Summary and agreement statement of the 2nd International Conference on Concussion in Sport, Prague 2004

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BACKGROUND PERSPECTIVE

In November 2001, the 1st International Symposium on Concussion in Sport was held in Vienna, Austria to provide recommendations for the improvement of safety and health of athletes who suffer concussive injuries in ice hockey, football (soccer), and other sports. The 2nd International Symposium on Concussion in Sport was organised by the same group and held in Prague, Czech Republic in November 2004. It resulted in a revision and update of the Vienna consensus recommendations, which are presented here.

BACKGROUND ISSUES

Definition of concussion

Over 35 years ago, the Committee on Head Injury of the Congress of Neurological Surgeons proposed a “consensus” definition of concussion. This definition was recognised as having a number of limitations in accounting for the common symptoms of concussion. In the Vienna document, a revised consensus definition was proposed as follows: “Sports concussion is defined as a complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces”. Several common features that incorporate clinical, pathological, and biomechanical injury constructs that may be used in defining the nature of a concussive head injury include the following.

1. Concussion may be caused by a direct blow to the head, face, neck, or elsewhere on the body with an “impulsive” force transmitted to the head.
2. Concussion typically results in the rapid onset of short lived impairment of neurological function that resolves spontaneously.
3. Concussion may result in neuropathological changes, but the acute clinical symptoms largely reflect a functional disturbance rather than structural injury.
4. Concussion results in a graded set of clinical syndromes that may or may not involve loss of consciousness. Resolution of the clinical and cognitive symptoms typically follows a sequential course.
5. Concussion is typically associated with grossly normal structural neuroimaging studies.

No changes were made to the definition by the Prague Group beyond noting that in some cases post-concussive symptoms may be prolonged or persistent.
Pathophysiological basis of concussion
At this time, there is no existing animal or other experimental model that accurately reflects a sporting concussive injury. It is noted that, in experimental models, of more severe injury a complex cascade of biochemical, metabolic, and gene expression changes occur. Whether similar metabolic changes occur in sports concussion, however, remains speculative at this time.5

Concussion grading scales
The Vienna recommendation that injury grading scales be abandoned in favour of combined measures of recovery in order to determine injury severity (and/or prognosis) and hence individually guide return to play decisions received continued support.
It was also noted that concussion severity can only be determined in retrospect after all concussion symptoms have cleared, the neurological examination is normal, and cognitive function has returned to baseline.6 There is limited published evidence that concussion injury severity correlates with the number and duration of acute concussion signs and symptoms and/or degree of impairment on neuropsychological testing.9, 10 The development of validated injury severity scales continues in the published literature.11

Subtypes of concussion
One of the issues speculated on at the Vienna conference was whether concussion represents a unitary phenomenon with a linear spectrum of injury severity or whether different concussion subtypes exist. These subtypes may represent differences in clinical manifestations (confusion, memory problems, loss of consciousness), anatomical localisation (such as cerebral versus brainstem), biomechanical impact (rotational versus linear force), genetic phenotype (apolipoprotein epsilon 4 (ApoE4) positive versus ApoE4 negative), neuropathological change (structural injury versus no structural injury), or an as yet undefined difference. These factors may operate independently or interact with each other. It is clear that the variations in clinical outcome with the same impact force require a more sophisticated approach to the understanding of this phenomenon than currently available.12

Significance of loss of consciousness
The traditional approach to severe traumatic brain injury using loss of consciousness as the primary measure of injury severity has acknowledged limitations in assessing the severity of sporting concussive injury. Findings in this field describe association of loss of consciousness with specific early deficits but does not necessarily imply severity.13 15 As such the presence of loss of consciousness as a symptom would not necessarily classify the concussion as complex (see below).

Significance of amnesia
There is renewed interest in the role of post-traumatic amnesia and its role as a surrogate measure of injury severity.15 16 Published evidence suggests that the nature, burden, and duration of the clinical post-concussive symptoms may be more important than the presence or duration of amnesia alone.6 15 17 Further it must be noted that retrograde amnesia varies with the time of measurement after the injury and hence is poorly reflective of injury severity.19 20

Paediatric concussive injury
The general recommendations outlined in the Vienna document were originally designed for the management of adult sporting concussion. Agreement was reached, however, that identified those recommendations as relevant and useful to management of children as well. In broad terms it was felt that the recommendations should be applicable to children (defined as 5–18 years of age) whereby children should not be allowed to return to play or training until clinically completely symptom free. In addition, the concept of “cognitive rest” was introduced with special reference to a child’s need to limit exertion with activities of daily living and to limit scholastic activities while symptomatic. There was also a recognition by the group that additional research is needed to better clarify the potential differences between adults and children with regard to recovery from injury and to develop cognitive assessment tools that better evaluate the younger athlete.

