MOUTHGUARDS FOR USE IN SPORTS

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PART 1 : DENTAL AND OROFACIAL INJURIES IN SPORTS, RISK FACTORS AND PREVENTIVE MEASURES

In its classification of sports with an oro-dental risk, the International Dental Federation distinguished the high-risk sports such as football and the medium risk sports such as Basketball (1). On the other hand, when the frequency of oro-dental traumas is considered, several studies (1,2) have shown that some sports present a high frequency (Ice Hockey), some a medium frequency (Basketball, Handball and Soccer) and others a low frequency (Football and Volley-ball). In another study on sports practice in Israel, Levin *et al.* (3) found that for oro-dental traumas the Basketball prevalence was the greatest, followed by that of soccer, cycling, martial arts and swimming. Therefore it seems that a discrepancy exists between the traumas frequency and the traumas risk. A first explanation was proposed by Flanders *et al.* (4) taking Football and Basketball as an example. A discrepancy should exist for Football and not for Basketball because the use of a mouthguard is compulsory in the former and not in the latter.

To clarify these points this review will firstly present an epidemiological report of the dental traumas encountered in sports, secondly an analysis of the factors involved in these traumas and finally a description of the preventive measures to reduce the traumas frequency.

I DENTAL AND OROFACIAL TRAUMAS

The causes and consequences of oro-dental traumas are analysed in many publications. They all precisely describe the sport traumatology but they use different classifications and different parameters to measure the traumas frequency (5). With such diversity, it seems difficult to compare the data, hence this review only presents the data which corresponded and were precisely defined (5).

Sports traumatology is one of the main causes of dental and orofacial injuries with the falls, the traffic accidents and the fights (6-12).

A/ Sports involved in dental and orofacial traumas:

The risk of oro-dental traumas depends on the sport (1), which is not systematically a contact sport (13). Dental and orofacial traumas are also observed in Skiing (8,9,11,12), Baseball (14,12), Cycling (8,11,15) and Swimming (3,16).

1- Basket Ball:

In Illinois between 1991 August and 1992 May, the cumulative incidence of orofacial traumas was 18.3 injuries for 10000 players (4). In the Finland championship, between 1979 and 1985 this cumulative incidence (calculated from the number of incidental cases and a number of involved players) was 33.4 injuries for 10000 players and the number of incidental cases was 5.8 % of the total number of injuries (2). During the 1989 Canadian games (2 weeks long) the cumulative incidence was very high and had different values for men and women (17): for men, 80 injuries for 10000 players and for women 250 injuries for 10000 players. It should be noted that none of injured players used a mouthguard (17).

Labella *et al.* (18) emphasised the protective role of a mouthguard during basket ball games: the cumulative incidence for a one year season was 1.2 dental traumas for 10000 players using a mouthguard whereas it was 6.7 dental traumas for 10000 players not using a mouthguard.

Finally, the dental injuries prevalence was 6.4% for players between 18 and 30 years old (19).

2- Football:

The cumulative incidence of orofacial injuries calculated on a 10 months period is 1.4 injuries for 10000 players (4). However, in another study (2) the data allowed to calculate the cumulative incidence on a period of 2 years, which was 67 injuries for 10000 players.

3- Ice Hockey:

A single study (2) gives the cumulative incidence, which was 51.2 dental injuries for 10000 players during a 5.5 years duration. However, another study in Finland (16) indicates that the number of incidental cases for dental traumas in a public dental health centre was 29 injuries during the 1983 season.

Ferrari *et al.* (19) found that for hockey players between 22 and 30 years old, the dental injuries prevalence was 11.5% which is much lower than the prevalence in handball (37.1%), basket ball (36.4%), martial arts (32.1%) and the football (23.1%). The hockey prevalence is low probably because most of players (91%) use a mouthguard, which is not the case in other sports (19).

4- Handball:

The cumulative incidence for dental traumas calculated on a 7 years period is 50.2 injuries for 10000 players (2). Handball as a relatively high-risk sport, is confirmed by a measure of the dental traumas prevalence which was 37.1% (19). However, Lang *et al.* (20) found a lower prevalence between 6.25% and 15.6%, depending on the player status (professional or not) and on the country (Swiss or Germany).

5- Soccer:

The cumulative incidence is 19.4 injuries for 10000 players (2,21). Two prevalence measurements are in agreement with this result: the dental traumas prevalence measured in soccer is the lowest (23.1%) among those measured in other sports (19) but Yamada et al. (22) found a slightly higher prevalence (32.3%).

For orofacial traumas observed during a 2 years period, the percentage of injured soccer players (25%) was the highest just above that of rugby (13) but other studies found different results. Tanaka et al. (12) reported for 17 years period 11 orofacial fractures for soccer, among 98 for all sports (percentage of incidental cases 11.2%) whereas rugby, skiing and baseball had higher numbers of fractures, 23, 23 and 13 respectively. Hill *et al.* (15), during a 1 year period, reported for orofacial traumas 109 incidental cases among 790 for all sports (percentage of incidental cases 13.8%), number of incidental cases well below those for rugby (206) and for Cycling (189).

For mandibular fractures, the soccer percentage of incidental cases observed in different studies is similar: 12.1% (11), 8.9% (8), 8.5% (12).

