

# Understanding the Acute Skin Injury Mechanism Caused by Player-Surface Contact During Soccer

## A Survey and Systematic Review

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**Background:** Superficial skin injuries are considered minor, and their incidence is probably underestimated. Insight into the incidence and mechanism of acute skin injury can be helpful in developing suitable preventive measures and safer playing surfaces for soccer and other field sports.

**Purpose:** To gain insight into the incidence and severity of skin injuries related to soccer and to describe the skin injury mechanism due to player-surface contact.

**Study Design:** Systematic review; Level of evidence, 4.

**Methods:** The prevention model by van Mechelen et al (1992) combined with the injury causation model of Bahr and Krosshaug (2005) were used as a framework for the survey to describe the skin injury incidence and mechanism caused by player-surface contact.

**Results:** The reviewed literature showed that common injury reporting methods are mainly based on time lost from participation or the need for medical attention. Because skin abrasions seldom lead to absence or medical attention, they are often not reported. When reported, the incidence of abrasion/laceration injuries varies from 0.8 to 6.1 injuries per 1000 player-hours. Wound assessment techniques such as the Skin Damage Area and Severity Index can be a valuable tool to obtain a more accurate estimation of the incidence and severity of acute skin injuries.

**Conclusion:** The use of protective equipment, a skin lubricant, or wet surface conditions has a positive effect on preventing abrasion-type injuries from artificial turf surfaces. The literature also shows that essential biomechanical information of the sliding event is lacking, such as how energy is transferred to the area of contact. From a clinical and histological perspective, there are strong indications that a sliding-induced skin lesion is caused by mechanical rather than thermal injury to the skin.

**Keywords:** soccer; artificial turf; skin injury; injury mechanism; review

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Soccer, or football, is the most popular sport practiced worldwide, with 265 million active players and expanding.<sup>43</sup> As

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the game's global popularity increases, the climate plays a greater part in limiting its development. In adverse weather conditions, the use of natural grass fields is limited, and athletic performance suffers. Current generations of artificial turf mirror the playing characteristics of natural grass and are resistant to inclement weather. The International Football Association Board (IFAB) has recognized the advances in artificial surface technology and decided to introduce artificial turf into the laws of the game in July 2004.<sup>20</sup>

From epidemiological injury studies, it can be concluded that the majority of football injuries (41%-81%) are caused by physical contact.<sup>18,19,22,25,26,32,41</sup> The physical contact is mainly attributed to player-to-player contact during tackling actions. Only Fuller et al<sup>25</sup> separately reported the incidence rate of player-surface contact. Of all reported

injuries of male players, 6.6% of those on artificial turf are from player-surface contact versus 7.5% on natural grass.<sup>25</sup> Unfortunately, Fuller et al<sup>25</sup> did not correlate the type of injury to this player-surface injury mechanism. Until now, there are no published data available on the skin injury incidence rate caused by player-surface contact.

When player-surface contact involves too much energy, the skin is likely to fail, resulting in an abrasion.<sup>12</sup>

Acute skin injuries have been reported to be more common when playing on earlier generations of artificial turf.<sup>18,30</sup> In a more recent study, Ekstrand et al<sup>16</sup> concluded that burns and friction injuries caused by third-generation artificial turf pitches are not a problem anymore.

On the other hand, interviews done by Yamaner et al<sup>69</sup> and the Royal Dutch Football Association (KNVB)<sup>34</sup> showed that up to 84% of players reported abrasions, indicating that these injuries are by far the most frequent type of injury when playing on artificial turf. Yamaner et al<sup>69</sup> attribute these abrasion injuries to different conditions of playing fields. Unfortunately, the different conditions were not described. Zanetti<sup>70</sup> interviewed 1600 amateur players who generally judged the artificial turf better than natural grass, with the exception of the risk of abrasion by sliding tackles in 3 of the 8 investigated fields. Although the injury incidence obtained from epidemiological research suggests otherwise, the perceived risks of abrasion and discomfort when playing on artificial turf calls for a deeper understanding of the acute skin injury mechanism due to player-surface contact.

The aim of this survey was 2-fold: (1) to gain insight into the incidence of reported skin injuries related to soccer and (2) to describe the skin injury mechanism due to player-surface contact.