Formal cognitive assessment is currently problematic until late teen years because of the continuing cognitive maturation that occurs during this period, which, in turn, makes the utility of comparison with either the person’s own baseline performance or population norms limited.20 Because of the different physiological response during childhood to head trauma, a conservative return to play approach is recommended. It may be appropriate to extend the amount of time of asymptomatic rest and/or the length of the graded exertion in children and adolescents. Future research is needed in this area.

A NEW CLASSIFICATION OF CONCUSSION IN SPORT
Historically, concussions have been classified with a number of different grading systems. In the Vienna Statement, this approach was abandoned. One of the key developments by the Prague Group is the understanding that concussion may be categorised for management purposes as either simple or complex.

Simple concussion
In simple concussion, an athlete suffers an injury that progressively resolves without complication over 7–10 days. In such cases, apart from limiting playing or training while symptomatic, no further intervention is required during the period of recovery, and the athlete typically resumes sport without further problem. Formal neuropsychological screening does not play a role in these circumstances, although mental status screening should be a part of the assessment of all concussed athletes. Simple concussion represents the most common form of this injury and can be appropriately managed by primary care physicians or by certified athletic trainers working under medical supervision.21 The cornerstone of management is rest until all symptoms resolve and then a graded programme of exertion before return to sport. All concussions mandate evaluation by a medical doctor.

Complex concussion
Complex concussion encompasses cases where athletes suffer persistent symptoms (including persistent symptom recurrence with exertion), specific sequelae (such as concussive convulsions), prolonged loss of consciousness (more than one minute), or prolonged cognitive impairment after the injury. This group may also include athletes who suffer multiple concussions over time or where repeated concussions occur with progressively less impact force. In this group, there may be additional management considerations beyond simple return to play advice. Formal neuropsychological testing and other investigations should be considered in complex concussions. It is envisaged that such athletes would be managed in a multidisciplinary manner by doctors with specific expertise in the management of concussive injury such as a sport medicine doctor with experience in concussion, sports neurologist, or neurosurgeon.
CLINICAL ISSUES
Pre-participation physical examination
Recognising the importance of concussion history, and appreciating the fact that many athletes will not recognise all the concussions they may have suffered in the past, a detailed concussion history is of value. Such a history may identify athletes that fit into the “complex” category outlined above and provides an opportunity for the doctor to educate the athlete about the significance of concussive injury.

A structured concussion history should include specific questions as to previous symptoms of a concussion, not just perceived number of past concussions. It is also worth noting that dependence on the recall of concussive injuries by team mates or coaches has been shown to be unreliable. The clinical history should also include information about all previous head, face, or neck injuries, as these may have clinical relevance to the present injury. It is worth emphasising that, with maxillofacial and neck injuries, co-existent concussive injuries may be missed unless specifically assessed. Specific questions pertaining to disproportionate impact versus symptom severity matching may alert the clinician to a progressively increasing vulnerability to injury.

As part of the clinical history, it is advised that details on protective equipment used at the time of injury be sought, both for recent and remote injuries. The benefit of this approach allows modification and optimisation of protective behaviour and an opportunity for education.

It is specifically recommended that:

1. both a baseline cognitive assessment (such as the Prague SCAT test in the absence of computerised neuropsychological testing) and symptom score is performed as part of the pre-participation evaluation;
2. although formal baseline neuropsychological screening may be beyond the resources of many sports or individual athletes, it is recommended that, in organised high risk sports, consideration be given to having cognitive evaluation regardless of the age or level of performance.

Signs and symptoms of acute concussion
The suspected diagnosis of sports concussion made on the sideline is applicable to both medical and non-medical personnel and can include clinical symptoms, physical signs, cognitive impairment, and/or loss of consciousness.

If any one of the following symptoms or problems is present, a head injury should be suspected and appropriate management instituted. These will be summarised on the sideline concussion assessment tool (SCAT) that accompanies this document (fig 1).