6- Rugby:

This sport is commonly thought to expose to risk (1) and it is not surprising that all studies agree with this idea. In a first study on rugby, Chapman (23) found that in Australia, the orodental traumas prevalence was 15.8% when the whole Australian championship was considered, 25% when the study was restricted to the Queensland team and 41.7% for the Australian national team. In a second study, Chapman and Nasser (24) confirmed the prevalence for the Australian team (42.3%) but found slightly different prevalences for other national teams: Ireland (26.9%), Scotland (50%) and Wales (54.2%). On average, these values are on agreement with that (56.5%) found by Yamada *et al.* (22). In France, for all championships the prevalence is similar to that found for the Irish team that is between 27% and 33%. (25, 26).

For the orofacial traumas, in Japan between 1977 and 1993, the rugby percentage of incidental cases was 23.5% (12). This was confirmed by Delilbasi *et al.* (14) also in Japan, who found for the 1986-2002 period a 28% rugby percentage of incidental cases which was lower than that of baseball. In France, the rugby is also the second cause of orofacial traumas (15%) but behind Soccer (25%) (13).
More specifically, in Rugby, for the mandibular fractures, the number of incidental cases in Japan was 15 to be compared to a total of 59 fractures (percentage of incidental cases of mandibular fracture 25%) (12). In France between 1992 and 1996, again for the mandibular fractures, the number of incidental cases was 16 to be compared to a total of 33 fractures in all sports (rugby percentage of incidental cases 48.5%) (11).
All these results suggest that the orofacial traumatology depends on the country.

7- Cycling:

Almost 85 million Americans regularly cycle and, each year, 540,000 of them experience a trauma (27). However, in sports, the incidence is probably high because Levin *et al.* (3), who studied the prevalence of sports for the oro-dental traumas, found that cycling was in third place after basket ball and football.
For the orofacial traumas, the number of cycling incidental cases during a one year period, was 189 with a 790 total injuries (cycling percentage of incidental cases 24%) (15).
Considering the mandible fractures, two studies give similar cycling percentage of incidental cases: 25.4% (8) and 30.3% (11).

8- Martial Arts:

The prevalence of dental traumas is 32.1% which seems normal for a fighting sport (19).
Among the orofacial traumas the most frequent ones concern the mandible. The number of incidental cases of mandible fracture between 1977 and 1993 was 6 in 59 fractures (percentage of incidental cases of mandible fracture 10.2 %) (12).
For taekwondo, very often, the head is injured with a cumulative incidence of 6.1 injuries for 1000 sportsmen and a cumulative incidence of 4.55 injuries for 1000 sportswomen (28).

9- Swimming:

For dental traumas during the 1983 year, the number of incidental cases (26) was just below that of Ice Hockey (16).

10- Baseball:

In a first study it was the first cause of maxillo-facial fractures with a 44% percentage of incidental cases just before the rugby (28%) and the soccer (18%) (14). However in a second study, again in Japan, between 1977 and 1993, for maxillo-facial fractures the number of incidental cases was 13 for 98 injuries (baseball percentage of incidental cases 13%) (12). Similar results were found for the mandible fractures: 8 incidental cases for 59 fractures (baseball percentage of incidental cases 13.6%) whereas the incidental cases were 14 for skiing and 15 for rugby (12).

11- Skiing:

As already noted, skiing is the first cause of orofacial traumas, the percentage of incidental cases between 1977 and 1993, being 23.5% (12). In Innsbruck, between, 1991 and 1996, Gassner *et al.* (29) found a slightly higher percentage (30%).
For mandibular fractures, again in Innsbruck but between 1984 and 1993 the percentage of incidental cases was very high (55.3%) (8). At the contrary Paoli et al. in Toulouse, between 1992 and 1996, found for mandibular fractures due to skiing a very small percentage, 3% of

the total of incidental cases (11). These 2 examples illustrate the dependency of the statistics on the studied areas or countries. Obviously mountains are required to practice alpin skiing.

12- Boxing:

Surprisingly, very few mandibular fractures are encountered in boxing. Tanaka *et al.* (12), during a 17 years period, observed only 2 incidental cases which correspond to a percentage of 3% of the total of incidental cases for all sports. No maxillary or malar fracture was observed as well as alveolar process fracture Tanaka *et al.* (12).
These low percentages are due to the use of mouthguard and of protective accessories.

B/ Types of trauma:

1- Teeth frequently injured:

In the whole population, the most frequently injured teeth are the maxillary central incisors (6,30-34). The maxillary central incisors are involved in 50.64% of the dental traumas, the maxillary lateral incisors in 12.1%, the mandibular central incisors in 7.96% and the mandibular lateral incisors in 6.37% (6). Lombardi *et al.* (31), Martin *et al.* (32) and Schaltz and Joho (33) also found that the highest proportion of dental traumas was for permanent or primary central maxillary incisors. In addition, Schaltz and Joho (33) observed that 94.6% of dental traumas involve permanent or primary maxillary incisors.
During sport practice (football, ice hockey, basket ball, handball, soccer) 76% of dental traumas involve the maxillary teeth, mostly the central maxillary incisors (2) whereas 6% of dental traumas involve the posterior teeth (24, 26).

2- Number of injured teeth:

For the whole population, in 60% of dental traumas, only one tooth is injured (6,30) and two teeth are injured in 29.1% of dental traumas (6). Surprisingly, the mean number of teeth involved in a dental trauma is two (10,32).
In sport practice the mean number of injured teeth per dental trauma is also two (26).

