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A. TITLE PAGE

COMBINING EPIDEMIOLOGY AND BIOMECHANICS IN SPORTS INJURY PREVENTION RESEARCH – A NEW APPROACH FOR SELECTING SUITABLE CONTROLS

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Running title

Biomechanical selection of epidemiologic controls

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Several important methodological issues need to be considered when designing sports injury case-control studies. Major design goals for case-control studies include the accounting for prior injury risk exposure and optimal definitions of both cases and suitable controls are needed to ensure this. This paper reviews methodological aspects of published sports injury case-control studies, particularly with regards to the selection of controls. It argues for a new approach towards selecting controls for case-control studies that draws on an interface between epidemiological and biomechanical concepts. A review was conducted to identify sport injury case-control studies published in the peer-review literature during 1985–2008. Overall, 32 articles were identified of which the majority related to upper or lower extremity injuries. Matching considerations were used for control selection in 16 studies. Specific mention of application of biomechanical principles in the selection of appropriate controls was absent from all studies, including those purporting to evaluate the benefits of personal protective equipment to protect against impact injury. This is a problem because it could lead to biased conclusions as cases and controls are not fully comparable in terms of similar biomechanical impact profiles relating to the injury incident, such as site of the impact on the body. The strength of the conclusions drawn from case-control studies, and the extent to which results can be generalised, is directly influenced by the definition and recruitment of cases and appropriate controls. Future studies should consider the interface between epidemiological and biomechanical concepts when choosing appropriate controls to ensure that proper adjustment of prior exposure to injury risk is made. To provide necessary guidance for the optimal selection of controls in case-control studies of intervention to prevent sports-related impact injury, this paper outlines a new case-control selection strategy that reflects the importance of biomechanical

considerations which ensures that controls are selected based on the presence of the same global injury mechanism as the cases. To summarise, the general biomechanical principles that should apply to the selection of controls in future case-control studies are: 1) each control must have been exposed to the same global injury mechanism as the case, (e.g., head impact, fall onto outstretched arm, etc) and 2) intrinsic (individual) factors (e.g. age, gender, skill level, etc) that might modify the person's response to the relevant biomechanical loads are adjusted for in either selecting the controls or in the analysis phase. The same considerations for control selection apply to other study designs such as matched cohort studies or case-crossover studies.

G. TEXT PAGES

1 INTRODUCTION

Although sports injuries are a major public health concern, and there has been a rapid growth in the number of studies conducted in this important area, commentators consistently raise the poor methodological design of many studies.[1] To date the majority of sports injury studies have been descriptive in nature, describing the frequency and patterns of injury in various sports.[2-4] There has been a surge of interest in designing methodologically-sound public health injury studies in the last few years, driven by the need for a quality evidence-base to inform safety policy and planning by government agencies and sports bodies. Importantly, accurate study designs are needed to provide confident estimates of injury risk trends and outcomes, against which significant investments in intervention dollars can be prioritised and allocated by health and sport agencies.

Observational epidemiological study designs are useful for studying sports injury because they can quantify and contribute valuable information about injury incidence, severity and aetiology across many sports, contexts of play and large groups of players.[1] In studies aiming to elicit the aetiology of sports injuries, a range of study designs, each with their pros and cons, can be adopted.[5] Randomised controlled trials, generally considered the highest form of evidence,[6] can be expensive and hard to conduct in real-world sport. Moreover, some of the standard approaches such as double blinding of interventions (e.g. in a trial of headgear use it will be very apparent who is, and is not, using the headgear) and providing strict control groups are not always ethically desirable (e.g. in a trial of mouthguard effectiveness in football, it is not ethical to require all control players to not wear mouthguards if their usual practice is to do so), Whilst RCTs are the preferred study design , observational studies can overcome some of these issues and help to provide valuable evidence about the effectiveness of prevention measures and the nature of injury risk.[7] Cohort studies are valued because of the prospective nature of reporting both risk factor exposure and injury outcomes. However, they can also be impractical because of the large population required for follow-up and the relative rarity of injury events.[8-10] Case-control studies have been used as the preferred design across a range of injury settings because they can be an efficient design when the injury outcome is relatively rare and can be used to assess the relative impact of different exposure patterns.[8, 10, 11]

The use of case-control studies to identify risk factors in epidemiological studies has been common practice in medical research, starting in the first half of the last century,[12] with many injury-related case-control studies being published since the 1980's (e.g. see [8, 10, 11, 13] for an overview). This observational study design is part of the standard repertoire of modern epidemiological study designs[11, 13-16] and specific guidelines have been developed for the reporting of such studies.[7, 17]

