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Maximum impact heights of currently used mouthguards in field hockey

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Abstract

Background/Aim: The effectiveness of mouthguards used in field hockey is unknown. The aim of this study was to compare the maximum impact heights between currently used mouthguards in field hockey to prevent dental injury.

Methods: Four boil-and-bite mouthguards (Dita, Shock Doctor, SISU, and Stag) and one custom-made mouthguard (Elysee) were tested for maximum impact height. A hockey ball was released in a tube from increasing heights onto plaster and polymethylmethacrylate (PMMA) dental models. Models were tested without mouthguard as a control. The experiment was repeated 10 times per mouthguard and for the control on each dental model. The maximum impact height for when the dental model broke was used to calculate the speed. The mouthguards and controls were compared.

Results: The maximum impact heights (median [25%-75%] in meters) onto plaster dental models were as follows: control 0.23 (0.15-0.25), Dita 0.35 (0.30-0.35), Elysee 0.45 (0.34-0.50), Shock Doctor 0.68 (0.60-0.74), SISU 0.23 (0.20-0.26), and Stag 0.35 (0.35-0.46). The maximum impact height for Shock Doctor was significantly higher than all other mouthguards and the control (all $P < .05$). The maximum impact heights onto PMMA dental models were as follows: control 2.00 (1.30-2.50), Dita 3.80 (2.65-6.95), Elysee 3.30 (2.30-4.20), Shock Doctor 6.20 (2.80-8.10), SISU 2.60 (1.90-3.15), and Stag 3.90 (1.25-5.15). The maximum impact height for Shock Doctor was significantly higher than for SISU, Stag, and the control (all $P < .05$), but did not differ significantly from Dita ($P = .43$) and Elysee ($P = .12$).

Conclusion: Shock Doctor had the highest maximum impact height compared to the other mouthguards and appears to be the most effective mouthguard tested in this study.

KEYWORDS
effectiveness, field hockey, impact height, mouthguard

1 | INTRODUCTION

Mouthguards have been recommended for decades to prevent oro-dental injuries in sports.[1,2] The ability to protect athletes from oro-dental injur is highly dependent on the ability of the mouthguard to act as a shock absorber - that is, to absorb the forces that would otherwise be transmitted to the teeth. Ethylene-vinyl acetate (EVA) appears to be the material of choice and is the most commonly used material to produce mouthguards.[3–6] Nevertheless, there are three different types of mouthguards: stock, boil-and-bite, and custom-made mouthguards. Stock-type mouthguards are purchased over the counter, have a standard fit, and cannot be modified. Therefore, the stock mouthguard is mainly held in place by clenching the teeth during use, which makes them more uncomfortable. Boil-and-bite mouthguards are formed to the teeth of the athlete by warming the mouthguard in warm water, which results in a better fit. Custom-made mouthguards are made by dental professionals using a plaster model of the athlete's dentition, and a vacuum-forming or heat-pressure lamination technique on the plaster model. Obviously, this method provides the best fit to the athletes' dentition. In addition to having the best fit, custom-made mouthguards also provide superior protection compared to the other types according to several studies.[7–10] There are also studies that have examined which properties make a mouthguard superior and what factors increase the shock absorption.[11–16]

Takeda et al tested three types of mouthguards: a conventional laminated type of EVA mouthguard, a three-layer type with acrylic resin inner layer (hard-insertion), and the third was the same as the second but with space so the material does not come into contact with the tooth surfaces (hard + space). This study concluded that the hard-insertion and the hard + space mouthguards had significantly greater buffer capacity compared to conventional EVA mouthguards.[11] Verissimo et al examined the effect of thickness of conventional EVA mouthguards to prevent oro-dental injuries. Increasing the thickness up to 4 mm decreased the peak strain value. There were no substantial differences in peak stresses and strains between mouthguards that were 4-6 mm thick. Considering the concerns about comfort, it was recommended to use 3-4 mm mouthguards for ideal shock absorption and comfort.[12,13] Other studies have also correlated thickness and rigidity to the amount of shock absorption of the mouthguard. They concluded that the ideal thickness of mouthguards should be 4.0 mm to protect the teeth from injury.[14,15]

It is remarkable that most studies in the literature have examined sports mouthguards in general using a steel ball or baseball for testing but there is no sports-specific consideration of the amount of force that a mouthguard must be able to absorb. In reality, most sports-related injuries are caused by objects other than a steel ball. Takeda et al[16] attempted to measure the impact force from actual sports equipment in order to clarify the exact mechanism of dental-related sports injuries and the protective effects of mouthguards. The aim of this study was to focus on field hockey and to compare the maximum impact height of different currently used mouthguards in field hockey by testing with a hockey ball.