3-Dental injury types:

As noted by Bastone *et al.* (5), it is difficult to describe the different injuries because the authors use different terminology.
For all sports, 74.8% of the dental injuries are fractures (2). But, large discrepancies are observed among the different sports. For Rugby the percentage of fractures 95% is higher (26) but is probably overestimated because of the underestimation of the injuries involving only the soft tissues (2.7% of dental and orofacial traumas). For skiing, 58% of dental traumas are luxations (35) but for rugby and soccer it is the reverse because 75 luxations are observed for 100 fractures and 42 luxations for 45 fractures respectively (22). For ice hockey which is considered as a high risk sport, the dental fractures are the injuries with the highest percentage (43.5% of dental and orofacial traumas) more precisely the crown fractures without pulp exposition (36).

C/ Causes of dental and orofacial traumas:

A dental trauma may be due to a direct impact or strain on the teeth located on the maxillar or on the mandible but it may also indirectly be due to an impact on the mandible. In the latter case, when the mandible and the maxillar are not interlocked and the mandible is free to

move, an impact transforms this one in a projectile. Therefore, mandibular and maxillary teeth may violently knock together leading to a traumatic closure of the mandible (37-39).
The proportions of different oro-dental traumas causes depend on the sport. For soccer, in 86.4% of instances, the dental trauma is caused by a collision between two players (21). However, for skiing this percentage is smaller (24.1%), the first trauma cause being the fall (42%) (35). For rugby, 60% of oro-dental traumas are caused by blows, which is much higher than the percentages due to collisions (16%) or tackles (10%) (26).
Oro-dental injuries may also be caused by the use of accessories. For example, for ice hockey, the main dental trauma cause is a blow with the hockey stick, between 54% (2) and 75% (40) of instances. This cause is more frequent during competition than during training (36). A surprising basketball accessory at the origin of dental trauma is the basket net because players may be caught in it (41).
The more frequent cause of orofacial traumas is a collision with another player, the second cause being a fall (12-14,29). The use of accessories during sports practice may also be a cause of orofacial traumas (42). For example, for children in softball, the direct impact of the ball had a percentage number of incidental cases of 68%, value well above that for the collision (18%) (43).

D/ Underestimation of the number of traumas:

In some types of epidemiological study the dental traumatology may be underestimated (5):

- Studies that use the incidence as main parameter rarely take into account the minor enamel and dentine fractures or the dental injuries without displacement (5,36). Furthermore, for rugby, only 50% of the oro-dental traumas are declared, those leading to a serious injury (25).
- Retrospective studies do not take into account injuries, which are not obvious during the examination (10) and those considered as minor by the sportsman, hence not declared (5, 26).
- The definition of a term (ex: injured) may not be exactly the same in different studies, which can elicit different injury frequencies (26). For example, in 1995, the avulsion of two permanent incisors of an American Basketball player was never included in the statistics done by the National Collegiate Athletic Association because, as the sportsman played again after he was injured, he was not considered as injured for the statistics (44).

II PREDISPOSITION FACTORS

A/ General factors:

<u>1- An accidents prone subject:</u>

Such a subject has frequent dental injuries (37,45). The existence of “accidents prone subjects” was discovered by several authors (45) who noted that a small proportion of the subjects corresponded to a high proportion of the recorded injuries. These subjects may have a special behaviour eventually due to the emotional stress. This is supported by Vanderas’ observation (47) that, in children, the increase in epinephrine level is related to the increase in orofacial injury frequency. Consequently, the children in an emotionally stressful state have more chance to be injured.

2- Player’s post:

The oro-dental injury risk is a function of the player’s post. For example in Rugby, the highest risk is observed for the forward players (23,24,26).

3- Periods in the sports season:

The number of oro-dental traumas in rugby is much higher at the start and at the end of the season probably because of a lack of training and of fatigue respectively (26).

4- Training time and number of competitions:

These two factors, as shown for rugby, increase the orofacial trauma risk. More precisely, 80% of the orofacial injuries are observed during competitions (26) and the injuries frequency increases with the competition level (23).

B/ Orthodontic disorders:

Several studies pointed the importance of types of occlusion in dental traumatology. Thus an incisors overjet associated with a short lip or a buccal breathing increases the traumas risk (48).

1- Incisors overjet:

This is the main factor for oro-dental traumas predisposition (23,45, 46, 48-51). Forsberg and Tedesman (50) compared the incisors overjet in children with only enamel fractures and the incisors overjet in children with serious injuries (enamel-dentine fracture exposing or not the pulp, root fracture and luxation). They observed that the mean incisors overjet for both populations was 4.3 and 5 millimetres respectively and the .7 mm difference probably explains the different injuries seriousness. This was confirmed by other studies (49, 51). The incisors overjet increases not only the injuries seriousness but also the injuries frequency. Two groups of children with and without maxillary incisors fractures had an overjet of 6.4 and 4.5 mm respectively (49). Moreover the mean number of injured teeth is increased with the value of the overjet (51).
The identification of the overjet as an accidents prone factor seems very important in the field of preventive dentistry (23).

2- Lip coverage:

Dearing (49) compared two groups of children with and without maxillary incisors fractures. He found that the first group’s children had shorter lips than those of the second group which tends to prove that the lip coverage is an accidents prone factor. This was confirmed by Forsberg and Tedesman (50).