A major reason for the popularity of case-control studies is that they can be much more efficient than cohort studies with relatively little time, less cost and a smaller amount of effort.[18] Although, appropriately designed case-control studies can have a high statistical power when they include a number of low incidence injury cases that can only be fully evaluated after a long observation period, they can be more susceptible to biases than other epidemiological designs if not used and interpreted properly.[19] The underlying requirement of most injury case-control studies is the need to identify risk factors for specific injury outcomes. In such studies, appropriate statistical analysis is used to compare the odds of prior exposure to risk factors in injury cases and controls that are injury free. The studies begin with the classification of injury status in all enrolled study participants (as either case or control) and then information about prior exposure to selected hazards is obtained.[15]

As with all observational studies, there are methodological challenges that need to be considered in the design and analysis of case-control studies [8, 10, 11] including: setting criteria for defining cases and controls; specifying eligibility criteria for case/control selection; matching when recruiting controls; prior exposure assessment; and adjustment for the confounding effects of covariates. For these reasons, it is important that a multidisciplinary approach towards the design of such studies is adopted, particularly when the goal is to provide evidence for the effectiveness of biomechanically-focussed safety interventions, such as protective equipment. It is therefore somewhat surprising that injury epidemiology studies often lack information about the actual biomechanical and other fundamental factors (e.g. behavioural determinants) associated with injury occurrence, despite the fact that this knowledge is fundamental to the development, evaluation and modification of safety interventions.[20, 21] This information is also needed for the appropriate selection of controls in case-control studies because the premise underpinning this design is that they control for, or allow the assessment, of relevant prior risk exposures. Given the role of biomechanical factors in the causation of many sports injuries, there is need to consider the application of biomechanical principles in the selection of appropriate controls in epidemiological studies. The same consideration is required when selecting behavioural, physiological and other multi-factorial controls.

The strong relationship between biomechanics and injury epidemiology was first described in 1996 and “Biomechanical epidemiology” proposed as a new phrase for this emerging field of research in the context of road safety.[22] Whilst there is inherently a clear role for this field of research in sports injury prevention, and there have been some successful applications of this approach in other injury areas (e.g.

[23]) this nexus has only rarely been discussed in the sports medicine/sports science literature.[21, 24-26]

This paper begins with a review of the focus and design features of published peer-reviewed case-control sports injury studies. In doing so, it provides an update of the status of the field concerning this study design since the advocating of such studies in this journal in 1994.[15] It then provides details of the case and control selection principles used in each of the identified studies, described from the traditional epidemiological perspective. Next, the biomechanical perspective on control selection is reviewed and the extent to which such principles have been used to select appropriate controls is summarised. Finally, this paper proposes a novel "biomechanical epidemiology" approach towards control selection to guide future sports injury case-control studies.

2 METHODS

2.1 Search strategy

A review process using nine electronic databases was conducted to identify peer-review sports injury case-control studies published between January 1985 and December 2008, inclusive. These databases were Academic Search Premier, CINAHL, EBSCO Electronic Journals Service, Health Source: Academic Edition, MEDLINE, PsychARTICLES, PsychINFO and SPORTDiscus. The keyword search terms were a Boolean combination of c*ase-control stud**, *sport**, and *injur**. Only English language articles published in peer-reviewed journals were considered. Case-control studies, covering all ages and genders, that reported sports injuries as an outcome were retrieved during the review.

In addition to the electronic database search, the strategy included secondary searching of the reference lists of identified articles. Finally, manual searching of the tables of contents of potentially relevant journals published between January 1985 and December 2008 was also undertaken (i.e. Sports Medicine, American Journal of Sports Medicine, British Journal of Sports Medicine, Clinical Journal of Sport Medicine, Medicine and Science in Sports and Exercise, Accident Analysis and Prevention, Scandinavian Journal of Medicine and Science in Sports, Injury Prevention, Journal of Science and Medicine in Sport, American Journal of Epidemiology, Epidemiology, International Journal of Epidemiology, Journal of Clinical Epidemiology, British Medical Journal, and the Journal of the American Medical Association).

2.2 Inclusion and exclusion criteria

Studies were eligible for inclusion if they were original research studies reporting a case-control design with sports injury as their major outcome. All studies were required to relate only to humans and to be written in English.

Case-control studies that were not directly related to sports injury were excluded. Bicycle-injury related studies were excluded because none of them explicitly mentioned that the bicycling activity was related to sport rather than to transportation. Even though this means that some potentially relevant bicycle helmets studies may have been excluded from this review, this is appropriate because most described helmet wearing was implemented and assessed in the context of road safety initiatives rather than sports safety. Similarly, playground-related studies were excluded because the vast majority do not mention sport and so would have been excluded by our search criteria. Studies that were purely descriptive without statistical comparisons of cases with controls were also excluded.