## MATERIALS AND METHODS

The injury prevention model described by van Mechelen et al<sup>65</sup> was taken as the framework for this survey. According to this model, the extent of the skin injury (incidence and severity) and mechanisms are the starting points to introduce preventive measures and assess its effectiveness. Different risk models for sport-related injuries have been proposed to study injury mechanisms.<sup>23,28,48,51</sup> The Bahr model<sup>8</sup> combines the epidemiological model of Meeuwisse<sup>51</sup> and the biomechanical perspective as described by McIntosh.<sup>48</sup> Furthermore, this model takes the characteristics of the sports into account. Bahr and Krosshaug<sup>8</sup> combined internal risk factors related to the athlete, external risk factors, and the event leading to the injury. This comprehensive model for injury causation was used to assess the risk factors for skin injuries caused by player-surface contact during soccer.

The PubMed database was searched using the keywords *injury*, *football*, and *artificial turf*. Inclusion criteria for this survey were provided as follows: (1) data about skin injury incidence and severity in combination with the applied injury definition and (2) possible epidemiology, mechanisms, and risk factors of skin injury related to player-surface contact in football. We used the following

exclusion criteria: (1) unavailable in English or (2) skin injury data that were unable to be recalculated to suit this article.

Article reference lists and relevant Dutch publications were used as additional supportive articles. A further search was conducted using the keywords *wound definition and assessment*, *tackle*, and *fall studies* in combination with *sports* and *thermal skin injury* in order to find papers that described potentially relevant skin injury mechanisms related to player-surface contact in soccer.

## SKIN INJURY DEFINITION AND INCIDENCE

In the past, different definitions for injury were used, which made it difficult to compare results of injury incidence studies. Therefore, an Injury Consensus Group, under the auspices of the Fédération Internationale de Football Association Medical Assessment and Research Centre (F-MARC), produced a consensus statement.<sup>27</sup> According to this statement, an injury is defined as

any physical complaint sustained by a player that results from a football match or football training, irrespective of the need for medical attention or time loss from football activities. An injury that results in receiving medical attention is referred as a “medical attention” injury, and an injury that results in a player being unable to take full part in a future football training or match as a “time loss” injury.<sup>27(p193)</sup>

Furthermore, this statement contains categories for classifying the type of injury. According to this statement, contusions are considered as a separate class of skin injuries compared with lacerations and abrasions. Unfortunately, definitions of these types of skin injuries are not included in the statement. An overview of the definitions and appearance of the relevant acute skin injuries described in literature are summarized in Table 1.

As stated in the review study of Junge et al,<sup>39</sup> the injury definition directly influences data collection and thereby the reported incidence of skin injuries. If duration of time loss is taken as the only criterion, minor injuries and injuries “cured” by analgesics or other medications will be neglected, and the incidence of injury will be underestimated.<sup>39</sup> This is known as the “tip of the iceberg” phenomenon.<sup>65</sup> As an example, when the incidence of skin injury using time loss injury criteria is compared with medical attention criteria (Table 2), the incidence of abrasions and lacerations using time loss varies between 0.4 to 1.81 injuries per 1000 player-hours. However, with the medical attention definition alone, abrasions and lacerations are more frequently reported, varying from 0.8 to 6.1 injuries per 1000 player-hours. The differences in contusion incidence are even greater than lacerations and other skin injuries. Only Fuller et al<sup>25</sup> found a significant difference between artificial turf and natural grass during soccer matches with male players. More skin injuries were reported on artificial turf compared with natural grass.<sup>25</sup>

TABLE 1  
Overview of Definitions and Clinical Appearance of Soccer-Related Acute Skin Injuries

Skin Injury	Reference	Definition	Appearance
Abrasion	Basler et al <sup>12</sup>	Superficial removal of the granular and keratinized cells from the underlying dermis, produced by acute contact of exposed skin with the immediate environment	Irregularly denuded epidermis and an exposed upper dermis with punctate bleeding and tissue exudate
Turf burn	Basler et al, <sup>12</sup> Metelitsa et al <sup>52</sup>	Injury that is part abrasion and part burn due to the friction heat as a result of a sliding contact of uncovered areas with artificially surfaced fields	Superficial abrasion
Contusion	Jennett <sup>37</sup>	Result of direct contact or blunt force without the skin being broken	If superficial, will result in visible bruising; if deep, a hematoma will develop within the affected tissue
Laceration	Miller-Keane and O'Toole <sup>53</sup>	Wound produced by the tearing of body tissue; external lacerations may be caused in many ways, such as a blow from a blunt instrument, a fall against a rough surface, or an accident with machinery	A cut or incision

No significant differences of incidence of skin injuries were found between surface and sex in other studies.