3- Buccal breathing:

the dental traumas frequency is lower for children with a nasal breathing than for children with buccal or buccal-nasal breathing (50).

4- Antero-posterior molar relationship:

the subjects with a molar neutrocclusion have less chance of dental traumas than those with a postnormal occlusion by half cusp or one cusp and more (50).

C) Position of the mandibular third molar:

In sportsmen, the main predisposition factor for a mandibular angle fracture is the presence of an unerupted mandibular third molar (11,52). Such a molar was present in 64% of sportsmen with a mandibular angle fracture (11).

III PREVENTION

A/ Oro-dental examination:

To prevent the oro-dental traumas, the first step is a dental examination to eventually detect bad teeth and then to cure or to reconstruct them (42). During this examination, a young sportsman needs to be made aware of oro-dental hygiene to keep his mouth in good condition. The orthodontic disorders responsible for oro-dental traumas (large overjet, small lip coverage or buccal breathing) and the presence of unerupted mandibular third molar should also be detected (23,44,45,48-51,53). McCarthy (53) said that each sportsman should have an examination to detect the position of the mandibular third molars and if necessary an avulsion.

B/ Mouthguard use:

Many studies have shown that the use of a mouthguard decreases the oro-dental traumas risk (3,4,17,19,20,23-27,36,38,39,42,52,54,55). Nevertheless it seems that additional studies are necessary to determine the material, the thickness and the type of manufacturing used to make the most efficient mouthguard to prevent dental injuries (40,56). Taking into account that the mouthguard wear depends on the sport (4,27), the American Dental Association (ADA) and the Academy for Sports Dentistry (ASD) have listed the sports and leisure activities for which the mouthguard use is recommended (57): "*Acrobatics, Bandy, Baseball, Basketball, Bicycling, Boxing, Equestrian events, Field events, Field hockey, Football, Gymnastics, Handball, Ice hockey, Inline skating, Lacrosse, Martial arts, Racquetball, Rugby, Shotputting, Skateboarding, Skiing, Skydiving, Soccer, Softball, Squash, Surfing, Volleyball, Water polo, Weightlifting, Wrestling*".
The mouthguard should be compulsory in some sports (58) and furthermore a custom-made mouthguard (made over a dental cast) should be compulsory as soon as the rugbyman has permanent teeth (26).

C/ Other protective equipment:

The mouthguard use decreases the mandibular traumas risk because in this case the mandible and the maxillary are interlocked (23,24). Emshoff *et al.* (8) proposed that the same effect could be obtained using an helmet with a chin piece.
In 1960, a report from the American Association for Health, Physical Education and Recreation has shown that for football, the number of oro-dental injuries accounted for half of the total number of injuries. At that time, the helmet had no facial protection and the players did not use a mouthguard. With the use of a facial protection the number of oro-dental injuries was divided by two and the additional use of a mouthguard decreased that number to almost zero (0.4% of the total number of injuries in football) (59, 60).

Similar observations have been done for Ice hockey (36).

D/ Dental health program:

In 1962, the dental societies have been encouraged to work with the schools on mouthguard programs (61): the dentist should inform and advise the high-risk sportsman on the use of a mouthguard (19,62). Other people may advise the sportsman: the coach, the teammates and the officials who monitor the compliance to the rules, particularly the use of a mouthguard when it is mandatory (44). The parents of young sportsmen should invite them to use a mouthguard in high-risk sports, especially when it is compulsory or if the sportsman had previous oro-dental injuries (44).

PART 2 : MOUTHGUARDS IN SPORTS

To use a mouthguard (MG) seems to be an efficient way to avoid dento-maxillary traumas (3,4,17,19,20,22,24-26,36,38,39,42,54,76-78). At the beginning of the last century, some “Prize Fighter” tried to protect themselves from lip injuries by inserting a piece of cotton under their lips (79,80), but the true predecessor of the MG seems to be a strip of Gutta Percha of which use was recommended by a Londonian dentist Woolf Krause (81). Now, most of studies agree on the role (38,39,45,65,67,76) and on the properties (1,45,65,82) of a mouthguard.
A mouthguard must:

1- Protect the soft tissues (tongue, lips and cheeks).
2- Decrease the risk of trauma for the anterior maxillary teeth by damping the impact force.
3- Avoid the violent blow between the mandibular and maxillary teeth after an impact on the mandible.
4- Decrease the risk of concussion.
5- Decrease the cervical injury risk.
6- Fill the spaces devoid of teeth.
7- Be comfortable, odorless and insipid.
8- Dampen impact forces.
9- Have a good retention in mouth.
10- Not disrupt speaking and breathing

Some authors have described the best materials, the optimal thickness and the best technique to fabricate a mouth guard but think that additional experiments are still necessary to optimize these parameters (40,56).
The aims of this part 2 are to describe the different types of mouth guards (MG) and to review the studies which describe the materials, the cranio-mandibular relationships, the ventilation when the jaws are closed on the MG, the perceived comfort and the control of head and neck posture.