2 | MATERIALS AND METHODS

Four commercially available boil-and-bite mouthguards and one custom-made mouthguard were selected for testing: Dita Mouthguard Senior (Dita International BV), Shock Doctor Gel Max (Shock Doctor Inc), SISU NextGen Aero Guard (Akervall Technologies Inc), and Stag Mouthguard Senior (Aimsports BV) and one custom-made Elysee mouthguard (Elysee Dental). The front thickness of all five mouthguards was measured at the incisor impressions, which receives the most impact. The thickness of the four boil-and-bite mouthguards was measured at the incisor site before modification. Then, the boil-and-bite mouthguards were processed according to the manufacturer's recommendations. The mouthguards were warmed and applied onto the dental model until the right fit was obtained. After that, the thickness of the mouthguards was measured again at the incisors. The thickness of the custom-made mouthguard was only

TABLE 1 The thickness of the tested mouthguards at the incisor impression, before and after modification

		Thickness	
Manufacturer	Material	Before	After
Dita	One layer of injected EVA	3.5 mm	2.5 mm
Elysee Dental[a]	Two layers of pressed EVA		2.5 mm
Shock Doctor Gel Max	Three layers: the first layer comprised EVA with copolymer polyurethane (PU), the second layer EVA, and the third layer is an impact shield on the outside from vulcanized rubber	5.5 mm	4.0 mm
SISU NextGen Aero Guard	One layer (perforated sheet) comprised EVA with copolymer polycaprolactone (PCL)	1.6 mm	1.3 mm
Stag	One layer of injected EVA	3.5 mm	3.0 mm

[a]This is a custom-made mouthguard, which is not modified. The thickness at the incisor impression is referred to as "after".

measured at the incisors because this mouthguard was not modified (Table 1).

A total of 50 plaster dental models were made from a rubber mold based on a standard Frasaco dental model (Henry Schein Inc) using Vertex Self cure plaster (Vertex). The composition of the plaster models consisted of 24 mL water per 60 g of plaster. This composition was mixed for 30 seconds and poured into a mold under light vibration (to remove air bubbles) for 3 minutes. The plaster dental model was finished after 15 minutes of hardening. Subsequently, 50 methyl methacrylate (PMMA) dental models were made from the same rubber mold using PMMA of Vertex Dental (Vertex). The composition of PMMA models consisted of 24 mL water per 60 g of PMMA. This composition was mixed for 20 seconds, poured into a mold, and cured in a pressure pan of 2.5 bar. After 15 minutes, the PMMA dental model was finished.

A tube of 8.00 m length was used for vertical impact. Two opposite holes were drilled through the tube every 0.20 m to insert a pin and drop a hockey ball from increasing heights on the dental model. A standard field hockey ball of 0.16 kg and a diameter of 0.07 m was used to create impact in this experiment (Figure 1).

Both the plaster and PMMA dental models were tested without a mouthguard applied as a control. The dental models were placed in a clamp underneath the tube with the occlusal surfaces perpendicular to the ground. The distance between the dental model and the tube was 0.10 m as seen in Figure 1. A hockey ball was dropped from increasing heights (every 0.20 m) in the tube onto the model until the model broke. This experiment was repeated 10 times on the plaster models and 10 times on the PMMA models. Next, a mouthguard was applied onto the model and was fixed into a clamp underneath the tube. The distance between the model with the mouthguard and the tube was 0.10 m. Again, a hockey ball was dropped from increasing heights (every 0.20 m) in the tube onto the model until the model broke. This experiment was repeated 10 times per mouthguard on the plaster models and on the PMMA models.