2.3 Identification of studies

All identified articles were screened by the second author (SU) with the help of a research assistant. This included viewing of all titles and reading of abstracts. The full text versions of potentially eligible articles were obtained and assessed against the exclusion/inclusion criteria and obvious exclusions were removed.

In the first review phase, 364 articles were identified (Figure 1). Figure 1 summarises the reasons why studies were excluded at each stage. Searching of the titles and abstracts of all identified studies excluded 284 (78%) articles that were not directly relevant to sports injury case-control studies, even though the search strategy was based on Boolean combination of sports and injury keywords (e.g. studies related to other injury contexts outside the scope of this review such as motorbike and bicycle injuries). In the second review phase, 80 retrieved articles underwent detailed review by one of the authors (SU) to ensure they met the underlying design principles of case-control studies. A further 52 articles were excluded, leaving 28 peer reviewed articles retained for the third phase review. Through the manual search of journal table of contents, an additional four articles were found.

<Insert Figure 1 about here>

A final set of 32 articles was retained for detailed review. Key case-control design methodological criteria were assessed in terms of: clearly defined injury outcome; specified methods of selection of cases and controls; matching of cases and controls; adjustment of confounding in the estimation of the independent contribution of stated risk factors to injury risk; adequate adjustment for prior exposure; and the interface between epidemiological and biomechanical control section principles.

3 EPIDEMIOLOGICAL REVIEW OF THE PUBLISHED CASE-CONTROL STUDIES

3.1 Study description

Table I summarises the methodological case-control study design details in the 32 reviewed sports injury case-control studies. Whilst a range of sports were covered in the published studies, more than one third (37.5%, n=12) related specifically to ski or snowboarding injuries and 9.4% (n=3) were related to rugby, Six studies (19%) were not related to specific sports. Almost three-quarters (72%, n=23) of the reviewed articles had been published since 2000.

<Insert Table I about here>

Overall, studies relating to knee/ACL injuries (n=8), head injuries (n=7) and the upper extremity combined (n=6) were the most common. Only two studies examined lower extremity injuries, other than the knee. Nine studies did not relate to a specific body region.

3.2 Choice of controls

Control of potential confounders can be achieved at either the design phase (i.e. in the selection of cases and controls) or in the analysis phase through the application of appropriate multivariable statistical analysis methods. When there is a clear and well established relationship between a factor and injury risk (e.g. age or gender) then it is most appropriate for such factors to be controlled at the design phase. In this case, it is not possible to further analyse those variables. Many authors prefer to adjust for confounding at the analysis stage so that they can quantify the strength of risk and protective factors. Half of the reviewed studies directly matched cases and controls, as a means of confounding adjustment (Table I). When matching was used, the most commonly matched variables were age and gender. In addition to age and gender, some studies selected their controls on the basis of matching with ski area, activity at time of injury and day;[27] body mass index and type of sports activity;[28] height, weight and exercise history;[29] height and mass.[30]

Table 1 shows that only eight of the 32 studies adjusted for confounding in the analysis phase, even when they did not adjust for confounding in the design phase and this is a major limitation of the published studies.

The majority of the published sports injury case-control studies aimed to identify injury risk factors. However, the stated purpose of some of the published case-control studies was to assess the protective effect of safety interventions. The review process identified 12 such studies and all were concerned with some form of personal protective equipment. They included five studies relating to helmets;[31-35] two studies of wrist guards;[27, 36] two mouthguard studies;[37, 38] one study each of footwear[39], wrist/elbow/knee pads for skaters[40] and elbow protectors for handball players.[41]

None of the published studies included discussion of biomechanical principles relating to the mechanism of injury, the injuries sustained and their implications for control selection. Importantly, this was not mentioned at all in any of the personal protective equipment studies which all considered a biomechanically-focussed intervention. Key considerations of variables such as where the protective equipment being assessed was situated on the player’s body at the time of injury or the direction, speed and site of any impact were notably absent.

4 BIOMECHANICAL PRINCIPLES FOR THE SELECTION OF CONTROLS

Injury has been defined as the failure of body structure and/or tissue arising from the transfer of excess energy to those structures.[42] In other words, injury at this fundamental level is a biomechanical phenomenon. Understanding injury causation has been approached very successfully from this perspective over many decades as shown by the biomechanical evaluations of occupant protection provided by motor vehicles (e.g. seat belts and airbags). Aetiological approaches towards studying sports injury which aim to understand how and why injuries occur need to be firmly planted in biomechanics.[20, 21] The following are well accepted facts and theories (covered in undergraduate textbooks) in relation to biomechanical aspects of injury causation:

a) injury (tissue failure) occurs when the tissue's strength is exceeded by an applied load;

b) tissue strength varies according to factors such as its morphology (bone, ligament, tendon, etc), age, gender and load characteristics (rate, direction, duration); the latter due in part to the intrinsic visco-elastic properties of these structures;

c) tissue strength can be increased over time by a number of factors, including resistance training, and can also decrease because of cumulative loading and non-use;[21]

d) the local injury mechanism is determined by a combination of external and internal factors,[20] (e.g. ACL injury - joint angle, segment motion, ground reaction force, and related ligament load; concussion - location, direction and magnitude of head impact force resulting in a specific combination of linear and angular acceleration and related brain loading).