(a) Cognitive features (see below)
- Unaware of period, opposition, score of game
- Confusion
- Amnesia
- Loss of consciousness
(b) Typical symptoms (see SCAT (fig 1) for standard symptom scale); other symptoms such as a subjective feeling of slowness and fatigue after an impact may indicate that a concussion has occurred or has not fully resolved.
- Headache or pressure in the head
- Balance problems or dizziness
- Nausea
- Feeling “dinged”, “foggy”, stunned, or “dazed”
- Visual problems—for example, seeing stars or flashing lights, double vision
- Hearing problems—for example, ringing in the ears
- Irritability or emotional changes
(c) Physical signs
- Loss of consciousness/impaired conscious state
- Poor coordination or balance
- Concussive convulsion/impact seizure
- Gait unsteadiness/loss of balance
- Slow to answer questions or follow directions
- Easily distracted, poor concentration
- Displaying inappropriate emotions—for example, laughing, crying
- Vomiting
- Vacant stare/glassy eyed
- Slurred speech
- Personality changes
- Inappropriate playing behaviour—for example, running in the wrong direction
- Significantly decreased playing ability

Sideline evaluation of cognitive function is an essential component in the assessment of this injury. Brief neuropsychological test batteries that assess attention and memory function have been shown to be practical and effective. Such tests include the Maddocks questions and the Standardised assessment of concussion. It is worth noting that standard orientation questions—for example, time, place, person—have been shown to be unreliable in the sporting situation when compared with memory assessment.

It is recognised, however, that abbreviated testing paradigms are designed for rapid concussion evaluation on the sidelines and are not meant to replace comprehensive neuropsychological testing, which is sensitive enough to detect subtle deficits that may exist beyond the acute episode, nor should they be used as a stand alone tool for the ongoing management of sports concussions. It should also be recognised that the appearance of symptoms may be delayed several hours after a concussive episode.

Convulsive and motor phenomena
A variety of acute motor phenomena—for example, tonic posturing—or convulsive movements may accompany a concussion. Although dramatic, these clinical features are generally benign and require no specific management beyond the standard treatment for the underlying concussive injury.

Development of the sport concussion assessment tool (SCAT)
Figure 1 outlines the SCAT. The intent was to create a standardised tool that could be used for patient education as well as for physician assessment of sports concussion. The SCAT was developed by combining the following existing tools into a new standardised tool:

1. Sideline evaluation for concussion.
Sports concussion is defined as a complex physiological process affecting the brain, induced by traumatic biomechanical forces. Several common features that incorporate clinical, pathological, and biomechanical injury constructs that may be utilized in defining the nature of a concussive head injury include:

1. Concussion may be caused either by a direct blow to the head, face, neck, or elsewhere on the body with an "impulsive" force transmitted to the head.
2. Concussion typically results in the rapid onset of short-lived impairment of neurological function that resolves spontaneously.
3. Concussion may result in a neuropsychological, changes but the acute clinical symptoms largely reflect a functional disturbance rather than structural injury.
4. Concussion results in a graded set of clinical syndromes that may or may not involve loss of consciousness. Resolution of the clinical and cognitive symptoms typically follows a sequential course.
5. Concussion is typically associated with grossly normal structural neuroimaging studies.

Post Concussion Symptoms
Ask the athlete to score themselves based on how they feel now. It is recognized that a low score may be normal for some athletes, but clinical judgment should be exercised to determine if changes in symptoms have occurred following the suspected concussion event.

It should be recognized that the reporting of symptoms may not be entirely reliable. This may be due to the effects of a concussion or because the athlete's desire to return to competition outweighs their natural inclination to give an honest response.

If possible, ask someone who knows the athlete well about changes in appearance, personality, behavior, etc.

Remember, concussion should be suspected in the presence of ANY ONE or more of the following:
- Symptoms (such as headache), or
- Signs (such as loss of consciousness), or
- Memory problems.
Any athlete with a suspected concussion should be monitored for deterioration (i.e., should not be left alone) and should not drive a motor vehicle.


What should I do?
Any athlete suspected of having a concussion should be removed from play, and seek medical evaluation.

