The Effectiveness of Shin Guards Used by Football Players

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Abstract

In football, injuries from opponent contact occur commonly in the lower extremities. FIFA the world's governing body for football requires players to wear shin guards. The aim of this study was to compare the protective effectiveness of polypropylene based shin guards with custom-made carbon fiber ones. Three commercial polypropylene shin guards (Adidas Predator[TM], Adidas UCL[TM], and Nike Mercurial[TM]) and two custom-made carbon fiber shin guards were examined. The experimental setup had the following parts: 1) A pendulum attached a load cell at the tip (CAS Corp., Korea) and a fixed prosthetic foot equipped with a cleat to simulate an attacker's foot. 2) An artificial tibia prepared by condensed foam and reinforced by carbon fibers protected with soft clothing. 3) A multifunctional sensor system (Tekscan Corp., F-Socket System, Turkey) to record the impact on the tibia. In the low impact force trials, only 2.79-9.63 % of the load was transmitted to the sensors. When comparing for mean force, peak force and impulse, both carbon fiber shin guards performed better than the commercial ones (Adidas Predator[TM], Adidas UCL[TM], and Nike Mercurial[TM]) (p = 0.000). Based on these same parameters, the Nike Mercurial[TM] provided better protection than the Adidas Predator[TM] and the Adidas UCL[TM] (p = 0.000). In the high impact force trials, only 5.16-10.90 % of the load was transmitted to the sensors. For peak force and impulse, the carbon fiber shin guards provided better protection than all the others. Carbon fiber shin guards possess protective qualities superior to those of commercial polypropylene shin guards.

Key words: Football, carbon, force, prevention, shin guard.

Introduction

Football is the most popular team sport worldwide; therefore, it is particularly important that the risks associated with this sport are managed effectively. Although soft tissue injuries such as strains, sprains and contusions frequently result from playing football fractures are more important (Hawkins and Fuller, 1999; Junge et al., 2004). Fractures represent 2-11% of all football injuries and lower extremity fractures account for 30-33% of all fractures (Cattermole et al., 1996). The maximum kinetic energy in football collisions has been roughly estimated as 680 Nm (Gainor et al., 1978), which may be sufficient to result in a fracture (Winston et al., 2007). Unexpected actions such as kicks or slide tackles are the main reasons of these injuries (Barrey et al., 1999). There is no consensus on the impact forces needed to produce a fracture. Studies reporting low impact velocities (Shaw et al., 1997) as well as high impact velocities (Boden et al.,

1999; Templeton et al., 2000) that cause fractures are reported in the literature. Different ranges, such as 2927 N (Francisco et al., 2000) or 4000-7000 N (Nyquist et al., 1985), have been reported for the amount of force that may cause a fracture of cadaver tibias. Similarly, no consensus exists on the impact forces required to produce soft tissue injuries such as contusions (Ankrah and Mills, 2003; Francisco et al., 2000).

The International Federation of Association Football (FIFA), as the international governing body, created FIFA's Medical Assessment and Research Centre (F-MARC) in 1994 to investigate and to prevent football-associated risks to players' health. Shin guards are one of the suggested preventive methods. Their main function is to protect the soft tissues and bones in the lower extremities from external impact. Shin guards provide shock absorption and facilitate energy dissipation, thereby decreasing the risk of serious injuries.

Many authors agree that shin guards may reduce the number of minor injuries (Árnason, 2004; Ekstrand and Gillquist, 1982); however, it is unclear whether they can prevent more serious injuries such as tibia fractures. Tackles causing injuries frequently produce tears or damage to the shin guard. The use of shin guards may not prevent fractures (Ankrah and Mills, 2003; Barrey, 1998).