e) safety systems and devices (or interventions), such as break-away bases for baseball, helmets for a range of sports, all function by reducing the magnitude of the forces applied to the body to a tolerable level.[43, 44] In the case of many helmets, the impact energy is attenuated and the impact force minimised through the deformation of the helmet liner and shell. If the liner is too soft, it will fully deform leading to high forces in comparison to a helmet designed for a range of representative impacts in the activity. Other interventions, such as neuromuscular training, act at a number of levels including reducing the external loads in a closed kinetic chain movement by acting on the sports skill execution.[45, 46]

When undertaking an accurate case-control study of injury risk factors and/or studies to evaluate interventions to assess biomechanical injury risks, points a) to d) would also need to be considered in defining controls. As the above points are characteristics of an injury case, for a control to provide a valid comparison, it must also share (with the case) the maximum number of these factors that are known or can be inferred. With the closest match possible, any outcome differences in cases and controls is, with greatest certainty, related to the exposure of interest, or particular use/non-use of a given intervention. The following examples highlight these points.

4.1 Impact head injury and ski helmet effectiveness example

A helmet is designed to reduce the magnitude of the force applied to the head during an impact to the head. It is not designed to protect any other body region, although the neck may be provided with some protection.[44, 47, 48] A skier who falls or collides with a person or object (e.g. tree) might sustain an impact to any part of their body. If they did not experience a head impact, then it was not possible for the helmet to offer any protection because it was not relevant to the other part of the body that may have sustained the impact (e.g. a knee or elbow). If the person fell, twisted their knee and ruptured their ACL, and landed sustaining an impact to the head of trivial force, a helmet would also not have offered any protection because there was negligible head injury risk present in the event due to the negligible energy transfer potential.

On the other hand, if a falling or colliding skier did experience a non-trivial impact to their head, then the injury outcome would be determined by the velocity and energy of the head at the time of impact, the site and direction of impact on the head, the mechanical characteristics of the struck object, and the energy attenuating properties of any helmet they were wearing. For example, a skier might strike a massive unyielding object like a rock at high speed, while wearing a helmet with a thin soft liner. Because of the rigidity of the impacted surface and the high energy, the limited energy attenuating properties of the liner may not be sufficient to prevent injury. In contrast, if the skier wore a helmet with a substantial liner then some significant protective benefits might be derived.

Reflecting on the points described above, a helmeted skier with a knee injury should not be selected as a control in a head injury study unless it is established that they also sustained a head impact that was equivalent to that experienced by a head injured skier (e.g. both skiers crashed head first into an unyielding tree, one with a helmet and one without a helmet). Through close matching of both cases and controls on key factors such as impact velocity and head impact characteristics, such as site and direction, the utility of the helmet can be examined. Furthermore, the postulated confounding effects of behavioural adaptation to the intervention, for example the helmet wearer was skiing faster than the non-wearer, could also be controlled for and studied separately.

4.2 Rules of the game example

Suppose that a new rule (as a safety intervention) is introduced into a form of football to reduce spinal injury arising from dangerous body contact. Historical data relating to all injuries and tackle incidents collected prospectively on an annual (seasonal) basis in a sample of games from before and after the rule change are reviewed as a source of cases (all players who sustained a spinal injury sometime during the given year) and controls (all injured players who never sustained a spinal injury over the same period). However, not all body-contact incidents in football leading to injury are associated with a risk of spinal injury. Considering all forms of football, the typical events that might load the spine are inverted falls from a height and/or an unbalanced position or high speed shoulder impacts to the head.[49] Of course, it is also reasonable to assume that in a fall onto an arm (or another body part), that this could also sustain an injury. In a case-control study of spinal injury risk associated with illegal tackles, it may be tempting to select controls as individuals with forearm fractures (with and without the new rule) and cases as players with spinal injuries (with and without the new rule). Whilst this would be better than selecting ankle sprains for controls, because there are multiple causes of ankle sprain, there is no clear rationale for someone fracturing their forearm to have an equal likelihood of spinal injury because a fall onto the outstretched arm without any head or spinal loading can only fracture the arm. The definition of the control could be tightened by the condition that the arm fracture was caused by a fall from a height in an inverted posture, thus replicating the mechanism underpinning the spinal injuries. For example, in the rugby football codes players are sometimes lifted and inverted in a tackle so that they are ‘speared’ headfirst towards the ground. Author AM has reviewed a number of these cases and the tackled player typically reaches out with one arm and controls their body’s impact with the ground, probably preventing spinal injury.