### SEVERITY OF TRAUMATIC SKIN INJURIES

The Injury Consensus Group has formulated the injury severity as follows: "The number of days that have elapsed from the date of injury to the date the player returns to full participation in team training and availability for match selection."<sup>27(p194)</sup>

Studies that reported the severity of skin-related injuries are summarized in Table 3. These data indicate that skin injuries such as abrasion and laceration are mainly qualified as slight to minimal injuries, which seldom lead to long absence from training or matches.

The normal healing time of an acute skin injury, like an abrasion, is 3 weeks. During this period, inflammation, proliferation, and remodeling takes place.<sup>6,42</sup> It is likely that during the healing process, the skin lesion has an influence on playing behavior. Uncomfortable postures and movements will consciously or subconsciously be avoided.<sup>40</sup> However, this perceived discomfort and its effect on the football match have never been investigated. The number of sliding tackles performed during a match could be an indicator of altered player behavior depending on the playing surface. Based on video analysis, Andersson et al<sup>4</sup> found a significantly lower number of sliding tackles on artificial turf compared with natural grass. However, Wooster<sup>68</sup> did not find significant differences when analyzing games played in the Union of European Football Associations (UEFA) Champions League and UEFA Cup. The number of sliding tackles probably not only depends on the surface but also on other factors, like tactics and soccer skills.

Although the effects of skin trauma on participation seem minimal, skin injuries need proper treatment to prevent complications, in particular, infections.<sup>1,21,42</sup> Infections can be caused by fungi, viruses, and bacteria like methicillin-resistant *Staphylococcus aureus* (MRSA).<sup>10,13,43,60</sup> It must be emphasized that these infections are mainly spread by direct skin-to-skin contact, as reported for wrestling and

American football. The risk of contamination due to playing surface-skin contact is low. McNitt and Petrunak<sup>49</sup> described that, in general, the numbers of microbes present in synthetic turf are lower than natural grass. The infectious *Staphylococcus aureus* bacterium was not found on any type of playing surface.<sup>49</sup>

### SKIN INJURY MECHANISM DUE TO PLAYER-SURFACE CONTACT

To describe the skin injury mechanism due to player-surface contact, the results of the literature search were categorized as intrinsic factors, extrinsic risk factors, and event according to the comprehensive injury causation model of Bahr and Krosshaug<sup>8</sup> (Table 4).

These results demonstrate that wet playing surfaces, protective equipment, and the use of a skin lubricant decreases the incidence of abrasion injuries. Conflicting results are reported with regard to the influence of age, sex, type of surface, behavior, position on the field, and level of performance on the incidence of skin injuries.

### DISCUSSION

Although skin injuries are uncomfortable and unpleasant, they seldom lead to absence from training or a soccer match. In addition, medical attention is not often needed.<sup>14-16,24,38</sup> The commonly used injury definition, which is mainly based on time loss or need for medical attention, determines data collection during incidence studies. Therefore, it is not surprising that abrasions and lacerations are not often reported. The reported incidence of these injuries varies from 0.8 to 6.1 per 1000 player-hours.<sup>||</sup> Retrospective studies in which players were questioned document that players sustained more abrasions than more severe injuries like strains, sprains, and fractures.<sup>34,36,69,70</sup>

<sup>||</sup>References 5, 14-16, 19, 24-26, 32, 38, 41, 47.