In this context, using the appropriate material and applying the right geometry are important aspects of football equipment design (Adrian, 1996). Currently, rigid materials (plastic, carbon, kevlar, etc.) are used for the outer shell, while soft materials are preferred as the lining of the guard. A well-designed shin guard should provide adequate protection for the shank, but allow range of motion of the ankle and the knee (Eugene, 2003). To increase energy absorption, the shin guard shell should be thick and rigid in the transverse direction; however, an increase in length does not provide better shock absorption (Ankrah and Mills, 2003; Francisco et al., 2000). Fitting the shin guard to the tibial geometry by adding soft material (e.g., foam) or air bubbles will reduce the peak impact force (Francisco et al., 2000). Some researchers have even suggested filling such gaps with semi-rigid materials (Ankrah and Mills, 2003). Although many authors advocate the use of shin guards, the ideal structural design characteristics have not been specifically defined. The BS EN 13061 (British Standard European Norm) standard for shin guards aims to prevent lacerations, contusions and punctures but not tibia fractures, and these standards determine the protective clothing for players in all football associations. The main concern

Table 1. The structural characteristics of the materials used.

Brand-Model	Weight (gr)	Outer Material	Outer Material Thickness (mm)	Inner Material	Inner Material Thickness (mm)	Max. Length X Max. Width (mm)
Nike Mercurial	91	Polypropylene	4	Eva	6	205X120
Adidas UCL	71*	Polypropylene	3	Eva	3	200X105
Adidas Predator	86	Polypropylene	3	Eva	7	220X115
Carbon-1 (Eva)	65	3 layer carbon fiber	1	Eva	5	220X120
Carbon-2 (Neoprene)	60	3 layer carbon fiber	1	Neoprene	3	220X120

* With ankle materials 103 gr

when formulating this standard was to avoid any harm that could be caused by a striker's cleats; high kinetic energy impacts and the related consequences were not taken into consideration.

Methods

In this study, two Adidas™ (Predator-AP and Adidas UCL-AC) and one Nike™ (Mercurial-NM) shin guards as well as two custom-made carbon fiber shin guards were tested (Table 1).
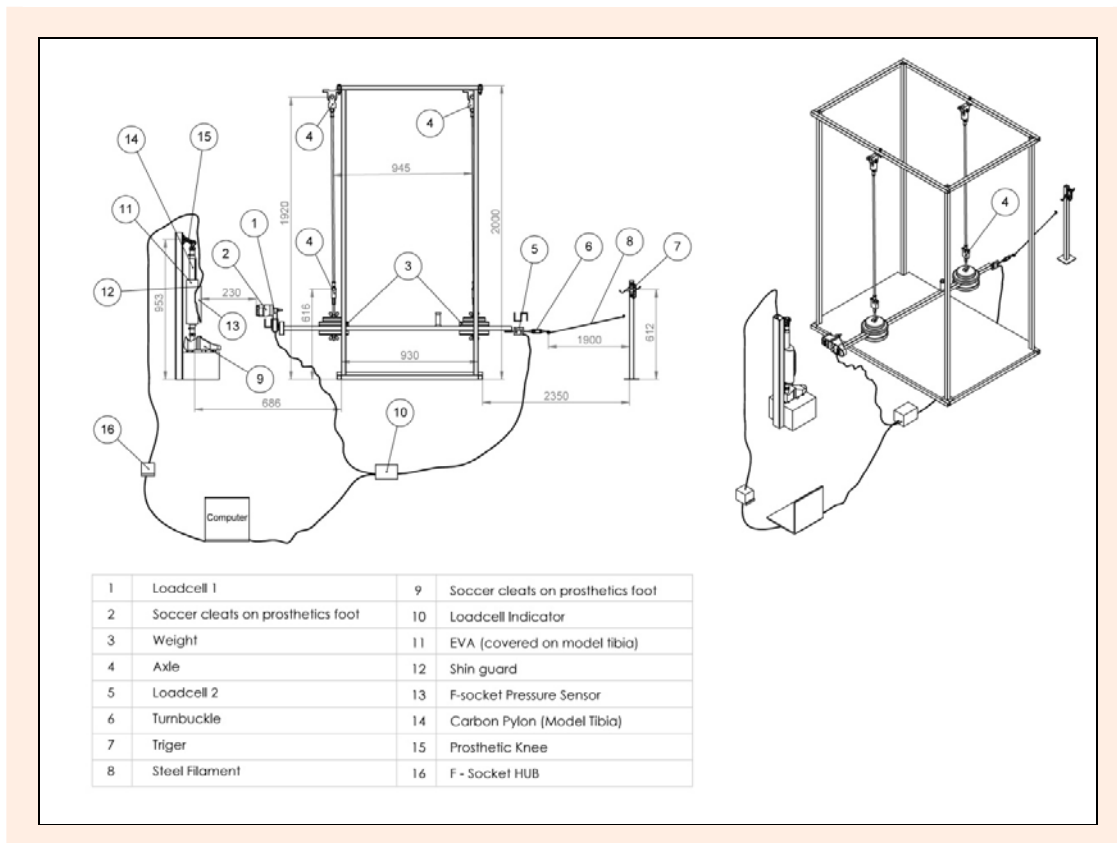
The test device