5 AN OPTIMAL APPROACH TOWARDS COMBINING EPIDEMIOLOGICAL AND BIOMECHANICAL PRINCIPLES IN CONTROL SELECTION FOR INTERVENTION EVALUATION

To generalise to the context of why biomechanical concepts are important in the selection of controls, consider a study to examine the effectiveness of an intervention (e.g. personal protective equipment) in preventing impact-related injuries. In such a study, cases would have sustained the injury of interest and controls would have not. A key exposure of interest to be compared across cases and controls is that of use of the intervention. The question reduces to asking “were fewer people injured in the group exposed to the intervention than were injured in the control group?” with the implication being that if the answer is yes that the intervention was protective.

Table II summarises the key case/control design components relating to this example scenario with impact injury to a specific body region as the outcome of interest and a general safety measure being evaluated. In the selection of cases, all are selected because they have an impact-related injury to the body region of interest. Some cases will have been directly exposed to the intervention at the time of injury and others would not. By implication, because of the selection of cases based on a clear injury outcome which would usually be diagnosis and/or severity related, all cases received their injury through the mechanism of receiving an impact to that particular body region.

<Insert Table II about here>

Application of the traditional "epidemiological" control selection strategy would select people without the injury of interest of whom, once again, some may or may not have been exposed to the intervention. Most studies select controls on the basis that they were undertaking the same activity as the controls but they remained either injury free or did not receive an impact injury to the body region of interest (though they may have done so to other regions). In other words, there is no consideration as to whether or not the controls actually also sustained an impact to the particular body region under investigation. This is a critical point because, by definition, impact-related injuries can only occur if a person sustains a blow to that part of their body. The broad control selection process outlined above is most likely to include a large proportion of people who did not receive an impact to the relevant body region and hence had no physical chance at all of being at direct risk of a corresponding impact injury. It does not make sense then, from a mechanistic point of view, in an impact injury study to select as controls people who did not impact their body at the site of the injury of interest but whom may have received another injury to a completely different body part.

Given these considerations, it is apparent that the ideal choice of controls is to select someone who sustained the same type impact as the cases but without injury. The correct comparison would be for BOTH cases and controls to have sustained the same impacts to the same body region (with the former sustaining injuries as a result of these impacts) and the risk exposure assessment to be made is whether or not they were exposed to the intervention at the time of impact.

Returning to the earlier helmet example, Table III summarises the reported case and control selections for the four identified case-control studies relating to helmet effectiveness.[31-33, 35] This table clearly shows that biomechanical considerations of relevant impacts and impact sites were not included, despite the intervention only having protective potential if the impacted head is wearing one. This omission leads to the potential for considerable bias in these studies because the control cases could have arisen in one of three ways: the case did not impact their head and so was not at risk of injury at all (irrespective of helmet use); the case sustained a very low force impact to their head that was below the threshold for injury (irrespective of helmet use); or the case sustained an impact that could have caused injury but the helmet they were wearing was effective in preventing this. Thus the strong conclusions from these studies about the effectiveness of helmets must be treated with caution, as the controls are not fully comparable to the cases of whom all (by definition) sustained an impact injury to the head.

<Insert Table III about here>

6 DISCUSSION

There is no doubt that well designed and conducted case-control studies can provide valuable information about sports injury risk and the likely protective capacity of preventive measures.[1] From a study design and analysis point of view, major challenges need to be considered in future sports injury case-control studies and this requires a new standard approach that includes biomechanical considerations. Firstly, the definition of cases and controls and the processes/rationale for control selection based on biomechanical considerations must be included upfront in the planning stages of all sports injury studies, as has previously been suggested in other injury contexts.[22, 23] We have argued that this new approach towards the selection of controls for sports injury case-control studies is needed as standard practice. In doing so, this will extend the traditional epidemiological concepts for case selection with an appreciation of the underlying, biomechanical mechanisms underpinning injury causation, thereby ensuring that exposure to injury risk is more appropriately quantified. It will still be important, however, to ensure that over-matching of cases and controls does not occur as this could reduce the power of the study to identify significant risk or protective effects when they do exist. This will need to be considered on a case-by-case basis in the light of the research question/s to be answered in any study as increasing levels of matching enable more specific questions are answered.

This paper has presented key findings from a review of the peer-review literature from 1985–2008 which identified 32 studies reporting methodological principles relating to the design and analysis of sport injury case-control studies. Although a definition of recruited cases and controls was given in almost all studies, matching of controls to cases was not common. Moreover, adjustment of confounders at the analysis stage was also uncommon.