TABLE 2  
Skin Injury Rate of Different Types of Skin Injuries Depending on Sex and Playing Surface  
Using Time Loss and Medical Attention as Injury Definition

Study	Injury Definition	Type of Skin Injury	Incidence of Acute Skin Injury in Matches (in Training) <sup>a</sup>			
			Males		Females	
			Artificial Turf	Grass	Artificial Turf	Grass
Fuller et al <sup>25,26</sup>	Time loss	Laceration/skin lesion	1.81 <sup>b</sup> (0.02)	0.61 <sup>b</sup> (0.04)	0.29 (0.04)	0.24 (0.02)
Ekstrand et al <sup>17c</sup>	Time loss	Laceration/abrasion	—	0.07	—	—
Ekstrand et al <sup>16</sup>	Time loss	Skin lesion	0.81 (0.06)	0.37 (0.07)	0.22 (0)	0 (0)
Hawkins and Fuller <sup>32c</sup>	Time loss	Laceration	—	0.38 (0.03)	—	—
Bjørneboe et al <sup>14</sup>	Time loss	Laceration	0.7	0.4	—	—
Bjørneboe et al <sup>14</sup>	Time loss	Contusion	4.0 (0.3)	3.8 (0.2)	—	—
Fuller et al <sup>25</sup>	Time loss	Contusion	5.83 (0.53)	6.35 (0.53)	4.57 (0.28)	5.05 (0.23)
Arnason et al <sup>7</sup>	Time loss	Contusion	—	5.9 (0.50)	—	—
Ekstrand et al <sup>16</sup>	Time loss	Contusion	7.17 (0.70)	6.04 (0.46)	3.55 (0.32)	3.29 (0.29)
Ekstrand et al <sup>17c</sup>	Time loss	Contusion	—	1.3	—	—
Hawkins and Fuller <sup>32c</sup>	Time loss	Contusion	—	3.53 (0.27)	—	—
Lindenfeld et al <sup>47</sup>	Medical attention	Abrasion	3.50	—	0.90	—
Dvorak et al <sup>15</sup>	Medical attention	Laceration	—	2.84	—	—
Junge et al <sup>38c</sup>	Medical attention	Laceration	—	6.15	—	—
Aoki et al <sup>5</sup>	Medical attention	Laceration/skin lesion	—	0.83	—	—
Kordi et al <sup>41</sup>	Medical attention	Laceration/skin lesion	3.62	—	—	—
Fuller et al <sup>24c</sup>	Medical attention	Laceration/abrasion	—	4.02	—	—
FIFA <sup>19c</sup>	Medical attention	Laceration/abrasion	4.72	3.09	—	—
Aoki et al <sup>5</sup>	Medical attention	Contusion	—	2.22	—	—
Fuller et al <sup>24c</sup>	Medical attention	Contusion	—	30.77	—	—
Dvorak et al <sup>15c</sup>	Medical attention	Contusion	—	35.03	—	—
Junge et al <sup>38c</sup>	Medical attention	Contusion	—	39.29	—	—
FIFA <sup>19c</sup>	Medical attention	Contusion	47.19	51.76	—	—

<sup>a</sup>Data are expressed as number of incidences per 1000 hours of exposure. A dash indicates that the specific incidence data were not described in the study.

<sup>b</sup> $P < .01$ .

<sup>c</sup>Data in original articles were recalculated to suit the format.

TABLE 3  
Injury Severity Classifications<sup>a</sup>

Study	Type of Skin Injury	Total Reported Skin Injuries, %	Severity Classification, % <sup>b</sup>				
			Slight	Minimal	Mild	Moderate	Severe
			(<1 d)	(≥1 d)			
Bargar <sup>9</sup>	Blisters/abrasion	100	90	10			
Junge et al <sup>38c</sup>	Contusion	49	39	61			
	Laceration	8	85	15			
Dvorak et al <sup>15c</sup>	Contusion	51	48	51			
	Laceration	5	83	17			
Bjørneboe et al <sup>14</sup>	Contusion	23			(1-7 d)	(8-21 d)	(>21 d)
	Laceration	2.5			79	17	4
Arnason et al <sup>7</sup>	Contusion	20			80	16	4
Ekstrand et al <sup>16c</sup>	Contusion	17		(1-3 d)	(4-7 d)	(8-28 d)	(>28 d)
	Laceration	1		41	38	19	2
	Abrasion	0.2		32	35	32	
				43	43	14	

<sup>a</sup>Injury severity was classified according to the number of days a player was absent because of an acute skin injury. Percentages were calculated from total reported skin injury data.

<sup>b</sup>Severity definitions according to Ekstrand et al.<sup>16</sup> Values in parentheses indicate injury severity depending on the days of absence during training and matches.<sup>16</sup>

<sup>c</sup>Data in original articles were recalculated to suit the format.

