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Abstract.

A review was completed to study the prevalence of musculoskeletal injuries in golf and to stimulate the discussion on possible injury mechanisms. The main conclusion of most published studies is that, although professional and amateur golfers show similar anatomical distribution of injuries by body segment, differences tend to be present in the ranking of injury occurrence by anatomical site. This could be explained as a result of several types of variables, like handicap, age, golf swing biomechanics, and training or playing habits. The impact of golf injuries deserves extra attention, namely the interaction between the nature of the injury, practice routines, level of practice, handicap, and frequency of activity. Individual differences and clinical and coaching procedures claim for prospective investigation. Other epidemiological information should still be regarded as insufficient with respect to a full comprehension of injury mechanisms, which can give us a better insight into the evolutionary nature of the injury. Also, a better understanding of golf swing mechanisms and individual neuromuscular aspects can help explain why some individuals are more injury-prone than others.

1. Introduction

Over the last decade, considerable attention has been given to the worldwide increase in popularity and attractiveness of golf to new players of different ages, skills and socioeconomic levels (Farrally *et al*., 2003; Fradkin, Windley, Myers, Sell & Lephart, 2007; Gluck, Bendo & Spivak, 2008; Sell, Tsai, Smoliga, Myers & Lephart, 2007; Theriault & Lachance, 1998). In the United States alone, the number of golf players is estimated to be more than 25 million (Stude & Gullickson, 2001). Within Europe, this number approaches 7 million, and in Germany the number of golfers has doubled since 1990, with 370,490 registered in 2000, a consistent increase of up to 10% per year (Gosheger, Liem, Ludwig, Greshake & Winkelmann, 2003). In more recent studies, the worldwide estimated number of golfers is 55 million (Farrally *et al*., 2003).

The number of golf courses is increasing steadily, also. In the US and Canada alone more than 400 to 600 golf courses are constructed each year (Knopper & Lean, 2004). Consequently, in a period of over ten years, the number of new golf courses within the US, Europe and Asia approximated 4000, 2000 and 1000, respectively (Farrally *et al*., 2003), resulting in a higher accessibility which has lead to the appearance of more and more participants.

With this increase of accessibility and participation, a multiplication of injuries is to be expected. Additionally, in golf, high performance and skill have limited ageing effects, and a player's career can span for more than 50 years, resulting in a wide variety of player profiles with diverse physical, psychological, socioeconomic, nutritional, and functional conditions. While enjoying the game for decades, both the professional and the persistent golfer show tremendous variations in practice level, competitive experience, intensity and frequency of practice. This can help explain why golf may represent itself as one of the most diverse sports activities, and may also reflect the diversity of musculoskeletal problems one may encounter in the game of golf (Farrally *et al*., 2003; McHardy, Pollard & Luo, 2006).

Various reports with respect to golf injuries and its prevalence and/or incidence were published in the last decade with various results of outcome measures (Faustin *et al*., 2007;

Finch *et al*., 1999; Gosheger *et al*., 2003; Grimshaw *et al*., 2002; Grinell, 1999; Hosea & Gatt, 1996; Kim *et al*., 2004; McCarroll, 2001; McHardy, Pollard & Luo, 2006, 2007; McHardy & Pollard, 2004, 2005; McNicholas *et al*., 1999; Stockard, 2001; Sugaya, 1999; Theriault & Lachance, 1998; Vad, *et al*., 2004; Wiesler & Lumsden, 2005). However, if there is one outcome all these studies have in common, it is the belief that golf injuries should not be undervalued, as they are often used as justification for missing tournaments or playing at an unsatisfactory level over a reduced period of time.

The aim of the present paper is to review the available epidemiological data in the scientific literature in order to establish the prevalence of musculoskeletal injuries in golf, and to discuss possible mechanisms of injury occurrence. This may help the reader to advise on possible strategies involving prevention, rehabilitation and/or enhancement of golf performance.

2. Methods

The electronic databases PubMed and Scopus were searched for relevant publications from 1989 to 2008 using the key words "*golf* AND *[injur*]*". Additionally, screening was performed electronically at GoogleScholar as well as ISI Web of Science, in order to match the references found.

Inclusion criteria of these articles were: having epidemiological data (prevalence, incidence, occurrence) on injuries in golf players, either by survey, interview, observation, or any mean that would lead to a plausible description of injury; from amateur and/or professional golf players, both genders, all ages; languages: English, German, French, Portuguese, Dutch and Spanish. Two exclusion criteria were also adopted: articles with anecdotic injury data, not founded on a methodology specifically aimed at the golf play (driving range and/or golf course), for example merely biomechanical studies, popular (media) articles and so on; publications in other languages, not mentioned in the inclusion criteria.

