The use of the helmet in the prevention of brain damage (acute and chronic)

El uso del casco en la prevención del daño cerebral (agudo y crónico)

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Introduction

Between 10 and 36% of traumatic pathologies are related to physical activity. Of these, up to 12% affect the craniofacial (CF) region and their incidence has increased worryingly from year to year. To understand the magnitude of the problem, nearly 4 million CF injuries require medical attention in the US alone. American football and ice hockey are the most injury-prone sports[1].

Research on the mechanisms of CF injuries in recent years has focused on their etiopathogenesis and strategies to minimise their severity. Changes have been made to the rules and regulations, and protective equipment has been developed which has evolved and improved over the years.

With the measures taken, the severity of CF injuries has decreased, but the effects on concussion are not so positive. Furthermore, many concussions are not reported by the athlete for fear of being taken off.

Helmets were one of the first personal protection methods and still are. They are the best way to prevent moderate or severe TBIs. However, there are no positive data on their efficacy against mild TBIs (Traumatic Brain Injuries).

Each helmet is designed to protect against the potential impacts to the head in each sport.

Helmets reduce the chance of a severe traumatic brain injury after collision by reducing head acceleration on impact, reducing both brain-skull collision and the sudden deceleration which causes axonal injuries[2].

Linear and rotational acceleration movements are the mechanisms responsible for concussions and more serious CF injuries.

Linear acceleration describes the translation of the head. It is currently the variable most used to certify helmets in the sports industry, and has been since the linear acceleration peak was associated with harmful pressure waves within the skull[3].

Linear acceleration has also been used as a measurement variable to predict the risk of skull fracture. To certify a helmet, it must be able to withstand forces of approximately 250-300 G. The use of this variable in manufacturing has reduced the incidence of severe brain injury and skull fracture but has had a limited effect in decreasing the incidence of concussion.

All impacts to the head cause translation and rotation. Assessing rotational acceleration is imperative. It has been shown that the type of diffuse brain tissue shearing associated with concussion is related to the severity of head rotation during impact. Brain tissue has a high resistance to translation but a very low resistance to rotation[3].

In the manufacture of helmets, only parameters which measure translation are taken into account. Rotational acceleration needs to be analysed when designing helmets. The exact determination of rotational acceleration is difficult because the movement of the head caused by an impact is measured rather than that of the brain, which floats freely in the cerebrospinal fluid and moves at a different speed to that of the skull in response to a collision. This inability to correctly measure rotational acceleration may be one of the reasons why the incidence of concussion has not decreased despite changes in helmet design.

When an impact occurs in the CF region, it can cause collision between the brain and the skull, either on the impact side (coup) or the opposite side (contrecoup). The high-speed deceleration associated

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with these impacts can also result in diffuse axonal injury. Depending on the extent of these circumstances, a neurological pathology may occur, although the threshold necessary to provoke these is still unknown[2].

Football, ice hockey and inline hockey helmets are effective against linear acceleration impacts but not against rotational acceleration impacts [4].

The degree of protection a helmet affords against TBIs depends, among other factors, on: design, thickness, dimension and type of materials. The design of a helmet involves finding a balance between comfort and optimal safety.

Helmets are basically made up of four fundamental parts: the outer shell, an impact-absorbing liner, padding and a retaining system. The outer shell is made of a hard material designed to disperse impact energy and thus decrease the force before it reaches the head. It also needs to be able to prevent objects reaching the head from penetrating. Generally, it is made with materials such as: plastics (polycarbonates, thermoplastics, Dyneema) and fibres (carbon, glass, Kevlar, tricomposite). The lining, located inside the outer shell, serves to absorb the impact, acting as a "mattress". It is important for the helmet to fit tightly so that it can fulfil its function properly.

The absorption of energy caused by rotational and translational forces and by impact speed is different, depending on the shell design. Currently, there is not a single design which offers protection against all types of impact.