TABLE 4  
Risk Factors Obtained From the Literature<sup>a</sup>

Risk Factor	Study	Outcome
<b>Intrinsic factors</b>		
Sex	Bargar <sup>9</sup>	Male subjects sustained a greater frequency and higher rate of skin trauma than females during the competitive season played on artificial turf
Age	Bargar <sup>9</sup> Akkaya et al <sup>3</sup>	A decrease in the number of wounds as the age of the subject increased Soft tissue injuries (superficial tears and abrasions) were most frequently seen in adult cases compared with adolescents as a result of soccer injuries on synthetic fields; the most frequently injured sites were the lower extremities
Location	Immers <sup>36</sup>	On artificial turf, abrasion injuries mostly occur on knee (77%) and upper leg (72%) resulting from self-reports of players
<b>Extrinsic factors</b>		
Field condition/ coefficient of friction	Immers <sup>36</sup> Verhelst et al <sup>66</sup>	Perceived less abrasion injuries (82% of population) on wet artificial turf The temperature rise measured with the novel sliding tester of a third-generation football field with sand and rubber infill in wet conditions (2°C) was much smaller than in dry condition (8°C)
	Sanchis et al <sup>57</sup>	The correlation between the coefficient of friction and the roughness increase due to damage of a silicone skin replacer was not good; there was, however, a good correlation between human perception and the damaged artificial skin
Type of surface	Ekstrand et al <sup>16</sup> Fuller et al <sup>25</sup> FIFA <sup>19</sup> Immers <sup>36</sup> Kordi et al <sup>41</sup> Hoekman and van den Heuvel <sup>34</sup> Zanetti <sup>70</sup>	No significant differences were found in skin lesions between grass and third-generation artificial turf Laceration/skin lesions in men were reported significantly higher on artificial turf than on grass ( $P < .01$ ) in matches The incidence of laceration/abrasion injuries between natural grass (3.09 injuries/1000 playing-hours) and football turf (4.72 injuries/1000 playing-hours) were comparable The average annually self-reported number of abrasion injuries per player on artificial turf was twice as high than on natural grass (7.44 vs 3.14) The incidence of laceration/skin lesions during a match were significantly higher ( $P < .01$ ) when played on dirt fields compared with artificial turf (16.34 vs 3.62 skin injuries/1000 playing-hours) 68% of the participants experienced abrasion-type injuries when playing on artificial turf Styrene-butadiene rubber infill material was preferred by all player roles with respect to skin abrasion on artificial turf pitches
Skin product	Peppelman et al <sup>56</sup> Immers <sup>36</sup>	Sliding on natural grass resulted in more erythema but less abrasions compared with artificial turf The use of a lubricant skin product significantly reduced the temperature rise of a skin replacer in sliding contact with artificial turf
Protective equipment	Basler et al <sup>11</sup>	Protective equipment such as sliding pads, long-sleeve shirts, long socks, "biker" shorts, or self-adhesive bandages applied on skin areas that may potentially receive trauma can prevent skin abrasions
<b>Event</b>		
Player behavior	Andersson et al <sup>4</sup> Wooster <sup>68</sup>	The number of sliding tackles performed on artificial turf was markedly lower ( $P < .05$ ) than on natural grass (2.1. s = 0.5 vs 4.3. s = 0.6) From a comparative performance analysis of games played in UEFA Champions League and UEFA Cup, the number of tackles performed on grass and football turf were comparable
Position	Bargar <sup>9</sup> Yamaner et al <sup>69</sup>	Midfielders were reported to suffer the majority of skin trauma, followed by defenders, forwards, and goalkeepers 85% of goalkeepers and 83% of defenders self-reported to suffer abrasion injuries, compared with 64% of midfielders and 77% of forwards
Activity	Bargar <sup>9</sup> Fuller et al <sup>25,26</sup>	Higher frequency of skin trauma in practice than in competition on artificial turf The incidence of laceration/skin lesions during training (0.02/0.04 injuries/1000 playing-hours) was significantly lower than during a match (1.81/0.61 injuries/1000 playing-hours) both on grass and on artificial turf
Tackle/action	Basler et al <sup>11</sup> Fuller et al <sup>29</sup> Tscholl et al <sup>62</sup>	Abrasion-type skin injuries were typically associated as a result of sliding contact with playing surfaces Tackled players and tackling players were nearly 3 times as likely to suffer a contusion as a result of a tackle from the side than for a tackle from behind The incidence of abrasion/laceration injuries from a slide-in tackle for a tackled and tackling player was 0.9 and 0.5 injuries/1000 tackles, respectively; the incidence of contusion from a slide-in tackle for a tackled or tackling player was 12.4 and 3.7 injuries/1000 tackles, respectively; 25% of the observed tackles for male players were sliding tackles, compared with 11% for female players