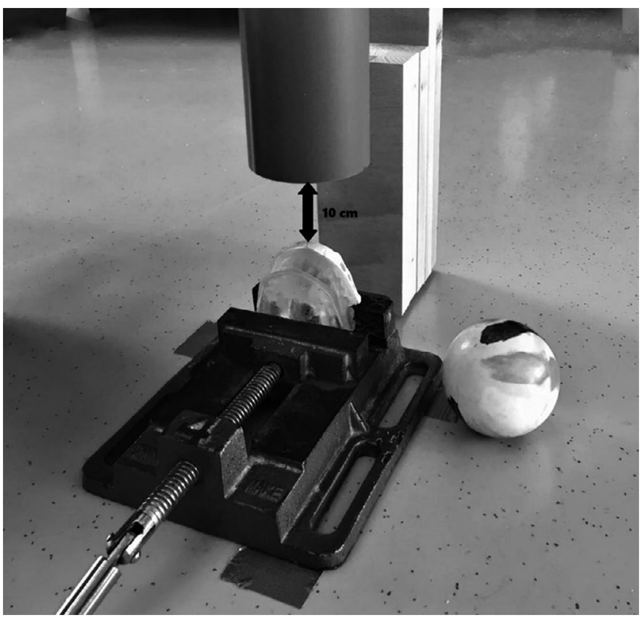

FIGURE 1 Test setup. The polymethylmethacrylate (PMMA) dental model with mouthguard was placed into a clamp underneath the tube with the occlusal surface perpendicular to the ground with 10 cm distance to the tube

The maximum impact speed in meters per second (m/s) was calculated from the maximum impact height in meters, using the following formula: $v = a \cdot t$. "t" is calculated by the formula $\sqrt{(s/(½ \cdot a))}$, where, "a" stands for acceleration of gravity, which is 9.81 m/s^2, and "s" stands for height at which the dental model had broken.

Statistical analyses were performed using SPSS version 25.0 (SPSS Corp. Released 2017. IBM SPSS Statistics for Windows, Version 25.0: IBM Corp). Differences in median height and speed between the different mouthguards were determined using the Kruskal-Wallis test. Survival analysis was performed using Kaplan-Meier survival analysis. Possible differences between the plaster models and the PMMA models were determined using the paired samples *t* test. As significance level, alpha was set at 0.05.

3 | RESULTS

All five mouthguards were made from EVA, but differed in the number of layers and method of production. Shock Doctor and SISU also added a copolymer to the EVA. The thickness at the incisor impression changed considerably after modification in the four boil-and-bite mouthguards. The custom-made mouthguard was considerably thinner compared to the other mouthguards (Table 1).

The median (25%-75%) in meters of the maximum impact heights on plaster models was calculated per mouthguard and for the control. SISU had the lowest maximum height of 0.23 (0.20-0.26). Then, consecutively, Dita and Stag, Elysee, and Shock Doctor had increasing heights. Shock Doctor had a maximum impact height of 0.68 (0.60-0.74), corresponding with a speed of 3.64 (3.43-3.80) m/s. This was significantly higher compared to the other mouthguards (all $P < .05$). The control compared to SISU ($P = .67$), Dita compared to Stag (0.28) and Elysee ($P = .21$), and Elysee compared to Stag ($P = .86$) did not significantly differ from each other in height (Table 2, Figure 2).

The median (25%-75%) in meters of the maximum impact heights on PMMA models was also calculated per mouthguard and for the control. When testing on PMMA dental models, three models with Shock Doctor mouthguards did not break at a maximum height of 8.10 m. SISU had the lowest maximum height of 2.60 (1.90-3.15). Then, consecutively, Elysee, Dita, Stag, and Shock Doctor had increasing heights. Shock Doctor had a maximum impact height of 6.20 (2.80-8.10), corresponding with a speed of 11.00 (7.41-12.61) m/s. This was significantly higher compared to SISU, Stag, and the control (all $P < .05$), but did not differ significantly from Dita ($P = .43$) and Elysee ($P = .12$) (Table 2, Figure 2).

In addition, paired *t* tests on PMMA models showed significantly higher median maximum impact heights compared to tests on plaster models for each mouthguard and for the control (all $P < .01$).