1. A special device with pendulum motion was designed for this purpose (Figure 1). To ensure that the swing moves on a consistent track, joints with broad surfaces and one-way trajectories were used.
2. Two load cells, one in the front (Load Cell-1; strain gauge-based, 50 Hz; CAS Corp., Korea) and one in the back (Load Cell-2; strain gauge-based, 50 Hz; CAS Corp., Korea), were placed on the.
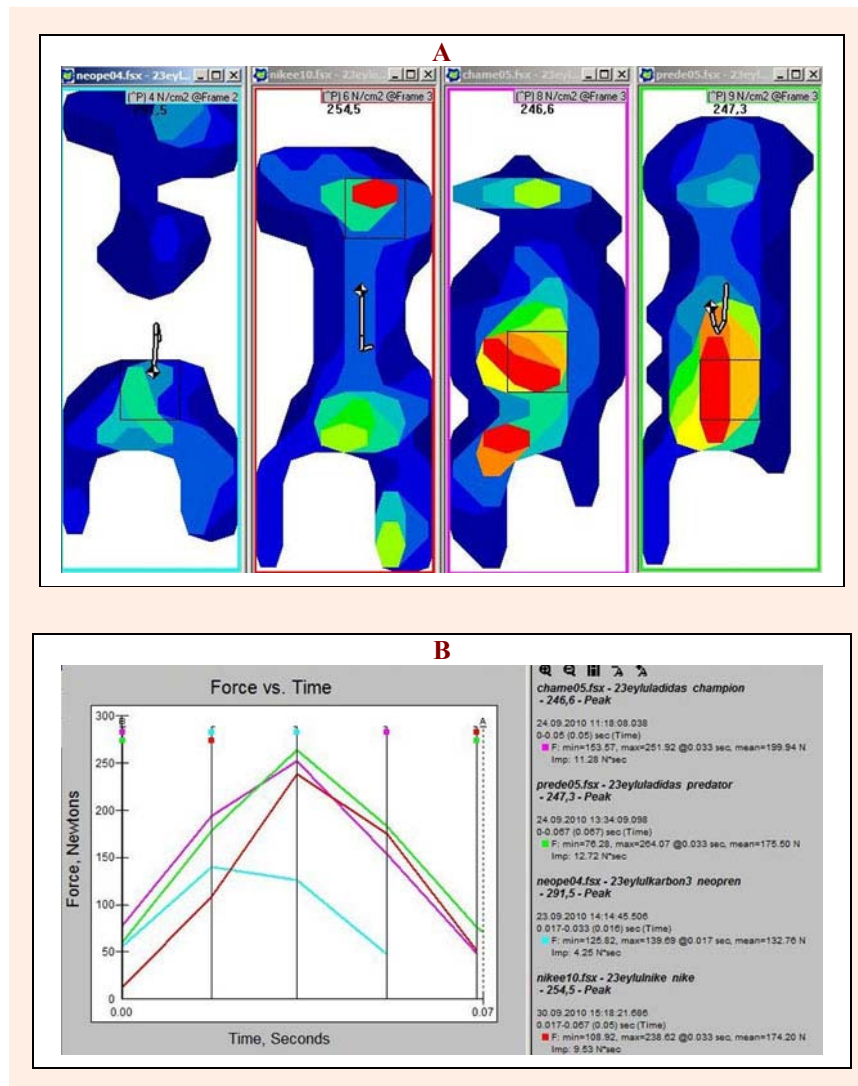
3. A SACH-type prosthetic foot (Otto Bock Company, Germany) was placed in front of Load Cell-1 and an injection-type football cleat was put on the foot (Picture 1).