<sup>a</sup>Data are organized according to the Bahr and Krosshaug<sup>8</sup> model applied for acute skin injuries resulting from player-surfact contact during soccer.

The difference between injury surveillance and retrospective player perception studies is noteworthy because previous studies demonstrate that injury reporting is more reliable and does not suffer from recall bias.<sup>14</sup> The difference between player perception of skin injuries and the injury criteria indicate that the time loss or medical attention injury definitions are not sensitive and accurate enough.

Wound assessments, common in dermatological practice, could be of increased value.<sup>2,44</sup> These assessments examine all aspects of an injury. In this perspective, the newly developed scoring system to quantify sliding-induced skin lesions described by van den Eijnde et al<sup>63</sup> is of interest. The Skin Damage Area and Severity Index (SDASI) is based on visual scaling of the clinical parameters abrasion, erythema, and exudation. The extent of the involved area complements the SDASI.<sup>63</sup> It must be noted that other new or additional methods of data collection could place greater time demands on the medical personnel involved in these studies.<sup>27</sup>

The model described by Bahr and Krosshaug<sup>8</sup> was used to address risk factors for acute skin injuries caused by player-surface contact. Based on this study, it can be concluded that there is consensus with regard to the positive effect of a wet surface condition and the use of protective equipment or skin lubricant. There are conflicting results regarding the influence of age, sex, type of surface, behavior, position on the field, and level of performance on the incidence of skin injuries. More important, this overview shows that there are multiple risk factors for abrasions, confirmed by Zanetti,<sup>70</sup> who demonstrated that skin abrasions are influenced by the field configuration, role in the game, weather condition, and infill type. For a third-generation artificial turf field, the infill consists of rubber granules, which are used as filling material between the grass artificial fibers.

According to Meeuwisse,<sup>51</sup> the event itself is the main risk factor in acute injuries. External and/or internal risk factors contribute to a lesser extent to the cause of injury.

A small contribution is required from other external and/or internal risk factors to cause an injury.<sup>51</sup> Few data are available on acute-type skin injury such as a sliding tackle. Only Fuller et al<sup>29</sup> compared the influence of tackle parameters to the propensity of injuries that required medical attention. Unfortunately, only player-to-player contact injuries were recorded. The lack of description of the biomechanical factors associated with the sliding tackle is another more essential limitation of this study. In the field of biomechanics, McIntosh<sup>48</sup> mentioned that injury analysis and prevention must explain how energy transfer arises, why it results in injury, and how it can be prevented. Several biomechanical studies were performed in the field of football skills like kicking, heading, throwing, running, and turning.<sup>45,46,59,61</sup> However, studies regarding the kinematics and energy transfer during a sliding tackle are lacking at the moment.

The types of biomechanical studies that are closely related to a sliding tackle are fall studies of walking or standing participants. Fall studies mainly focus on the risk factors of hip fracture and not skin injuries. Table 5 gives

an overview of characteristic kinematic parameters such as vertical impact force and vertical impact velocity. Based on the findings of the study of Schmitt et al,<sup>58</sup> an impact pressure value of approximately 110 to 125 N/cm<sup>2</sup> (4000-4500 N) could result in a contusion. Furthermore, it was demonstrated that the present literature lacks suitable values for contusion injury risk.<sup>58</sup> It is likely that the vertical kinematic parameters of a sliding tackle are comparable to a side jump of a goalkeeper. The horizontal initial speed of a sliding tackle even increases the total energy transfer during contact. Finally, the mechanical properties of the human skin, such as stiffness and ultimate strength, in combination with the physical condition of the skin determines how the skin will respond to physical loads during sliding.<sup>8</sup>