Appropriate definition of cases and selection of controls is vital to ensuring the validity of case-control studies and conclusions drawn from them. Theoretical, epidemiologically-focussed frameworks for the selection of controls, such as a three-part review published in the leading international epidemiological methodology journal,[50-52] stress that all case-control studies should be designed to reduce three key biases: a) selection bias – so that comparisons should be made within the study base; b) confounding bias - comparisons of the effects of exposure level on risk should not be distorted by the effects of other factors; and c) information bias - any errors in exposure measurement must be non-differential in both cases and controls (to avoid bias in one group but not another).

Clear threats to case-control studies being bias free can also exist if the cases and controls are not fully comparable in terms of key exposures of interest. Theoretically, the control group provides an estimate of the prevalence of the study exposure in the population from which the cases arose. From an epidemiological perspective, random sampling from the population base, where controls are chosen independently of characteristics of the cases, is the simplest strategy. However, controls should also be representative of those individuals who would have been selected as cases had they developed the outcome. For this reason, it is critical that sports injury case-control researchers use caution when selecting samples of cases and controls and provide clear definitions of the outcome/s being studied and the likely biomechanical determinants of injury risk/exposure.

7 CONCLUSION

To provide necessary guidance for the optimal selection of controls in case-control studies of intervention to prevent sports-related impact injury, this paper has outlined a new case-control selection strategy that reflects the importance of biomechanical considerations to ensure that controls are selected based on the presence of the same global injury mechanism as the cases. There is no doubt that adopting this method in practice will add additional steps, both ethically and logistically, for injury researchers, some challenging. However, the additional information describing the injury event (impacted object, body region/s struck, velocity at time of collision and impact velocity) could be collected through specifically designed questionnaires and with increasing sophistication using video analysis of injury producing or possible events in both cases and controls.[53, 54] This argues for the need for strong multi-disciplinary approaches to be adopted in all sports injury studies, especially as evidence is translated from the laboratory; to the implementation of safety devices and other interventions in the real world context of sport; to actual on-field sports behaviours in relation to these interventions; and finally though to the setting of safety policies and formal procedures.[3]

Future studies should emphasise the interface between epidemiological and biomechanical concepts of selecting appropriate controls for accurate case-control design. This is consistent with a recent conclusion[55] that sports injury researchers need to understand differences between causes, risk factors and confounders in relation to injury risk. To summarise, the general biomechanical principles that should apply to the selection of controls in future case-control studies are:

1) The global injury mechanism[20] or event be considered. Each control must have been exposed to the same global injury mechanism as the case (e.g., head impact, inverted fall, fall onto outstretched arm, step and cut on floor of similar friction).

2) The intrinsic (individual) risk factors are also considered in either selecting the controls (e.g., matching) or in the analysis phase (e.g., age, gender, skill level, anatomical and physiological factors, fitness) unless they represent the intervention. These factors are important as they reflect underlying biomechanical characteristics.

Finally, whilst this paper has focussed on case-control studies, the same considerations for control selection apply to other study designs such as matched cohort studies[56] or case-crossover studies[8].

H. FOOTNOTES

None

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J. TABLES

Table I. Summary of the methodological design aspects of the 32 identified sports injury case-control studies

Year	Study	Sporting activity	Specific injury type of injured body region	Intervention *	Definition of case-control	Matching	Adjustment of confounding	Assessment intervention
2008	[36]	Snowboarding	Wrist/elbow	Wrist guard	No	No	No	Yes
	[57]	Skiing/snowboarding	Humerus fractures	-	Yes	No	No	No
	[30]	Female soccer/basketball	Anterior Cruciate Ligament (ACL)	-	Yes	Yes	Yes	No
	[58]	Skiing/snowboarding	All injuries	-	No	No	No	No
2007	[34]	Skiing/snowboarding	Head/face/neck	Helmet	Yes	No	Yes	No
	[37]	Various school/league sports participated in by children aged 12-14 years	Orofacial	Mouth guard	Yes	Yes	No	Yes
	[59]	Kickboxing	Brain	-	Yes	Yes	No	No

Table I. Contd.

Year	Study	Sporting activity	Specific injury type of injured body region	Intervention	Definition of case-control	Matching	Adjustment of confounding	Assessment intervention
	[60]	Female, specific activity not specified	Patellofemoral pain	-	No	No	No	No
2006	[39]	Running	Knee	Footwear	Yes	No	No	No
	[61]	Adolescent baseball pitchers	Shoulder/elbow	-	Yes	Yes	No	No
	[62]	Male tennis	ACL	-	Yes	Yes	No	No
	[35]	Skiing/snowboarding	Head	Helmet	Yes	No	Yes	No
2005	[63]	Rugby union	All injuries	-	Yes	No	Yes	No
								No
	[27]	Snowboarding	Upper extremity	Wrist guard	Yes	Yes	Yes	Yes

Table I. Contd.