I DIFFERENT MOUTH GUARD CATEGORIES

As soon as 1961, the Joint Committee of the American Dental Association and the American Association for Health, Physical Education and Recreation stated that three general types of MG exist (83). In agreement with this report, the American Society for Testing and Materials (ASTM) proposed the following classification (57) which is now commonly used (1,56,65,84-87):

- Type I, the stock mouth guards
- Type II, the mouth formed mouth guards
- Type III, the custom fabricated mouth guards (usually over a dental cast).

A/ Type I mouth guards:

This mouth guard is sold ready to use. It can be dangerous as it often slipped off the teeth (79). To keep it in place, the subject must bite on it (1,56,82,88). Then, during an effort the MG may be dislodged outside or into the oropharynx causing in this case an acute airway obstruction (38,39,67,79,82). For this reason, Turner has suggested to stop the sale of such protections (82) while the American Academy of sports dentistry has declared this type of MG not acceptable (54). The present stock MG only differ from the first mouth guards only by their materials (88).

B/ Types II mouth guards:

This type of mouth guard is intermediate between the stock and custom made mouth guards (57).
A first model, the "shell liner" is described in the literature (1,57,60,65). It is a hard shell made of polyvinyl chloride filled with methyl-methacrylate or silicone rubber mouth formed (1,57,60,65). This type of protection should be rejected because its smoothness does not allow to efficiently block the mandible (63). Furthermore, it induce an unpleasant odor and taste (57,65).
The second model is known as the "boil and bite" model and almost 90% of the mouthguards used by sportsmen are of this type (22,65,85,89). They are often made of polyvinyl acetate – ethylene copolymere (PVAc-PE) (1,45,82) which becomes plastic at a relatively low temperature. To adjust the shape of his mouth guard a sportsman must put it first in boiling water for 10 to 45 seconds, then in cool water during 1 or 2 seconds and finally in mouth to press on it with the tongue, the fingers or a gentle bite (60).
In a study of boxers, Porter *et al.* (88) noticed that during the 1992-1993 season 23% of them used a custom made mouth guard (Type III), 70% a self-formed (type II) mouth guard and 7% a "boil and bite" mouth guard but not mouth formed. Hence, the latter mouth guard is similar to a type I mouth guard (88).
If the adjustment of the mouth guard shape is not done carefully the decrease in thickness of the mouth guard may reach 99% (40,90) eliciting to a change in mouthguard properties (65).

C/ Type III mouth guards:

This protection fashioned on a dental cast made by a dentist is thought to be more efficient than those of other type (1,45,56,57,87,88,91). Two techniques are used to make these mouth guards: 1) Technique which not using a wax model of MG like thermoforming technique (40,65,86,87,92), 2) Technique using a wax model like injection (85,93-95) or packing technique (96-98).

<u>1- Technique without wax model:</u>
Thermoforming technique was developed in the USA between 1950 and 1965 and was firstly used to make the mouth guards of football players (88). The materials generally used are plates of polyvinyl acetate-ethylene copolymeres (PVAc-PE) with different thickness (40,60,65,86,87).
Thermoforming can be done in conjunction with one of two processes (86,87):

a) Vacuum:
A mouth guard is made from a single layer of PVAc-PE (40,86,87). By using a depression (Maximum 1 atm), the heated plate is dragged on the plaster model of the maxillary or mandibular teeth (57). This technique presents some drawbacks.

The material PVAc-PE has a high elastic memory and the MG slowly lost their fit and retention (99). Furthermore, because the plate is not uniformly stretched the thickness of the maxillary incisor edge could became very thin (86,92)

These disadvantages lead the laboratories to use the following technique (86).

b) Multilaminated material formed under high heat and high pressure: multilaminated MGs are made of PVAc-PE. (40,57,86,87).

To compress the layers on a dental cast, the pressure is of the order of 10 atm (57). To use a high temperature and a high pressure decreases the internal stress due to the elastic memory of the material (86,87). Furthermore, this technique ensures a complete link between the layers (86). Because of the thickness and the number of layers may be adjusted, the MG can be customized to suite the requirements of different sports (40).

2- Technique with wax model:

To apply injection or packing technique, a wax model of the MG on a maxillary and mandibular dental cast must be done (93-98). The wax model can give a well control of the limits and thicknesses of the custom made mouth guard (94).

Then, from this wax model, a mould is made in which the material is injected (93-95) or packed (96-98) after boil out the wax.

a) Injection under high pressure and high temperature:

The material is usually a polyvinyl acetate-polyethylene copolymer (PVAc-PE) (85,94). The temperature and the pressure used for this material are 160°C (320°F) and 3-6 atm respectively (100)**.**

b) Room temperature and high pressure injection followed by heating for polymerisation:

The material is a methyl methacrylate resin mixed with a synthetic rubber. It is injected under a 6 atm pressure which is maintained during the polymerisation at 95-100°C (203-212°F) (95).

c) Packing technique:

The material is a silicone which press and place in water at boiling temperature for 1 hours (96) or an acrylic resin which press and place in water at 74°C (165°F) for 9 hours (97).

II CUSTOM-MADE MOUTHGUARDS : STUDIES ON THE CHARACTERISTICS

In the aim to increase the efficiency of MGs the optimal shape, the optimal thickness and the best material were determined.

A) Shape and thickness:

Most of studies found the same essentials criterions for an efficient custom-made MG (39,65,67).