Picture 1. Photo of experimental setup.

1	Loadcell 1	9	Soccer cleats on prosthetics foot
2	Soccer cleats on prosthetics foot	10	Loadcell Indicator
3	Weight	11	EVA (covered on model tibia)
4	Axle	12	Shin guard
5	Loadcell 2	13	F-socket Pressure Sensor
6	Turnbuckle	14	Carbon Pylon (Model Tibia)
7	Triger	15	Prosthetic Knee
8	Steel Filament	16	F - Socket HUB

Figure 1. Experimental setup.

Picture 2. Force transmitted on the tibia. A) A view of maximal force distribution. B) Graphic of maximal force.

4. The impact mechanism of the experimental set up was designed to hit the shin guard by the heel of the foot (an area of approximately 20 cm^2). The impact values (Low Impact Force-LIF/High Impact Force-HIF) were recorded from Load Cell-1 (Picture 2).

5. The Load Cell-2 (at the back of the swing) was attached to the tip of an adjustable turnbuckle with a steel string. Values from Load Cell-2 were monitored to guarantee that the pre-tensioning of the impacts remained within a certain range. Adjustments were made with the turnbuckle.

6. Another steel string was tied to the rear end of the turnbuckle and was connected to a table fixed to the floor, thus creating a special trigger mechanism.

7. To generate comparable impacts, the pre-tensioning of the rig was calibrated by manipulating the turnbuckle. This tension was set at 142.2 N for LIF trials and at 255.1 N for HIF trials. Thus, impacts of approximately the same force were generated.

8. An indicator (Kyowa Corp, PCD Model 30 A) was used to collect data coming from the load cells and to transfer them to a computer.

9. A special software compatible for the PCD Model 30 A was used. At the beginning of the study, the system was calibrated using the calibration factors recommended by the load cell manufacturer. A balance adjustment was made before each impact with the relevant software for both of the load cells. All calibration and balance checks were repeated each time the shin guard was changed.

10. Three artificial tibias with natural anthropometric properties were produced similar to those used in previous studies (Francisco et al., 2000; Ankrah and Mills, 2003). Artificial bones of spongiform structure made of condensed foam material (resembling the tibia anatomy) were manufactured and coated with carbon fiber. Three layers of carbon fiber were laminated to the material with epoxy resin (Otto Bock, 617H55 C-Orthocryl Lamination Resins).

Two of the artificial tibias produced were used to test load levels lower than 3000 N, which is the predicted fracture threshold impact force/loading values in cadaver models (Heiner and Brown, 2001). The resistance of each tibia was tested until the 3000 N load was reached. During these trials, soft tissue was not wrapped around the tibia and shin guards were not used (Loadcell-1 hit the midline of the tibia directly).

The impacts started at 800 N, until 2850-3000 N no change was observed in the artificial carbon fiber tibias. But in the 2850-3000 N range, some cracks formed on the front of the tibias. This proves that we produced tibias with a resistance level close to those recommended in previous studies (Heiner and Brown, 2001).

The third artificial tibia was used only in the actual impact trials. The dimensions of the test tibias used in the impact trials are as follows:

Tibia length: 40 cm
Tibia midline circumference: 13 cm
Tibia midline anterior-posterior diameter: 45 mm
Tibia midline medial-lateral diameter: 38 mm