Year	Study	Sporting activity	Specific injury type of injured body region	Intervention	Definition of case-control	Matching	Adjustment of confounding	Assessment intervention
	[32]	Skiing/snowboarding	Head/neck	Helmet	Yes	Yes	No	Yes
	[31]	Skiing/snowboarding	Non- head/neck	Helmet	Yes	Yes	No	Yes
	[64]	Various	ACL tear	-	Yes	Yes	No	No
2004	[33]	Rugby union	Head	Helmet	Yes	No	No	Yes
	[65]	Skiing/snowboarding/skiboarding	All injuries	-	Yes	No	No	No
2002	[66]	Skiing/snowboarding	All injuries	-	Yes	No	No	No
2001	[28]	Not specified	Recurrent lower leg stress fractures	-	Yes	Yes	No	No
	[67]	Not specified	Knee	-	Yes	Yes	No	No

Table I. Contd.

Year	Study	Sporting activity	Specific injury type of injured body region	Intervention	Definition of case-control	Matching	Adjustment of confounding	Assessment intervention
2000								No
	[68]	Australian football	All injuries	-	Yes	No	No	No
1999	[69]	Skiing	All injuries	-	Yes	No	No	No
	[70]	Rugby	All injuries	-	Yes	No	No	No
1996	[40]	In-line skating	Wrist/elbow/knee/head	Wrist/elbow/knee pads	Yes	No	Yes	No
	[71]	Various	ACL	-	Yes	Yes	No	No
1994	[38]	Wrestling	Dental	Mouth guard	Yes	Yes	No	No
1993	[72]	Weightlifting	Spine	-	Yes	Yes	No	No

Table I. Contd.

Year	Study	Sporting activity	Specific injury type of injured body region	Intervention	Definition of case-control	Matching	Adjustment of confounding	Assessment intervention
1992	[41]	Handball	All injuries	Elbow protectors	Yes	Yes	Yes	No
1990	[29]	Various	Lower leg	-	Yes	Yes	No	No
1989	[73]	Downhill skiing	All injuries	-	Yes	No	Yes	No

* The term “helmet” includes all forms of protective headgear

Table II. Optimal case and control selection strategies in studies of intervention effectiveness for preventing impact injuries

Approach	Selection approach	Outcome Impact injury to specified body region	Exposure Relevant intervention used^	Consideration of global injury mechanism	Comment*
Cases	Both (traditional and new)	Yes	No	Implied	would not have had injury (and hence be a case) if they had not impacted this body region
		Yes	Yes	Implied	
Controls	Traditional - epidemiological considerations alone	No	No	No	
		No	Yes	No	
	New - combination of biomechanical and epidemiological considerations	No	No	Yes	controls required to have impacted this body region, but not sustained an injury
		No	Yes	Yes	controls required to have impacted this body region but not sustained an injury even though they were using/exposed to the relevant intervention

* Even further than only considering an impact to have occurred, the severity of the impact in terms of impact velocity or energy could be controlled for.

^ Relevant intervention means relevant to the body part/injury under investigation. For example, wearing a helmet would not be relevant to the incidence of impact-related knee injury

Table III. Control selection in published headgear intervention effectiveness case and control studies