Signs to watch for:
Problems could arise over the first 24-48 hours. You should not be left alone and must go to a hospital at once if you:
- Have a headache that gets worse
- Are very drowsy or can’t be awakened (woken up)
- Can’t recognize people or places
- Have repeated vomiting
- Behave unusually or seem confused; are very irritable
- Have seizures (arms and legs jerk uncontrollably)
- Have a weak or numb arm or leg
- Are unsteady on your feet; have slurred speech

Remember, it is better to be safe. Consult your doctor after a suspected concussion.

What can I expect?
Concussion typically results in the rapid onset of short-lived impairment that resolves spontaneously over time. You can expect that you will be told to rest until you are fully recovered (that means resting your body and your mind). Then, your doctor will likely advise that you go through a gradual increase in exercise over several days (or longer) before returning to sport.
Figure 1

RETURN TO PLAY

6. Medical clearance should be given before return to play.
7. Return to competition (game play).
8. Return to full sport-specific training.
9. Return to full neuromotor training (e.g., stationary cycling).
10. Return to full sport-specific strength training.
11. Return to full sport-specific skill training.
12. Return to full sport-specific performance (e.g., game play).
13. Return to full sport-specific activity (e.g., game play).

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13. Return to full sport-specific activity (e.g., game play).

The SCAT Card

Medical Evaluation

Date:

Name:

Scorer:

Instructions: The SCAT Card is an aid for the evaluation of athletes returning from a period of medical absence. It is strongly suggested that all athletes participating in the SCAT Card for return to play assessment. The SCAT Card is a suggested guide only for sport concussion and is not to be used for the diagnosis of concussion. The SCAT Card is to be used to document the athlete's return to play after a period of medical absence.

Scoring:

1. Mild gray to white (0 points)
2. Moderate gray to white (1 point)
3. Severe gray to white (2 points)
4. Very severe gray to white (3 points)
5. Critical gray to white (4 points)

For more information, see the Summary and Agreement Statement for the Second International Conference on Sport Concussion in Long Island, NY, 2004.

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INVESTIGATIONAL ISSUES

Neuropsychological assessment after concussion

The application of neuropsychological testing in concussion has been shown to be of value and continues to contribute significant information in concussion evaluation. It has been shown that cognitive recovery may precede or follow clinical symptom resolution, suggesting that the assessment of cognitive function should be an important component in any return to play protocol. It must be emphasised, however, that neuropsychological assessment should not be the sole basis of a return to play decision but rather be seen as an aid to the clinical decision making. Although neuropsychological screening may be performed or interpreted by other healthcare professionals, the final return to play decision should remain a medical one in which a multidisciplinary approach has been taken.

Neuropsychological testing should not be performed while the athlete is symptomatic because it adds nothing to return to play decisions, and it may contaminate the testing process by allowing practice effects to confound the results. In certain cases, however, serial follow up after the injury is valuable, both as a means to encourage athlete compliance and for comparison purposes. Over-riding principles common to all neuropsychological test batteries is the need for and benefit of baseline testing before injury and serial follow up. Recent work with computerised platforms, however, suggests that performance variability may be a key measure for acute concussion diagnosis even in the absence of a baseline test. This strategy is currently the subject of research. Inherent problems with most neuropsychological tests include the normal ranges, sensitivity and specificity of tests, and practice or learning effect, as well as the observation that players may return to baseline while still symptomatic. Computerised testing using infinitely variable test paradigms may overcome some of these concerns. Computerised testing also has the logistical advantage that the tests may be administered by the team doctor (or be web based) rather than requiring a neuropsychologist for a formal assessment. The strengths and weaknesses of such testing have been reviewed.

It is recommended that neuropsychological testing remain one of the cornerstones of concussion evaluation in complex concussion. It is not currently regarded as important in the evaluation of simple concussion. Although this modality contributes significantly to both the understanding of the injury and management of the individual athlete, neuropsychological testing should not be the sole basis of management decisions, either for continued time out or return to play decisions.

Objective balance assessment

Balance testing, either with computerised platforms or clinical assessment, may offer additional information in concussed athletes and may be used as a part of the overall concussion management strategy, particularly where symptoms or signs indicate a balance component.