1. The artificial tibia was covered with ethylene vinyl acetate (EVA). Thus, a lower leg model capable of mimicking the surrounding soft tissues was developed (Francisco et al., 2000; Lees and Cooper, 1995).
2. To facilitate the assembly of the components, the lower and upper ends of the artificial tibias prepared were not modeled to resemble the lower and upper ends of a natural tibia. Instead, they were rounded for a better fit with the adapters used to mount the prostheses. The adaptor at the lower end was fixed to the human-like SACH-type prosthetic foot applying the appropriate prosthetic technique. One football cleat was put on the prosthetic foot. An adapter similar to the one on the lower end was mounted on the upper end of the artificial tibia, and a prosthetic knee joint 3R15 (Otto Bock, Germany) was attached. The prosthetic knee joint was fixed to the steel structure in a flexion position of 45°.
3. A special sensor system (Tekscan, F-Socket system), 0.18 mm thick with 0.6 sensors per cm^2, was placed on the front of the artificial tibia directly over the EVA material. Data were collected by a software program developed for this system. The impulse (force*time) and the maximum force values were obtained from this system. The sensor system was calibrated using the calibration methods recommended by the manufacturer.
4. Special carbon shin guards were produced for the study. The previously prepared lower leg model (artificial tibia covered with EVA) was used for the modeling of these shin guards by taking a Paris plaster. This Paris plaster model served as the master mold for the production of carbon shin guards. The carbon shin guards were made of three layers of carbon fiber and one layer of polyester-based knit fabric after each layer of carbon fiber. Otto Bock Lamination Resins (Otto Bock, 617H55 C-Orthocryl Lamination Resins)

were used. Four (two right and two left samples) of these custom-made carbon shin guards were tested. The left carbon shin guards were used in the preparatory stage, and the right ones were used in the actual test.

5. In the LIF trials, the carbon shin guards were tested with two different types of liner, a 3 mm-thick EVA liner and a neoprene fabric. In HIF trials only neoprene-lined shin guards were used.
6. The left shin guards of all models were tested to check reliability. To test the experimental set up, each shin guard received at least 30 impacts. Problems with the sensor system (the load cells or the swing system) and shin guards were assessed. Shin guard fixation, calibration of the load cells the estimated minimum duration between consecutive impacts, the adjustments required to ensure that the swing oscillates on a single axis, etc. were checked.
7. After the pre-test, measurements were started with the right shin guards of all models. To eliminate deformations of shin guards during trials, the repetitions for the impacts were limited to 13. The minimum and the maximum values measured by Load Cell-1 in the trials were not included in the statistical analysis. The Carbon-1 (EVA) shin guard tested in the low impact trials was damaged by non-experimental reasons (it was broken accidently during a transfer following a LIF trial) and therefore excluded from the high impact trial statistics.
8. A football cleat was mounted on the foot delivering the blow to ensure that the impact was caused by the spiked portion of the sole.

Results

Low Impact Force (LIF)

In the LIF trials, 2.79-9.63 % of the load was transmitted to the sensors (Table 2). When comparing the maximum force and the impulse, a significant difference was found between the shin guard models (p = 0.000). In the post-hoc comparison, the maximum force and the impulse were significantly lower (p = 0.000) for both carbon shin guards (Table 3); there were no significant difference between the two carbon shin guards. The Nike Mercurial[TM] shin guard provided better protection than the Adidas Predator[TM] and the Adidas UCL[TM] (p = 0.000); the Adidas Predator[TM] and the Adidas UCL[TM] were similar (p > 0.05).

During LIF trials, the maximum force measured by the sensors attached in front of the tibia under the shin guard was 26.49-79.36 N. This demonstrates that only

Table 2. LIF trials and a comparison of the groups. Data are means (±SD).

Shin Guard	Impact Force (IF, N) (from Load cell 1)	Transmitted Force (TF, N) (Max Force from F-socket)	Impulse (N*sec) (from F-socket) (Force*Time)	Ratio (%) (TF/IF)
Nike Mercurial (n =10)	877.91 (.03)	54.48 (3.50)	1.96 (.29)	6.21
Adidas UCL (n = 9)	824.08 (.01)	79.36 (4.32)	3.17 (.19)	9.63
Adidas Predator (n = 10)	844.35 (.02)	77.08 (7.94)	2.98 (.41)	9.13
Carbon-1 (Eva) (n = 10)	862.49 (.02)	24.03 (3.22)	.94 (.12)	2.79
Carbon-2 (Neoprene) (n = 8)	875.24 (.02)	26.49 (11.17)	1.01 (.05)	3.03
ANOVA		p = 0.000	p = 0.000	

Table 3. Post-hoc comparison of LIF trials. Values are p <.