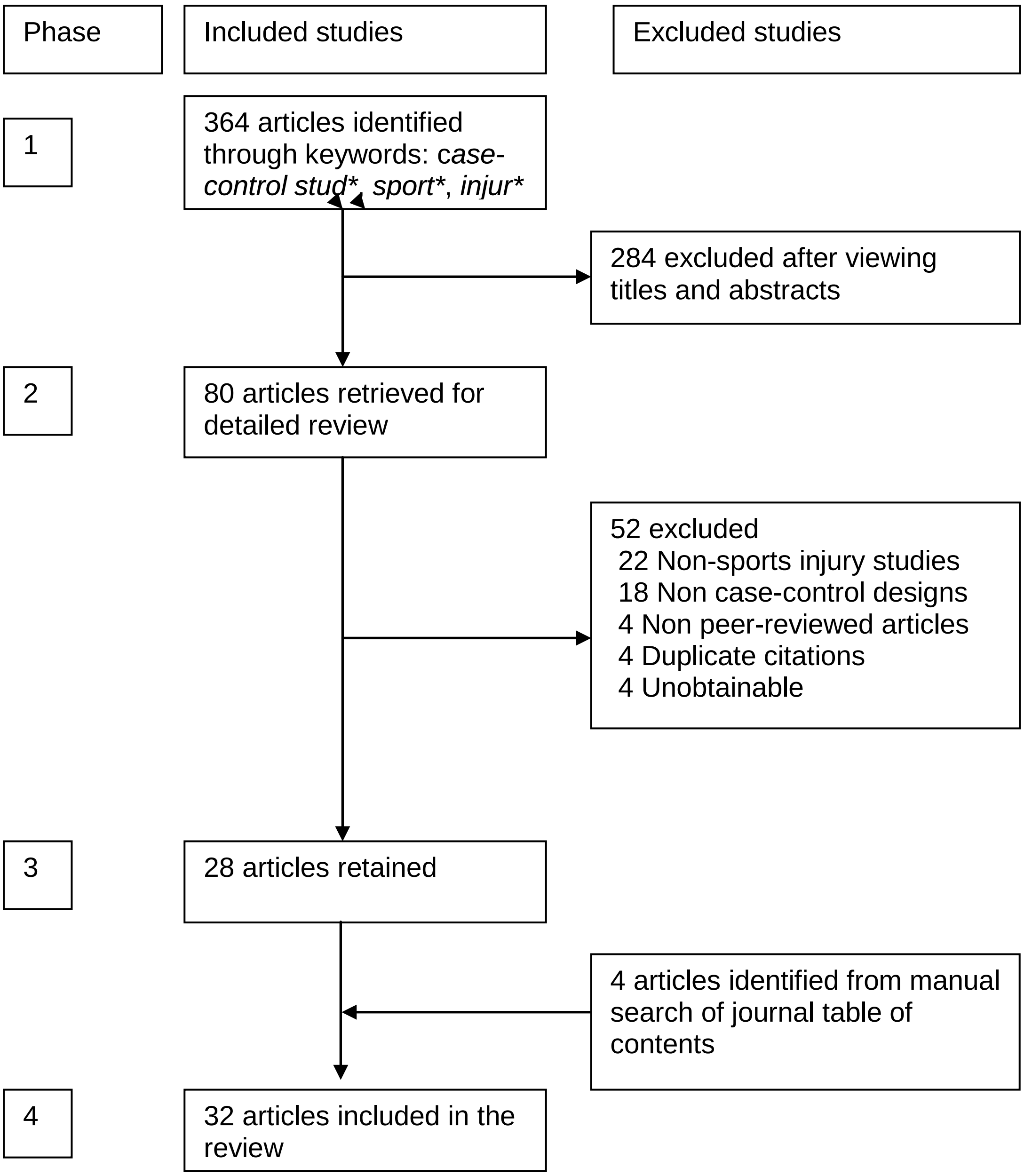
Study	Case definition	Control definition	Underlying global injury mechanism for BOTH case and control selection	Improved control choice (in addition to not having the injury of interest)
Rugby union, South Wales, [33]	Players with a superficial head or facial injury (abrasion, laceration or fracture) presenting to an emergency department for treatment	The injured player's opponent playing in the same position during the injury game	No	Player in same position, sustained impact to the head and specific game event
Skiers/snowboarders, Quebec, Canada [32]	Injured skiers/snowboarders with a completed ski patrol accident report for a head (incl. face) or neck injury	Non-head/non-neck injured skiers/snowboarders with a completed ski patrol accident at the same ski areas	No	Skier/Snowboarder, by age, experience, ski area, sustained impact to the head, and impacted object descriptor
Skiers/snowboarders, Quebec, Canada [31]	Injured skiers/snowboarders with a completed ski patrol accident report for a non-head/non-neck injury. Group 1: severe injuries (evacuation by ambulance, admission to hospital or time loss >7days from normal activities). Group 2: high – energy crash circumstances	Injured skiers/snowboarders with a completed ski patrol accident report for a non-head/non-neck injury but who did not belong in either Group 1 or Group 2 cases.	Only partially in terms of identifying high-energy crashes. Assumption is that because they did not have head/neck injuries then they did not sustain an impact to those regions.	As above

Table III (cont.)

Study	Case definition	Control definition	Underlying global injury mechanism for BOTH case and control selection	Improved control choice (in addition to not having the injury of interest)
Skiers/snowboarders, Norway [35]	Injured skier/snowboarder who was treated by, or consulted with, the ski patrol or first aid room staff after an incident in the skiing area during skiing or lift transport	Random sample of non-injured skiers/snowboarders as they entered the bottom of the main ski lift at each resort	No	As above, but could include skiers despite injury, if impact descriptors known
Skiers/snowboarders, Western United States [34]	Injured skiers/snowboarders with an injury to the head/face or neck reported by ski patrol, associated with a fall or collision.	Injured skiers/snowboarders with injuries below the neck reported by ski patrol, associated with a fall or collision.	No	Skier/snowboarder matched for age, experience, ski area, sustained impact to the head, and impacted object descriptor

K. FIGURES

Figure 1



L. SUPPLEMENTAL DIGITAL CONTENT

None