Mouthguard	Maximum impact height (median [25%-75%] in m)	Maximum impact speed (median [25%-75%] in m/s)	Mean rank
On plaster dental models			
Control	0.23 (0.15-0.25)	2.10 (1.72-2.21)	10.10
Dita	0.35 (0.30-0.35)	2.62 (2.43-2.62)	28.90
Elysee	0.45 (0.34-0.50)	2.97 (2.57-3.13)	38.65
Shock Doctor	0.68 (0.60-0.74)	3.64 (3.43-3.80)	54.65
SISU	0.23 (0.20-0.26)	2.10 (1.98-2.27)	13.40
Stag	0.35 (0.35-0.46)	2.62 (2.62-3.01)	37.30
On PMMA dental models			
Control	2.00 (1.30-2.50)	6.26 (4.99-7.00)	14.45
Dita	3.80 (2.65-6.95)	8.63 (7.21-11.68)	38.60
Elysee	3.30 (2.30-4.20)	8.04 (6.72-9.06)	32.80
Shock Doctor	6.20 (2.80-8.10)	11.00 (7.41-12.61)	44.80
SISU	2.60 (1.90-3.15)	7.13 (6.11-7.86)	23.05
Stag	3.90 (1.25-5.15)	8.74 (4.95-10.05)	29.30

TABLE 2 The medians of maximum impact height and speed, and mean rank per mouthguard and control on plaster and polymethylmethacrylate (PMMA) models

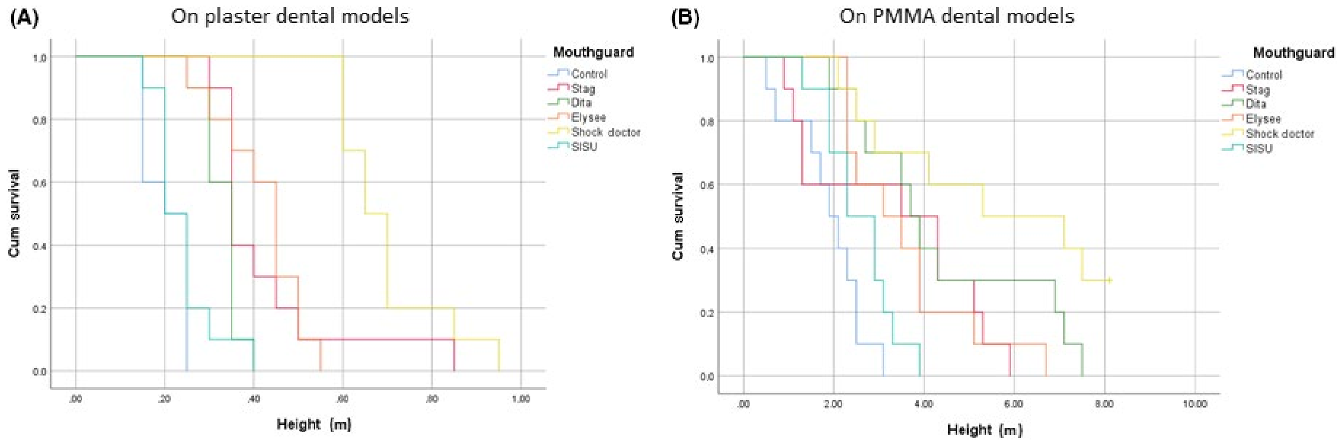

FIGURE 2 Survival curve of different mouthguards and controls at different heights (in meters). A, on plaster models. B, on polymethylmethacrylate (PMMA) dental models, where 3 PMMA dental models with Shock Doctor mouthguard did not broke at maximum high of 8.10 m

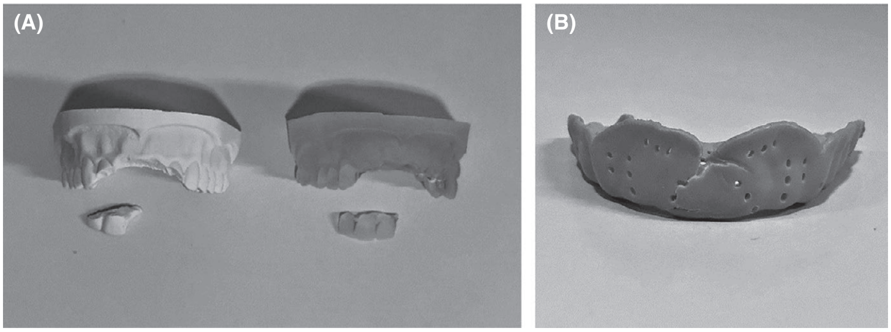

FIGURE 3 A, Breaking pattern of a plaster and a polymethylmethacrylate (PMMA) dental model after impact. B, Damaged SISU mouthguard after impact

After finishing the experiment, the dental models and mouthguards were visually assessed. Overall, the plaster and PMMA dental models broke with the same patterns - that is, the incisors and sometimes the adjacent canines were affected (Figure 3A). Dita, Elysee, Shock Doctor, and Stag were visually undamaged. SISU fractured in the front between the perforations in the design after impact (Figure 3B).