Shin Guards	Shin Guards	Max. Force*	Impulse*
Nike Mercurial[TM]	Adidas UCL[TM]	.000	.000
	Adidas Predator[TM]	.000	.000
	Carbon-1 (Eva)	.000	.000
	Carbon-2 (Neoprene)	.000	.000
Adidas UCL[TM]	Nike Mercurial[TM]	.000	.000
	Adidas Predator[TM]	n.s.	n.s.
	Carbon-1 (Eva)	.000	.000
	Carbon-2 (Neoprene)	.000	.000
Adidas Predator[TM]	Nike Mercurial[TM]	.000	.000
	Adidas UCL[TM]	n.s.	n.s.
	Carbon-1 (Eva)	.000	.000
	Carbon-2 (Neoprene)	.000	.000
Carbon-1 (Eva)	Nike Mercurial[TM]	.000	.000
	Adidas UCL[TM]	.000	.000
	Adidas Predator	.000	.000
	Carbon-2 (Neoprene)	n.s.	n.s.
Carbon-2 (Neoprene)	Nike Mercurial[TM]	.000	.000
	Adidas UCL[TM]	.000	.000
	Adidas Predator[TM]	.000	.000
	Carbon-1 (Eva)	n.s.	n.s.

* Multiple Comparisons, Tukey HSD. n.s. non significant

2.79-9.63% of the loads applied were transmitted to the front of the tibia (i.e., 97.21-90.37% of them were absorbed).

High Impact Force (HIF)
In the HIF trials 5.16-10.90% of the load was transmitted to the sensors (Table 4). When comparing the maximum force and the impulse, significant differences were found between the shin guard models (p = 0.000). In the post-hoc comparison, the maximum force and the impulse were significantly lower (p = 0.000) for the carbon shin guard than for the polypropylene ones (Table 5). There were no significant differences in the maximum force (p > 0.05) among the Adidas Predator[TM] and the Adidas UCL[TM] and the Nike Mercurial[TM], However, significant differences were observed between the impulse values of the Adidas Predator[TM] and the other shin guards (p < 0.05) (Adidas Predator[TM] had the highest transmitted values).
During HIF trials, the maximum force values measured by the sensors attached to the front of the tibia under the shin guard were 143.95-262.41N. This demonstrates that 5.16-10.90% of the loads were transmitted to the front of the tibia (i.e., 94.84-89.10% of them were absorbed). Although the rate appears to be low, the possibility of a maximum force of 262.41 N being transmitted to the front of the tibia demonstrates the risk that a player faces when receiving HIF impacts.

Discussion

The protective properties of commonly used shin guards were compared with specially designed carbon ones. For this purpose, three custom-made tibia models simulating natural anthropometric and mechanical characteristics were produced. Shin guards provide crucial protection against high kinetic energy impact as the anatomical structure of the shank possesses insufficient soft tissue on the medial surface and anterior border of the tibia. Using standard size shin guards do not always allow perfect fit and protection. Athletes try to compensate for this shortcoming by inserting various soft materials between the shin guard and the tibia, but this increases the weight. For this reason, athletes prefer custom-made shin guards. It is accepted that custom-made carbon fiber shin guards, as tested in this study have a better fitting between tibia and shin guard (Ekstrand and Gillquist, 1982).

In some studies wooden (Lees and Cooper, 1995) or car-crash dummy (Bir et al., 1995) tibia models have been used in shin guard tests. Using such tibia (core) models cannot simulate the flexibility of a natural tibia. Because of those limitations have also been noticed in other studies, artificial tibia models were preferred (Francisco et al., 2000; Ankrah and Mills, 2003).

In this study, three artificial carbon fiber tibias were produced as described by Heiner and Brown (2001). The artificial tibia models were tested under impact forces within the 2850-3000 N range. Although no fractures were observed, cracks occurred in front side of the artificial tibia similar to the results obtained in the study of Francisco et al. (2000). The core (tibia) models were

Table 4. HIF trials and a comparison of the groups. Data are means (±SD).