The thickness of the foam and the dimensions of the helmet are important in order to absorb impact energy.

It is more difficult to design helmets which can safely reduce low-energy accelerations and pressures which are distributed all over the brain than it is to manufacture helmets to absorb focal impacts [5].

A primary goal is to decrease maximum deceleration and increase the time over which deceleration occurs; this can be achieved by a thicker, more flexible layer of material which improves energy absorption at the time of impact. Size should not favour any increase in rotational acceleration generated by impact.

When interpreting data on the safety benefits of helmets, it is important to know that a reduction in linear or rotational acceleration is not necessarily associated with a similar reduction in concussion risk. The injury risk curve describing the likelihood of concussion for a specific rotational acceleration is not linear but sigmoidal (S-shaped).

For it to be used for a certain activity, a helmet must meet certain criteria in order to be approved and certified, and must include the corresponding certifications in its specifications:

- Baseball: NOCSAE ND022 for the batter, NOCSAE ND0204 for the catcher.
- American football: NOCSAE ND022, NDOO6.
- Ice hockey: NOCSAE NDO30, ASTM F1045.
- Studies evaluating the effectiveness of helmets in preventing injuries have a number of limitations:
- No standardised definition of concussion.
- No standardised way to examine the effectiveness of a helmet.
- Small samples which decrease statistical power.
- No control groups without helmets.

Although studies have been conducted to see if using other protective measures, such as faceguards (visors or full face shields) and mouthguards, together with helmets, reduces the incidence and severity of concussion, there are no conclusive studies which demonstrate any benefit.

In the 1960s and 1970s, the use of mouthguards was made mandatory in many sports: football, ice hockey, lacrosse, field hockey and boxing. Mouthguards are effective in preventing dental alveolar injuries but not the severity of concussion.

Use of helmets in different sports

Football

Concussion related to collision sports such as American football and hockey has been extensively studied. Lately, lower-risk contact sports, such as football, have also attracted attention. Football is the most widely played sport in the world, with more than 265 million players.

One of the most frequent actions when playing is voluntarily striking the ball with the head and although it may be a mechanism capable of causing injuries and neurological sequelae, we know that most injuries are caused by head-to-head and elbow-to-head impact.

As long ago as 1999, Delaney[6] recommended both the mandatory use of a soft protective helmet in those populations most susceptible to TBIs: goalkeepers, players aged between 6 and 15, and players with a history of head injuries, and prohibiting under-15s from heading the ball in the rules and regulations; a recommendation which was not accepted by the associations which govern the game because it would completely change youth football and, these claimed, the brains of young people, even though they may seem more vulnerable, have greater plasticity and may be able to compensate for impacts.

Helmets would be useful to reduce the impact of head-to-head and elbow-to-head blows, but are not effective when it comes to reducing the impact of the ball when heading[6] and players wearing helmets may behave more aggressively on the pitch.

Where emphasis should be placed is in youth football because of the possible consequences of repeated contact between the ball and the head. Children are maturing. The size of their skulls and brains is disproportionate (at the age of 5, the skull is 90% adult size) with respect to the rest of the body and their necks are not prepared to withstand blows like those of adults.

Consideration should be given to the need for independent doctors not conditioned by either the player or the coach to evaluate concussions produced during matches.

Baseball

Baseball is not considered a dangerous sport. However, there is a real risk of injury as a result of uncontrolled pitches, batted balls and collision on the field.

Most CF injuries are caused by the ball, which can travel at speeds of up to 145 km/h, directly hitting the batter.

Studies recommend: improving the safety of helmets, wearing face shields and cages, using softer balls and reducing the linear speed of metal bats (rotating speed).

CF injuries account for about a quarter of all baseball injuries: 10% are concussions and more than 30% fractures. Even in children from 5 to 14 years old, direct impact causes four deaths every year, which are totally avoidable[7].