1- The MG must enclose the maxillary teeth until the distal surface of the second molars.
2- The MG must have a thickness of around 3 mm on the labial aspect, 2 mm on the occlusal aspect and 1 mm on the palatal aspect.
3- The labial flange should extend to within 2 mm of the vestibular flexion.
4- The palatine flange should extend about 10 mm above the gingival margin
5- the edge of labial flange should be rounded in cross-section whereas the palatal edge is tapered.

Recently, the Australian Dental Association recommended almost the same values 2 mm for the occlusal flange and 4 mm for the labial flange (101). But the protection from indirect impacts seems to depend on the material thickness of the MG above the incisors and the dental cuspids. The occlusal flange thickness and the labial flange thickness should be 4 mm to ensure a good comfort as well as a good protection (101). However, the lamina thickness seems to change the material properties (90,101,102).

The MG prevents dento-maxillary trauma by absorption and dissipation of energy in the material thickness (103). This phenomenon avoid the maxillary teeth vibration because of the wide distribution of the forces (103). However, this reduction in transmission may be different with the type of accessory responsible of the impact (ball or baseball bat) (104,105).

The final MG thickness depends on the technique used to make the MG (101). Effectively, with technique using wax model of MG the thickness is known before the process (94,96,97) whereas with thermoforming the MG thickness may vary with the process (106).

Some authors tried to increase the absorption of the MG by incorporating a structure between two layers of material. Watermeyer *et al.* (107) incorporated a metal arch in a MG made of PVAc-PE and observed the effect of impacts on maxillary dental cast with MG. The number of tooth fractures was lower for MG with metal arch than for MG without metal arch. This results do not agree with those of De Wet *et al.* (108). These authors studied the deformations and the displacement of several parts of an artificial skull using strain gages and accelerometers. They observed the highest deformations when a MG with a metal arch was used which indicates that this structure decreases the mechanical absorption of the MG (108). This is in agreement with the observations of Westerman *et al.* (106) and Greasley *et al.* (109).

Bulsara *et al.* (110) tested a viscoelastic polyurethane, the sorbothane which seems to have a good mechanical absorption. The forces transmitted by a MG made of this material and with a 3.4 mm thickness were 30% lower than those transmitted by a MG made of PVAc-PE with a 5 mm thickness.

The criterions described above are general but the MG may have also specific designs to fulfill the requirements of special case. Three types of MG were defined to especially protect some anatomical parts :

1- Maxillary MG: It is adjusted only on the maxillary arch. Initially designed for the American footballers, it is used in conjunction with an helmet and a facial protection (59-61). The labial flange may be extended by about 4 mm above the mandibular teeth (111). In the case of a sportsman with a class III malocclusion this type of MG seems inefficient and it is recommended to place the MG over the mandibular arch (1,57,60,65,67).

2- Modified Maxillary MG: An anterior airway is made in this MG to make easier the ventilation during occlusion (63,88).

The mandibulo-maxillary need an increasing of vertical dimension which is obtained by two blocks localisated on each side of both dental arches from the canine to the second molar mandibular (63).

Mekayarajjananonth *et al.* (97) suggested to extend the labial flange that is the anterior part of the MG to cover the labial surfaces of the anterior mandibular teeth in order to protect this teeth.

3- Bimaxillary MG. It's a one piece mouthguard which adjusted on both the maxillar and the mandible. Designed by Chapman (38,39), this mouth protector decreases the risk of trauma resulting from a mandibular impact when the mouth is opened. In addition, during occlusion, this type of MG does not alter the ventilation which is mediated by an anterior window (38,39,112). The bimaxillary MG covers both dental arches except on the incisor and canine mandibular teeth: the covering part of the mouthguard is cut away by 1 to 2 mm labially and lingually (112).

Chapman's technique was applied by others such as Jaegger (112), Lee Knight (54), Milward (96), sometimes with slight modifications. For example, Porter *et al.* (88) suggested that the mouthguard should enclose the anterior mandibular teeth. For an edentulous patient two types of MG are used: a one piece MG which encloses the anterior mandibular crest (113) or two separate MG, one per dental arch (114), which can slot in when the jaws are closed (115).

The bimaxillary MG is well suited for patients with class III malocclusion (1,20,65,67) because it protects both dental arches.

B) Materials:

Most of studies are concerned with PVAc-PE plates used for thermoforming (90,101,104-106,110,116-118).

To determine the material properties, the tests are usually conducted on plane lamina or on a layer thermoformed either on a maxillary dental cast (102,107,109,119) or on a human maxillary dental arch (103,108,120).

Ou *et al.* (120) studied the vibrations dampening and concluded that for the MG efficiency the mechanical absorption of the material is more important than the shape. Therefore, PVAc-PE might be recommended because its mechanical absorption is greater than those of latex and polyurethane (102).

An increase in dampening of forces can also be obtained by inclusion of air bubbles in the material usually EVA. In this case, Westerman *et al* (116,118) have shown that the transmission of forces is 32% less than that of MG without bubbles.

C) Mandibulo-maxillary relationship:

To shape the custom made MG, the mandibulo-maxillary relationship is important but this relation is differently determined by the dentists.
Mekayarajjananonth *et al.* (97) mounts the maxillary and the mandibular dental cast in an articulator in centric occlusion and increase the vertical dimension by about 2 to 3 mm. Sametzky *et al.* determined the mandibulo-maxillary relationship using a negative overbite (-1 mm) (63).
On the other hand Chapman (38,39) uses the technique named "maximal ventilation". An anterior airway is opened in the bimaxillary MG which imply an increase in the vertical inter incisal opening. This increase may be as high as 8 mm in early teenagers and 10 mm in adults (39). Chapman developed this technique to allow the ventilation during occlusion while avoiding a traumatic closure of the mandible (38). In edentulous patients, the mandibulo-maxillary relationship corresponds to the rest vertical dimension (39).