Shin Guard	Impact Force (IF, N) (from Load cell 1)	Transmitted Force (TF, N) (Max Force from F-socket)	Impulse (N*sec) (from F-socket) (Force*Time)	Ratio (%) (TF/IF)
Nike Mercurial (n =10)	2407.62 (103.46)	262.41 (31.86)	11.25 (1.55)	10.90
Adidas UCL (n = 9)	2443.27 (14.46)	242.30 (9.84)	11.15 (.93)	9.92
Adidas Predator (n = 10)	2469.61 (47.18)	256.30 (8.51)	12.92 (.33)	10.38
Carbon-2 (Neoprene) (n = 8)	2792.08 (76.51)	143.95 (10.98)	5.41 (.70)	5.16
ANOVA		**p = 0.000**	**p = 0.000**	

Table 5. Post-hoc comparison of HIF trials. Values are p <.

Shin Guards	Shin Guards	Max. Force*	Impulse*
Nike Mercurial[TM]	Adidas UCL[TM]	n.s.	n.s.
	Adidas Predator[TM]	n.s.	.003
	Carbon-2 (Neoprene)	.000	.000
Adidas UCL[TM]	Nike Mercurial[TM]	n.s.	n.s.
	Adidas Predator[TM]	n.s.	.003
	Carbon-2 (Neoprene)	.000	.000
Adidas Predator[TM]	Nike Mercurial[TM]	.000	.000
	Adidas UCL[TM]	n.s.	n.s.
	Carbon-2 (Neoprene)	.000	.000
Carbon-2 (Neoprene)	Nike Mercurial[TM]	.000	.000
	Adidas UCL[TM]	.000	.000
	Adidas Predator[TM]	n.s.	n.s.

* Multiple Comparisons, Tukey HSD. n.s. nonsignificant

covered with human soft tissue-like material (EVA), similar to the one used by Ankrah and Mills (2003) in their study. Francisco et al. (2000) covered their tibia model with butyl rubber material. But most studies did not use soft tissue analogues.

Shin guard tests should be designed to simulate the high kinetic energy impacts observed in football. Testing shin guards according to the BS EN 13061 standard will only aim to evaluate protection from soft tissue injury caused by cleats. Cattermole showed that damage on the shin guards occurred in 16,9% during a tackle (Cattermole, 1996). It has been reported that fractures occurred even though shin guards were used (Ankrah and Mills, 2003; Boden at al., 1999). These data were obtained from players who wore standard shin guards meeting the requirements of the BS-EN 13061. Lees and Cooper, (1995), Ankrah and Mills (2003) and Barrey (1998) reported that the protection by shin guards would not be sufficient in high force impacts which could cause a tibia fracture. In this study, in the HIF trials high forces were recorded from the sensors under the shin guards which demonstrate the risk of real football tackles. In the HIF impact trials the Carbon-2 (neoprene) shin guard provided better protection compared to the plastic counterparts, similar to the results of Ankrah and Mills (2003) and Francisco et al. (2000).

Impulse (force*time) is the most important parameter for evaluation of the protective efficiency of shin guards. But apart from Ankrah and Mills (2003) and Francisco et al. (2000), impact duration has not been considered.

Carbon-1 (EVA) had to be excluded from the study during the HIF trials. During those trials, Carbon-2 (neoprene) provided the best protection compared to the other shin guards, evidenced by lower impulse values. In the LIF trials the Nike Mercurial[TM] model was superior over the Adidas Predator[TM] and the Adidas UCL[TM] models, whereas in the HIF trials all three models behaved similarly. The Adidas UCL[TM] model had the highest impulse value during HIF trials, presumable this product tend to bend more easily. The difference between the impulse values of the commercial shin guards of comparable outer shells (PP) and padding material during the HIF trials can be attributed to the difference in designs.

However, the fact that there was no significant difference between the Carbon-1 (EVA) and Carbon-2 (neoprene) models during the LIF trials does not imply that this effectiveness would continue during HIF trials.