The use of helmets has been mandatory since 1971. In professional leagues, these must completely cover the top and back of the head and the two ears on the sides. They must also fit snuggly. The helmets are made of very resistant thermoplastic (acrylonitrile butadiene styrene or ABS), which lends them 300% more rigidity. In 2018, C-shaped flaps began to be used to cover the jaw. The protection they afford is good against low-speed impacts but not so good against high-speed impacts.

It is mandatory for children up to 15 of age to wear helmets and polycarbonate eye protection. Also recommended are the use of low-impact balls and the prohibition of metal bats, as is technically correcting batting to avoid being exposed during pitches.

The use of a helmet is recommended for players when batting, waiting to bat and running the bases, and for base coaches.

Catchers should also always wear a helmet, mask and throat protection.

Ice hockey

Ice hockey is an aggressive sport involving a high risk of injury, due to contusions from impact with hard surfaces: wood, glass, ice, goalposts, sticks, pucks and between players.

It is estimated that up to 25% of professional players have had concussion at least once. The main mechanism leading to injury is impact to the head from the opponent's shoulders, elbows and hands[8]. The use of helmets became mandatory in Europe in 1963, in college hockey in Canada in 1965 and in the U.S. professional league (NHL) in 1979.

To reduce the risk of injury, numerous changes have been made over the years, not only in the protective equipment (helmets and face protection) but also in the regulations, and protocols have been developed to prevent, recognise and treat concussion.

The new technologies used in the manufacture of helmets allow improved protection against linear acceleration, but they do not completely protect against the rotational acceleration which has been linked to concussion, nor are they completely effective against impacts from the puck at a speed of over 90 km/h[9]. The puck can move at a speed of 145-180 km/h when shot and 50-100 km/h when being passed.

The helmets consist of a hard outer shell made of vinyl nitrile, which helps to disperse the force from the point of contact and does not deform but compresses and returns to its original state. The lining may be made of vinyl nitrile foam, expanded polypropylene foam or another material which absorbs energy and reduces the chances of concussion.

A study conducted in Canada in 1978 reported 43 eye injuries which led to blindness and pre-college and college players were obliged to wear face visors together with helmets[10].

Although face protection was first used in 1972, it wasn't until 1996 that the NHL made it mandatory.

There are three types of face protection: visor, full face shield and cage.

Visor: made of transparent waterproof plastic which gives the player unhindered vision, designed to protect against harm to the eyes from sticks and pucks. The teeth and jaw, however, remain exposed. 94% of NHL players wear visors.

Cage: made of aluminium, steel or titanium. Although cages provide the maximum possible protection, they can hinder vision.

Full face shield: offers the same protection as a cage but does not impede vision. Made of sturdy plastic, full face shields offer a large field of vision and have openings at the bottom for the mouth. Obligatory for under-18s.

In a study which assessed which type of face protection better served its function when it came to concussion following an impact, no differences between the different options were obtained, although those who used only a visor were slower to recover when concussed. This may be due to the fact that players wearing visors tilt their helmets back in order to have better vision, thereby decreasing protection of the forehead, which is where most impacts occur, and increasing the risk of serious concussions.

Skaters must wear at least a visor and the goaltender must wear a full face shield or cage (which neither sticks nor the puck can enter).

Compulsory additional protection: mouthguard for under-20s and neck guard for those under 18. Mouthguards are not mandatory in the NHL despite the fact that, in a study of 1,033 players, the concussion rate was 1.42 times higher in those who did not use them.

The game is played with a wooden or synthetic stick with a length of 163 centimetres (cm), a width of 3 cm and a thickness of 2.54 cm. The puck has a diameter of 7.62 cm and a thickness of 2.54 cm, and weighs 156-170 grams. Due to its size, it is capable of injuring the eye because it can enter the socket.

American football

Some two million people play American football in the US. It is the sport which causes the greatest number of concussions.