Neuroimaging

It was recognised in the Vienna agreement document that conventional structural neuroimaging is usually normal in concussive injury. Given that caveat, the following suggestions are made. Computed tomography (or, where available, magnetic resonance imaging) of the brain contributes little to concussion evaluation, but should be used whenever suspicion of an intracerebral structural lesion exists. Examples of such situations may include prolonged disturbance of conscious state, focal neurological deficit, or worsening symptoms. Newer structural magnetic resonance imaging modalities, including gradient echo, perfusion, and diffusion weighted imaging, have greater sensitivity for structural abnormalities, but the lack of published studies as well as the absence of pre-injury neuroimaging data limits the usefulness of this approach in clinical management at the present time.

In addition, the predictive value of various magnetic resonance imaging abnormalities that may be incidentally discovered is not established. Although there have been some compelling findings with promising new functional imaging technologies—for example, positron emission tomography (PET), single photon emission computed tomography (SPECT), and functional magnetic resonance imaging (fMRI)—they are still at early stages of development.

Although neuroimaging may play a part in the assessment of complex sports concussions or more severe brain injury, it is not essential for simple concussive injury.

Genetic testing

Genotyping has been shown to be of benefit in traumatic brain injury. Published studies have shown that ApoE4 is a risk factor for adverse outcome after all levels of brain injury. Similarly ApoE4 has been shown to be a risk factor for the development of chronic traumatic encephalopathy in boxers. The significance of ApoE4 in sports concussion risk or injury outcome is unclear. Other published studies have noted the association of a particular calcium subunit gene abnormality with brain swelling after minor head trauma. Although still in the early stages of understanding, routine genetic screening cannot be recommended at the present time. Furthermore, doctors are urged to be mindful of the ethical implications of such testing.

Experimental concussion assessment modalities

Different electrophysiological recording techniques such as evoked response potential and electroencephalogram have shown reproducible abnormalities in the post-concussive state. However, not all studies reliably differentiated concussed athletes from controls. The clinical significance of these changes remains to be established.

In addition, biochemical serum markers of brain injury (including S-100b, NSE, MBP, GFAP) have been proposed as means by which cellular damage may be detected if present. However, there is currently not sufficient evidence to justify the use of these markers clinically.

CONCUSSION MANAGEMENT

Acute injury

When a player shows any symptoms or signs of a concussion, the following should be applied.

(1) The player should not be allowed to return to play in the current game or practice.
(2) The player should not be left alone, and regular monitoring for deterioration is essential over the initial few hours after injury.
(3) The player should be medically evaluated after the injury.
(4) Return to play must follow a medically supervised stepwise process.

A player should never return to play while symptomatic. “When in doubt, sit them out!”

**Return to play protocol**

As described above, most injuries will be simple concussions, and such injuries recover spontaneously over several days. In these situations, it is expected that an athlete will proceed rapidly through the stepwise return to play strategy.60

During this period of recovery in the first few days after an injury, it is important to emphasise to the athlete that physical and cognitive rest is required. Activities that require concentration and attention may exacerbate the symptoms and as a result delay recovery.

The return to play after a concussion follows a stepwise process:

(1) No activity, complete rest. Once asymptomatic, proceed to level 2.
(2) Light aerobic exercise such as walking or stationary cycling, no resistance training.
(3) Sport specific exercise—for example, skating in hockey, running in soccer; progressive addition of resistance training at steps 3 or 4.
(4) Non-contact training drills.
(5) Full contact training after medical clearance.
(6) Game play.

With this stepwise progression, the athlete should continue to proceed to the next level if asymptomatic at the current level. If any post-concussion symptoms occur, the patient should drop back to the previous asymptomatic level and try to progress again after 24 hours.

In cases of complex concussion, the rehabilitation will be more prolonged, and return to play advice will be more circumspect. It is envisaged that such cases should be managed by doctors with a specific expertise in the management of such injuries.

An additional consideration in return to play is that concussed athletes should not only be symptom-free but also should not be taking any pharmacological agents/drugs that may affect or modify the symptoms of concussion. If antidepressant treatment is started during the management of a complex concussion, the decision to return to play while still receiving such medication must be considered carefully by the clinician concerned (see below).

In professional sport, where there are team doctors experienced in concussion management as well as access to immediate—that is, sideline—neurocognitive assessment, return to play management is often more rapid, but it must still follow the same basic principles, namely full clinical and cognitive recovery before consideration of return to play.