A more fundamental question with respect to energy transfer is whether skin damage is caused by mechanical or thermal injury due to friction, as the term *turf burn* suggests. Poppelman et al,<sup>56</sup> in a histological study, found only removal of the stratum corneum. The deeper skin tissue was undamaged. This suggests that a sliding tackle does not result in a deep dermal or full-thickness wound, which is characteristic for a deep second- or third-degree contact burn.<sup>33</sup> However in the same study, the expression of the thermal stress protein HSP70 was increased on both dry artificial and dry natural grass but not on water-sprinkled natural grass. Therefore, the concept of reversible superficial burns cannot be excluded at the moment. The surface temperature threshold at which irreversible epidermal injury occurs is dependent on the contact time. The typical contact time of a sliding tackle is in the range of 1 second. The corresponding temperature threshold at which epidermal injury occurs is at least 60°C.<sup>54</sup> A temperature rise of 8°C, as measured by Verhelst et al<sup>66</sup> at 20°C laboratory conditions, indicates that friction energy is not high enough to cause burns. Furthermore, they reported that there was abrasion in dry conditions. This suggests that the skin failure mechanism caused by sliding is more mechanical than thermal. However, the environmental conditions are also important to take into account. It has been reported that the temperature of synthetic turf surfaces are significantly higher (range, 35°C-60°C) compared with natural grass surfaces when exposed to sunlight.<sup>50,67</sup> The temperature in the area of contact due to environmental conditions may be more important than the differences in sliding friction.

## CONCLUSION

Current injury surveillance lacks information about the incidence of acute skin injury. The development of a non-invasive, reliable technique to assess skin injury such as the SDASI may help to obtain a more accurate estimation of the incidence and severity of acute skin injuries.

Clinical and histological data indicate that under normal environmental conditions, sliding-induced skin injuries are mainly caused by mechanical failure instead of thermal injury to the skin. Consequently, *abrasion* would be the correct term for a sliding-induced skin injury rather than *turf*

TABLE 5  
Characteristic Kinematic Parameters Reported by Different Fall Studies<sup>a</sup>

Study	Type of Experiment	Surface of Impact	Side of Impact	Body Mass Index, kg/m <sup>2</sup>	Vertical Impact Force, N	Vertical Impact Velocity, m/s	Horizontal Impact Velocity, m/s	Impact Pressure, N/cm <sup>2</sup>
Nankaku et al <sup>55</sup>	Fall from standing height	Mattress	Hip	—	2251 ± 442.4	1.99 ± 0.32	—	—
van den Kroonenberg et al <sup>64</sup>	Fall from standing height	Mattress	Hip	—	—	2.75 ± 0.42	—	—
Hsiao and Robinovitch <sup>35</sup>	Fall from standing height	Mattress	Pelvis	—	—	2.55 ± 0.85	—	—
Schmitt et al <sup>58</sup>	Side jump by soccer goalkeepers	Foam layer	Hip	25 ± 1.0	5171 ± 1029	3.38 ± 0.42	2.71 ± 0.46	—
Schmitt et al <sup>58</sup>	Side jump by soccer goalkeeper	Grass	Hip	25 ± 0.8	—	—	—	117 ± 54
Groen et al <sup>31</sup>	Sideways falls of judokas	Judo canvas	Hip	21 ± 6.4 <sup>b</sup>	2579 ± 120 <sup>b</sup>	1.4 ± 0.1	—	—

<sup>a</sup>Values are expressed as mean ± standard deviation. A dash indicates that the specific kinematic parameter was not described in the study.

<sup>b</sup>Data in original articles were recalculated to suit the format.

burns. The chance of a reversible superficial burn cannot be excluded. A sliding tackle can cause a burning feeling but not a deep burn wound. Sprinkling water on synthetic turf makes sliding more comfortable; whether this also has a significant effect on the injury incidence has not been determined.

From this literature survey, it can be concluded that essential biomechanical information of a sliding tackle is lacking. A first step for future research is to quantitatively describe the kinematic parameters of a sliding tackle. These parameters are the boundary conditions for the mechanical stress to which the skin and body are exposed.

Finally, together with a sufficiently sensitive skin injury assessment method, multifactorial studies are necessary to identify the critical risk factors that contribute to a sliding-induced skin injury.

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