In 1905, 18 players died and 159 suffered serious skull injuries, and the US president Theodore Roosevelt threatened to ban the game unless urgent action was taken.

The main injury-causing mechanism, accounting for 61% of cases, is helmet-to-helmet impact.

In 1939, helmets were made mandatory in college football and in 1943 in the National Football League (NFL). Facemasks have been required since 1962.

With helmet use, the severity of CF trauma has decreased; the incidence of brain injury-related deaths dropped from 150 deaths in 1974 to 25 in 1994. The risk of skull fracture has also fallen by 60%-70% and the risk of focal brain contusion by 70%-80%, but the risk of concussion has dropped by only 20%.

Most impacts are received on the front of the helmet, meaning there is more linear and rotational acceleration and, consequently, more concussion. Impacts on the top of the helmet are less harmful. These data need to be taken into account in the design of helmets.

A prospective cohort study analysing injury rates among players wearing different types of helmets found that those wearing Riddell's Revolution helmet had significantly lower concussion rates (31% reduction in relative risk and 2.3% reduction in absolute risk) compared to those wearing other helmets, because it reduces g-force by 50%[11].

To date, no helmet is effective for impact speeds of 42 km/h or higher. However, most players do not reach these speeds but ones which are within the range of protection offered by the current helmet design.

More studies are needed to evaluate the energy-absorbing characteristics of the different materials used in the manufacture of helmets: vinyl, nitrile and expanded polypropylene work well for multiple low-energy impacts and polystyrene (PS) for high-energy impacts[11].

The biggest mistake is to think that the helmet alone prevents concussions, and that is not true, because these occur when the brain moves inside the skull and the helmets currently available do not prevent this from happening, although they do protect from lacerations, fractures and eye injuries.

The history of concussions and sub-seizure impacts received must also be added.

Rugby

Rugby is a contact sport which, despite having an incidence of CF injuries similar to that of American football and ice hockey, does not require the use of protection as these do.

The use of a helmet decreases the scalp lacerations and "cauliflower ears" typical of rugby[12] and even significantly decreases the incidence and severity of TBI according to Brooks[13], though not so according to McIntosh[14].

The only protective helmets allowed in rugby consist of polyethylene foam skull caps with a recommended thickness of 10 mm and a density of up to 45 kg/m[3].

Critics of their use argue that they are not advisable for all players because there is some evidence that they can encourage more aggressive behaviour and that the main preventive measure against TBIs should be that players use correct tackling techniques[15].

Wearing mouthguards with helmets does not decrease the incidence of concussion in those players who use them.

Field hockey

A study by Gil Rodas[16] which recorded the incidence of injuries in an elite Spanish club over three seasons highlights the low incidence of injuries to the face and skull: only 1-3% were reported in both sexes. The results are similar to those of Barboza[17].

The only mandatory protections are: shinpads, gloves and mouthguards.

Most CF injuries are caused by ball impact, collision with other players and falling to the ground. CF injuries caused by stick impact are very rare.

Defenders wear face masks at penalty corners to avoid eye injuries and incised wounds with contusion in the facial region by direct impact of the ball. When shot, the ball can reach speeds of up to 180 km/h.

In the United States, it has been mandatory for pre-college players to wear goggles since 2011.

The ball weighs 156-163 grams and has a diameter of 22.4-23.5 cm. It is made of plastic and is hollow inside with a 1-cm wall. It is similar in size to a tennis ball or baseball. The stick has a maximum length of 105 cm and must weigh no more than 750 grams.

Inline Hockey

The protective equipment is similar to that used for ice hockey.

Following the studies by Hutchinson[18] and Varlotta[19], which showed most injuries were to the head and face, 38% and 21%, respectively, under-19s were required to wear full facial protection and over-19s had to wear visors.

With the measures taken, Moreno Alcaraz[20] reported that the incidence of CF injuries decreased to 7.5%.

