it is also essential to take into account the distribution of forces on both the attacking and defending sides after the impact. While choosing such a material, one must account for the characteristics of the respective body part (flexibility, joint mobility, balance, proprioception, etc.) and the force radiation and absorption by the materials on both sides of the contact.

Conclusions

Two main conclusions regarding Taekwondo training and the properties of protective equipment can be drawn from our study. First, there is an urgent need to construct better foot protectors. Our results should provide an impetus for producers of protective sport materials. The nature of the protective material (thickness, rigidity, etc.) should be developed as a compromise between protective and functional properties. The ideal protective material would absorb a maximal amount of force and impulse but allow functional movement by its elastic nature. Protectors that are too hard and stiff may provide good protection for the athlete but present a potential threat for the opponent.

Second, the Taekwondo athlete should implement feedback regarding the impact and force development of his kick during the technical training period. The ability to challenge his opponent by using adequate force development and kicking impact, enabling him to score but not injure himself, will be important for long-term success. Our study shows that the attacker's foot is more likely to be injured than the defender's arm. Strength training of the ankle should be emphasized to reduce this risk.

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