D) Ventilation:

Wearing a mouth guard modify the ventilation of sportsmen (121,122).
If the air flow is less than 30-40 l/min, the nasal ventilation is sufficient (121) but above this limit, the sportsman needs a buccal ventilation to decrease the ventilatory effort. (121). To favor this buccal ventilation, the sportsman wearing a MG tends to open the mouth (122) and increases the risk for a traumatic closure of the mandible because the maxillary and the mandible are no longer interlocked (38,39). For the use of type II and single layer type III MG with and without control position, inspiratory and expiratory airflow resistance were calculated at an airflow of 0.4 Ls^{-1} during tidal breathing and 1.0 Ls^{-1} during voluntary hyperpnea. The results suggest that wearing a MG tends to increase the airflow resistance and that this resistance is compensated with a mouth opening (122).
The effect of the exercise level on the ventilation of sportsmen wearing a MG was also tested (121). MG of three categories were used: uni- and bi-maxillary type I MG and bi-maxillary type II MG. The low level of exercise corresponds to the nasal ventilation whereas the high level corresponds to the buccal ventilation, the transition limit being 30-40 Ls^{-1}. For a low exercise level, the sportsman airflow is not modified by the use of the 3 categories of MG but for a high level of exercise, the airflow is increased (121).
This result shows that it is necessary to open an anterior window to provide an adequate oral airflow during occlusion (38,112).

E) Fitting and comfort:

The sportsman will use his MG only if it is well fitted and comfortable (83). As early as 1964, the Bureau of Dental Health Education and the Bureau of Economics Research and Statistics compared the 3 types of MG (83). During 3 periods of 2 weeks duration each, American footballers wore at random the 3 types of MG. Almost all these sportsmen (99%) agreed that a MG efficiently protect the teeth and 65 % declared that they would wear a MG although it was not compulsory. They also declared that the smell and the taste of the custom made MG is the most pleasant and it is also the most comfortable because of its thickness and volume. None of the MG was nauseate or induced a feeling of "dry mouth" but the type I irritated the gum of 78% of the footballers, whereas type III was the least painful. Similarly, the type I MG impaired the phonation in 77% of the footballers whereas type III was the least

disturbing. The ventilation, the easiness to wear and the retention in mouth seemed better with the type III than with the type II, type I being the worst. In conclusion, 87% of the footballers chosed the type III MG, 11.3% the type II and 1.7% the type I. A more recent study confirmed these results (123) but also noted that the cost of a type III MG and the need of a dentist intervention incite the sportsmen to choose a type II MG.
In France young rugby men were used to compare MGs, with a same shape and no metal arch, made of either acrylic or silicone rubber (98). There was no difference between the 2 types of MG for the ventilation, the phonation, the comfort and the dryness feeling. However, acrylic MGs were perceived as more stable and harder than silicone MG and a tendency to chew the latter ones was observed. Finally 56% of the players in this study choosed an acrylic MG and 44% a silicone MG (98).

F) Control of head and neck posture:

Several authors observed that the use of a mouth guard may also prevent concussions (38,40,64,66,68,69,124,125) and cervical injuries (66,68). Two mecanisms are suggested :

-A decrease in mandibulo-cranial force transmission (38,40,64), but this hypothesis is classified in the "neuromythology" by McCrory (126).

- An increase in cervical muscles activity when the sportsman is wearing his mouthguard jaws closed (66). This activity should stiffen the muscular stay of the cranio-cervical complex and stabilize the head (6,75,124) and the neck (126-129). Indeed the anatomy tend to prove that hyoid muscles have two effects when a subject is jaws closed (70). Firstly, these muscles with an insertion far from the cervical column have a long lever arm which enforce the flexion of the neck (70). Secondly, the action of these muscles, which is a flexion and winding up of the neck, combined with the action of the prevertebral muscles, allows the action of the sterno-cleido-mastoid muscles during the neck flexion (70).
The hyperextension of the cervical column is very important in cervical traumatology (71) especially when the subjects are prone to a cervical spinal stenosis (130-134). The contraction of the hyoid muscles added to the cervical muscles contraction could help to decrease this hyperextension and by that way could limit the risk of concussion due to the head acceleration or deceleration and the risk of cervical spinal trauma. This hypothesis should be confirmed in a study of the force developed by the cervical muscles when a subject wears a mouth guard jaws closed.

CONCLUSION : PART 1 AND 2

Sports are a major cause of dental and orofacial traumas though only the serious injuries are usually included in the statistical analysis.

Some sports are more often quoted in the field of the oro-dental traumatology (football, ice hockey, basketball and handball). Most often, the injury involves the teeth and mainly the central maxillary incisors whereas for the bone injuries, the mandible is mainly involved. However, the type and the cause of the injuries depend on the sport.

For these traumas, general predisposition factors exist: accidents prone subject, player’s post, period in sports season and competition level. Oro-dental predisposition factors also exist: the occlusion type and the existence of an unerupted mandibular third molar.