Quad hockey

Due to the high speed at which the game is played, the continuous contact between players, the weight and speed of the ball, and the use of sticks to strike it, there is a considerable risk of CF injuries in quad hockey.

The stick can be made of wood, plastic or other non-metallic material, has a curved end (blade) which is used to propel the ball, measures 110 cm in length and weighs approximately 500 grams. The ball, made of cork with 2-cm thick rubber coating, measures 23 cm in circumference and weighs 160 grams. When struck, it can travel at 70-125 km/h, with peaks of up to 160 km/h. Rebounds off other players and rink structures can cause the ball to move at a speed between 108 km/h if it is at ground level and 36 km/h if it is at a height of one metre. The size of the ball prevents direct impact to the eye. Players can reach speeds of up to 70 km/h on their skates.

The obligatory protection for players includes gloves, kneepads, shinpads and groin guard, and goalies must also wear a throat protector, breastplate and guards to protect the legs.

Team sports with similar cases of CF injuries took the decision to modify the regulations and require the use of preventive methods years ago, and these have been effective in decreasing the incidence and severity of CF injuries.

Statistical records have been created to determine the incidence and assess the mechanisms, severity and most frequent type of CF injuries, and thus be able to implement modifications in the rules of the game and suggest new safety measures.

Last season in Spain, serious injuries with functional and aesthetic consequences occurred, including:

- Double lower jaw fracture with instability which required treatment with osteosynthesis and subsequent orthodontics. Mechanism: long shot.
- Aggression with the stick to the skull of an opponent, resulting in suture and TBI.
- Direct contusion with the stick in the face which required 40 stitches in the cheekbone area.
- Impact with the stick in the eye with permanent visual impairment.
- In two cases analysed, the scalp was only very mildly affected and this should be taken into account in the design of specific helmets for roller hockey[21].

In Catalonia, a geographical area where there are more players, monitoring injuries sustained in the last three seasons showed that 25% of the total were CF. Injury mechanisms: stick (39%), an opponent's elbow (24%) and the ball (21%).

The data confirm and ratify the need to review the rules and regulations of the game, bringing in new safety measures and requiring the use of helmets and face protectors.

Despite the evidence, in a survey of players in Catalonia, only 61% are in favour of using additional protection measures; of these 8% would wear a helmet and 4% faceguards, and what they would value most would be panoramic vision (19.7%), protection (18.58%), comfort (16.62%) and a light weight (11.73%).

Currently there are two helmet prototypes with built-in faceguards, one made by a federative body and another by a private company, which differ in design and are pending approval and certification for use. To prevent the helmet from causing injuries voluntarily or involuntarily, it should not be optional as it has been until now but obligatory for all players so they are all equally protected.

Conclusions

A balance between safety and comfort must be achieved in the design of helmets, which must protect wearers from injuries, be low weight with a perfectly adjustable fit, and permit a wide range of vision and peripheral protection.

Helmet designs usually use linear accelerations as injury criteria without evaluating rotational acceleration, which causes most concussions. However, until now the only type of test performed for the certification of helmets has been to use a drop platform representing a fall to the ground and linear acceleration.

Concussion has been shown to be complex in nature and is not easily described using engineering parameters. There are many types of injury mechanisms associated with it, meaning that a single mechanism cannot effectively describe the risk of injury for all concussions. Impacts to the head cause a variety of dynamic responses and it is an illusion to think we can predict the risk of all kinds of concussion.

At present, helmets in most sports are effective at cushioning the impacts responsible for serious brain injury but not for concussion-causing impacts.

There is no epidemiological evidence that the use of faceguards or mouthguards in conjunction with helmets reduces concussions.

In those sports in which the use of helmets and faceguards is not possible, changes in the rules and regulations, improving technique and strengthening the neck muscles should assume their function.

What we do not know is what happens to these players later or the risk to which they are exposed if they continue on the playing field after concussion. The mass media record the moment of the trauma, but not what happens afterwards because it is no longer news.

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