4 | DISCUSSION

This study investigated the maximum impact heights of five different field hockey mouthguards for field hockey purposes. The results showed significant differences in impact heights between the mouthguards. Shock Doctor had the highest maximum impact height compared to Dita, Elysee, SISU, and Stag. It is noteworthy that the most effective mouthguard, Shock Doctor, is also the thickest at the incisor site of all mouthguards, with a thickness of 4.0 mm after impression of the incisors, while the thinnest mouthguard, SISU, with a thickness of 1.6 mm after impression of the incisors was the least effective mouthguard. This confirms conclusions in the literature about the relationship between thickness and amount of impact of the mouthguards.[12,14,15] However, increasing the thickness of the mouthguard compromises the comfort of the player. Comfort is proven to be an important factor that determines whether players will wear the mouthguard or not.[17] This study also showed that thickness of the boil-and-bite mouthguard decreases considerably when applied to the teeth. Also, the custom-made mouthguard is considerably thinner at the incisors compared to the rest of the mouthguard. While clinically relevant, the difference in thickness before and after impression is not described in other experimental studies testing sports mouthguards.

During the hockey World Cup 2014 in The Hague, ball speeds between 80-140 km/h were recorded.[18] In this study, Shock Doctor had the highest impact absorbance and was able to handle ball speeds around 11 m/s or 40 km/h. Although this may be an underestimation, mouthguards may only be effective to prevent dental injury from low-impact trauma.

A strength of the present study is that mouthguards specifically designed for field hockey were used, along with a hockey ball to induce the impact on the models. By repeating this test several times, possible small differences in the models that occur during manufacturing processes are negligible and results are more reliable. This study has also taken into account the site of impact on the teeth and the thickness of the mouthguard at that particular site when testing. Mouthguards should be sport-specific and mouthguards should meet different requirements because forces and objects in each sport differ. For example, an Olympic boxer receives a punch from a large leather glove with an average speed of 32 km/h compared to a field hockey player receiving a small hard plastic ball with a much higher maximum speed.[18,19]

Limitations of this study were that both dental models had teeth that were rigidly stuck in the model, while in reality teeth are not ankylotic but are slightly flexible due to the periodontal ligament (PDL). Soares et al emphasized the direct influence of the periodontal ligament (PDL) on tooth displacement and type of fracture by comparing the PDL of bovine jaws with artificial PDL. They mentioned that the resistance of the periodontal ligament fibers against root displacement is low on impact, causing more coronal fractures. If the tooth is rigidly forced within its alveolus in artificial models, the periodontal resistance increases, causing more root fractures.[20] Verissimo et al did an in vitro study using bovine jaws with PDL to test the shock absorption of mouthguards by using a pendulum device with two objects: a steel ball and a baseball. This study concluded that mouthguards significantly reduced the strain on the dentoalveolar model compared to no mouthguard. Without a mouthguard, stresses were concentrated at the enamel where the impact was applied. With a mouthguard, at the peak impact, the stresses were concentrated in the root dentin structure.[21] Therefore, the results in this study on artificial dental models cannot fully be transferred to the natural dentition.

Another limitation in this study was that the same mouthguard was used until the dental model had broken. Therefore, it is unclear whether or not microtrauma in the mouthguard had already occurred during testing before the maximum height was reached. The endurance of the mouthguard may be higher if a new mouthguard was used for every new height or by using a new mouthguard starting from the previous breaking height. In addition, the mouthguards in this study were tested under dry conditions, while in reality the impact on the mouthguard is received while in the athlete's mouth and hence in a saliva-enriched, moist environment. The literature has shown that EVA mouthguards perform better in saliva conditions than in dry or deionized water conditions.[22]

This study recommends additional research about mouthguard effectiveness for each individual sport. The use of cadaver models is recommended because of the shock-absorbing features of the PDL ligament surrounding the tooth root.

5 | CONCLUSION

Shock Doctor had the highest maximum impact height compared to the other mouthguards and was the most effective mouthguard tested in this study to prevent damage to both types of dental models (plaster and PMMA). Although these results are not fully transferrable to the natural dentition, mouthguards may only be effective to prevent dental injury from low-impact trauma.

CONFLICT OF INTEREST

The authors confirm that they have no conflict of interest.

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