This study proved that impulse values and impact times decreased in trials when carbon fiber shin guards were used. These findings are in agreement with those of Ankrah and Mills (2003) and Francisco et al. (2000). Polypropylene shin guards bend more because of being plastic-based and forces acting on the tibia/soft tissue longer. The fact that the carbon models proved to be superior to the other shin guards, both with regards to maximum force and impulse values, could be attributed to their more rigid material as well as to their custom-made design.

Both the shell and the ridge of the lining of the Nike Mercurial[TM] model were thicker than those of the Adidas UCL[TM], which resulted in a superior performance during the LIF trials. The findings of Francisco et al. (2000) support this conclusion. The Nike Mercurial[TM] and the Adidas Predator[TM] models have an identical total thickness of 10 mm, but the outer shell of Nike Mercurial[TM] is 1 mm thicker. During high-energy impact trials, these three shin guards responded similarly even though there were differences in the thickness of the liner. Despite the fact that the carbon shin guards were thinner, they provided better protection due to superior material qualities. Although this argument does not concur with the opinion of Francisco et al. (2000) that thicker shin guards will provide better protection, the low number of products tested prevents us from giving any definitive judgments.

Phillipens and Wismans (1989) reported that the peak force decreased by 28-53%. Francisco et al. (2000), observed an average absorption rate of 11-17% with the use of shin guards. Bir et al. (1995) found that the force was reduced by 41.2-77.1% when shin guards were used. Moreover, Ankrah and Mills (2003) showed that the models they tested absorbed the maximum force by 86-93%. With the exception of the study of Ankrah and Mills (2003), the absorbed forces reported in the literature are lower than our findings. This might be because of a difference in the types or positioning of the sensors used. In this study, the sensors were attached to the front of the tibia on the soft tissue covering the whole surface under the shin guard. By using this setting, we measured the forces transmitted to the front of the tibia covered with soft tissue rather than the forces reaching the inside of the shin guard.

The absorption rates obtained in this study were

comparable to those identified in the study by Ankrah and Mills (2003), in which they placed a similar sensor system on the cover around the tibia, under the shin guard. The fact that the sensors were placed in similar positions might be the reason for the close results with the present study. Nonetheless, in this study we used a sensor-sheet consisting of 0.6 sensors per cm^2 covering the whole surface under the shin guard, whereas Ankrah and Mills (2003) placed only seven sensors of 9.5 mm diameter.

In addition, using a prosthetic foot to simulate the human foot instead of some rigid material as the unit delivering the impact and putting a football cleat on it during the kick ensured that the trials mimicked real impacts, thereby differentiating this study from others.

Conclusion

In conclusion, it was observed that the carbon shin guards provided better protection at both levels of impact. Carbon shin guards with EVA and neoprene liners gave comparable results for the maximum force and the impulse values at low-level impacts. When the protection capabilities of the shin guards were compared, the carbon shin guards were more effective specially with the EVA liner. However, players wearing carbon shin guards, generally prefer neoprene liners. The reason might be the comfort of a porous fabric in contact with the skin and a feeling of full contact compared to the EVA liner.

The load transmitted onto the front of the tibia in both levels of impact was significantly below the predicted load level required to fracture the tibia. All shin guards were able to provide adequate protection in that range. However, their possible role in soft tissue injuries could not be assessed. Standard shin guards may not be able to protect against HIF, because a considerable load of 276 N was transmitted onto the tibia, Football tackles can create much higher forces than those tested in this study. As an increased bending of the shin guards would prolong the time the force stays on the tibia, it also would increase the incidence of injuries. This highlights the main disadvantage of PP-based shin guards; however, it is obvious that choosing the right padding material requires as much care as the selection of a shell.

Simulation of the human foot using a prosthesis was an advantage of this testing apparatus. Some amount of the impact force generated is absorbed by the foot-cleat combination delivering the impact. With this in mind, in this study the various forces transmitted to the front of the tibia under similar impacts were measured. By this methodology different shin guard models were compared rather than the absolute amount of force absorbed by the shin guards. In this context it was crucial to plays the sensor systems on the tibia.

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Key points

- Shin guards decrease the risk of serious injuries.
- Carbon shin guards provide sufficient protection against high impact forces.
- Commercially available Polypropylene based shin guards do not provide sufficient protection against high impact forces.

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