The prevention of the oro-dental traumas requires: 1) An oro-dental examination to detect the predisposition factors. 2) The use of a mouthguard in risk sports. 3) Some education programs to make the sportsmen aware of the benefits of a mouthguard.

The oro-dental damages are very often irreversible (63) and it is important to use a mouthguard to protect the teeth and the soft tissues from direct impacts while avoiding a traumatic closure mandible (23, 37-39, 54).

The use of a mouthguard may also prevent concussions and cervical injuries (23,24,38,39,64-69). Anatomical data on cranial, facial and cervical areas suggest that the hyoid muscles could be involved in the head-neck control (70), which could help to prevent cervical injuries (71-74) and concussions (75).

PART 3 : MOUTHGUARD AND ESSENTIAL REQUIREMENTS

I READY-MADE MOUTHGUARDS

Ready made mouthguards placed in mouth by the user without preliminary adaptation, present some inconvenient largely described in scientific literature and whom compatibility with essential requirements of PPE Directive appear questionable regarding innocuousness of the PPE and comfort and efficiency factors

A/ Innocuousness of PPE

- PPE are not supposed to generate some risks and other (autogenous) nuisance factors:

However some authors reported some incidents showing the lack of retention capacity of ready made mouthguards causing death by obstructing the oral channel of the athlete (79, 82).

- All part of mouthguard in contact with the user shall not cause injuries:

Nevertheless scientific literature showed that ready made mouthguards could cause injure soft tissue (1,80).

- Mouthguards shall not be at the origin of gestures that would put the user or other persons in danger:

Scientific literature noted that the athlete (for instance boxer) is used to change his position when seeking to reposition his ready made mouthguard no longer in good position, and thus was weakened versus his opponent (79).

All the incidents, related from 30’s until now, underline the poor evolution of this current type of mouthguards that are different only about the material used nowadays (88).

B/ Comfort and efficiency factors

When worn, PPE shall maintain its appropriate position during all the foreseeable necessary period. To fulfil this, they shall match as much as possible the user’s morphology:

However, due to a lack of retention, ready made mouthguards cannot maintain themselves on maxillary arch they are supposed to protect (1,82).

In the same way, a protective helmet for ice hockey or American football without chin strap or any other retention system would few chance to stay in good position and thus to act its role of protection.

Furthermore, would such type of helmet comply with essential requirements of PPE Directive and obtain CE Marking ?

II MOUTH ADAPTED MOUTHGUARDS (« Boil and bite »)

This type of mouthguard represent about 90% of protections used by athletes. Contrary to the ready made mouthguard, this type II mouthguard can be adapted to the user's mouth after heating and moulding. This fitting can be more or less successful (88).
Some authors underscored incidents with a risk of suffocation because of type II mouthguards ("boil & bite") not properly or not at all adapted in mouth by the users (135, 86).
Then, it shows that, when the process of moulding and adaptation has not been respected by the user, a type II mouthguard stands up as a type I mouthguard (ready made) and all its inconveniences. In that case, and if the manufacturer's information booklet is enough clear and complete, the CE marking could not be contested regarding the current rules.

Regarding certain types of mouth adapted mouthguards that have been properly adapted, i.e. adapted in accordance with manufacturer's recommendations, international literature made some remarks on innocuousness of PPE:

- PPE shall not generate risks in foreseeable conditions of use:

However certain types of mouth adapted mouthguards can loose until 99% of their occlusal thickness during mouth adaptation process (40,90), and this phenomenon can affect properties of these mouthguards (65).

PART 4 : EUROPEAN STANDARD « prEN 15712:2008 »

I OBSERVATION

This document is noted for its lack of bibliography references and its poor level of proofs (« empirical evidence and user testimonials… »).
Moreover, information about traumatology and even principles of design of mouthguards appear to be defective regarding international references currently admitted.

A/ Scope:

Bimaxillary mouthguards are clearly excluded from scope.
The standard mouthguards (type 1 ASTM) and boxes are not expressed in the scope but boxes are widely developed the further clauses (5, 6 & 7).

B/ Requirements:

According to Directive 89/686/EEC, this document has to comply with essential requirements. Concerning innocuousness, that seems to be the case (see clauses "5.1 chemical safety" and "5.2 surface safety" written in respect of principle of innocuousness).
However, the clause "5.3 Dimension and thickness" does not appear conform to current scientific data. Indeed, the limits of protection regarding the sulcus reflection or any fraenal attachments, and the minimum thickness of buccal flange or occlusal surface (1 mm) are insufficient to allow an efficient protection of the buccal-dental structures.

C/ Test methods and procedures:

Tests apply to mouth adapted and made to measure mouthguards. Nevertheless, the made to measure devices are not considered as business shop. They are done under responsibility of a health specialist (dentist, stomatologist or maxillofacial surgeon), with a "care contract" between the practitioner and the user. The sole materials used are supposed to comply the requirements regarding innocuousness of the PPE Directive.
Impact resistance test proposal lacking in relevance whereas it would be more suitable to characterise the mouthguard construction material in terms of absorption of a traumatic blow force or again of dispersion capacity.

III CONCLUSION

French stakeholders disapprove the present document submitted to CEN enquiry but stay convinced about the need for European standard on mouthguard, according to current scientific knowledge.

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