**Role of pharmacological treatment**

Pharmacological treatment in sports concussion may be applied in two distinct situations: (a) management of specific symptoms—for example, sleep disturbance, anxiety—in complex concussion; (b) to modify the underlying pathophysiology of the condition with the aim of shortening the duration of the concussion symptomatology.61

In broad terms, this approach to management should be only considered in complex sports concussions and by clinicians experienced in concussion management.

**Sports psychology**

In addition, sport psychology approaches may have potential application in this injury, particularly in complex concussion.62 Caregivers are also encouraged to evaluate the concussed athlete for affective symptoms such as depression as these may be common in concussion.69

**OTHER ISSUES**

**Prevention**

There is no clinical evidence that currently available protective equipment will prevent concussion. In certain sports, protective equipment may prevent other forms of head injury which may be an important issue for those sports.

Consideration of rule changes—for example, no head checking in ice hockey—to reduce the head injury rate may be appropriate where a clear-cut mechanism is implicated in a particular sport. Similarly, rule enforcement is a critical aspect of such approaches, and referees play an important role.

An important consideration in the use of protective equipment is the concept of risk compensation.65 This is where the use of protective equipment results in behavioural change such as the adoption of more dangerous playing techniques, which can result in a paradoxical increase in injury rates. This may be a particular concern in child and adolescent athletes in whom head injury rates are often higher than in adult athletes.66

**Medicolegal considerations**

Although agreement exists on the principal messages conveyed in this document, we acknowledge that the science of concussion is at an early stage, and therefore management and return to play decisions remain largely in the realm of clinical judgment on an individualised basis.

**Education**

As the ability to treat or reduce the effects of concussive injury after the event is minimal, education of athletes, colleagues, and the general public is a mainstay of progress in this field. Athletes and their healthcare providers must be educated about the detection of concussion, its clinical features, assessment techniques, and principles of safe return to play. Methods to improve education including web based resources, educational videos, and international outreach programmes such as Think First (www.thinkfirst.ca) are important in delivering the message. In addition, concussion working groups plus the support and endorsement of enlightened sport groups such as FIFA, IOC, and IIHF who initiated this endeavour have enormous value and must be pursued vigorously.

The promotion of fair play and respect for opponents are ethical values that should be encouraged in all sports and sporting associations. Similarly coaches, parents, and managers play an important part in ensuring that these values are implemented on the field of play.

**Research methods**

A number of research protocols and data evaluating concussion injury assessment, injury susceptibility, and brain function after injury were presented at both the Vienna and Prague conferences. Although they offer great potential for injury assessment, all of these techniques must be considered experimental at this time. Elite and professional teams are well placed to contribute to these efforts through athlete
Concussion in sport

Future

The issue of sports concussion management is continually evolving, and the usefulness of expert consensus in establishing a standard of care has been demonstrated by the Vienna agreement. The consensus group established at that meeting has provided continuing leadership in this field based on the initial mandate established at that time. We expect that this Prague agreement will be revised and updated at future meetings.

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REFERENCES


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Human articular cartilage fails to respond to physical training

An in vivo study has suggested that the amount human articular cartilage deforms after exercise is independent of physical training, as shown by responses of patellar and femorotibial cartilage between professional athletes and others.

Deformity of patellar cartilage ranged from −5.9% to −2.8%, in a dose dependent manner, for various activities in 12 healthy young volunteers (−5.9% knee bends, −5.0% running, −4.7% squatting, −4.5% cycling, and +2.8% walking). Deformity of femorotibial cartilage, however, was greatest for high impact loading—as in jumps from 40 cm height (−7.0%)—but small for other activities. There was no significant difference in deformity of patellar cartilage in weightlifters (−2.9%), bobsleigh sprinters (−3.9%), or non-athletes (−4.1%).

Deformity was measured by magnetic resonance imaging and three dimensional image analysis before and after exercise. Of the 50 volunteers, six men and six women did patellar exercises and five men and five women femorotibial exercises (knee bends, (one leg) static loading of weight, and jumps from 40 cm height onto one leg. Seven weightlifters and seven bobsleigh sprinters were compared with 14 healthy young men for deformity of patellar cartilage induced by knee bends.

This is the first in vivo study of human patellar and femorotibial cartilage response to such a wide range of physical activities. The authors hypothesised from animal studies that physical training would result in less deformity, but this seems not to be true for humans. Understanding how cartilage behaves in vivo is important for understanding the process of osteoarthritis and the local environment of transplanted cartilage.