The search described above resulted in a total of 547 references. After importing all references found using a reference manager software (Papers v.1.8.6, Mekentosj B.V., The Netherlands), duplicates were eliminated either automatically or manually. The remaining 317 articles were then screened according to title and abstract for relevance, which revealed that 204 could be eliminated from our database. The full text of the selected 113 articles was then read and again 54 could be rejected because of lack of relevance to golf injuries. At the end of the screening procedure, 59 articles were withheld for further in-depth reading and analysis for our systematic review (Figure 1). Four additional citations were collected from the references of the papers found electronically. As such, 63 articles were withheld for the discussion which follows below.

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3. Results

3.1. Golf injuries in general

In general, golf is considered to be a moderate risk activity for sport injury. Injuries originate either from overuse or from a traumatic cause, and primarily affect the elbow, wrist, shoulder and dorso-lumbar sites. Professional and weekend golfers tend to present differences in the ranking of injury occurrence by anatomical site; this can probably be explained by their playing habits and the biomechanical characteristics of their golf swing (Theriault & Lachance, 1998).

The annual prevalence of golf related injuries in amateur players is estimated to be between 25.2 and 62%, with minor gender differences (McCarroll, 1996; McCarroll *et al*., 1990; Theriault & Lachance, 1998). The main risk factors that may contribute to an increased prevalence are: a lower handicap (a proficiency measurement specific to golf), and age over 50 years. Older amateur golf players incur in a higher total number of injuries than their younger peers, and this can be attributed to physiological changes in the musculoskeletal system during ageing (Fradkin *et al.*, 2007; Soto-Quijano *et al.*, 2004).

Injury rates in amateur golfers may vary between 1.19 to 1.31 per golfer per year but in professional golfers this number is close to 2 per year, with a prevalence around 88%, which can be most likely associated with increased hours of play per day (Theriault & Lachance, 1998).

A study published in 2003 showed that the most common injuries in professional golfers were back injuries, followed by wrist and shoulder injuries. In contrast, injuries were distributed differently in amateur golfers, with the elbow being the most affected region, followed by the back and shoulder (Gosheger *et al*., 2003). A one-year prospective study in 2007 showed injury incidence rates in amateur golfers of 15.8 injuries per 100 golfers. The lower back was the most common injury site (18.3%), closely followed by elbow/forearm (17.2%), foot/ankle (12.9%), and shoulder/upper arm (11.8%) (McHardy *et al*., 2007).

Golf cart related injuries in the U.S. have increased over the past several years (Rahimi *et al*., 2005). Falling or jumping from a golf cart was the most common cause of injury for both adults and children, and the most common injury was soft tissue damage occurred to the legs and feet (Watson *et al.*, 2008).

However, generally speaking, golf can be regarded as a safe sporting activity. Golf injuries represent only 4% of all injuries encountered in a university hospital (McNicholas, *et al*., 1999) and have similar proportions to that for badminton and weight aerobics (in comparison, for instance, to the 30% football related injuries).

3.2. Groups at risk of golf injuries

As the game becomes more and more popular, different groups or types of golfers appear: the *occasional golfer*, the *recreational golfer* playing for health, pleasure and social reasons on a regular basis, and the *professional golfer* representing only a minor part of the golf population.

Occasional golfers may be prone to injuries related to ill-known rules of the game resulting in traumatic (impact) injuries (Fradkin *et al*., 2007) or to injuries related to badly executed golf swings, especially at ball impact (McHardy *et al*., 2006).

The recreational (amateur) players are, apart for overuse injuries commonly encountered due to various ill-known behaviors (lack of warming-up, reduced mobility and/or flexibility, no or badly executed strength training, lack of physical condition, etc.), additional victims of collision type of injuries (ball or club impacts). In this context, elderly golfers may represent a group at "higher than normal risk", showing problems not only associated to the game, but also to physiological factors related to ageing (see below). A survey conducted on recreational golfers observed that in 90% of cases golf is played at least 3 times a week, mostly for reasons that include social contact, exercise and, to a lesser extent, competition.

The competitive player (professional tour players, coaches and amateur competitive players) usually reports soft tissue and musculoskeletal injuries associated with overuse. Especially in short periods of intensive play or high number of practice hours that may lead to "imbalances" in the muscular system and thereby predisposing players to these overuse syndromes. The lower back seems to lead to more complaints than any other anatomical region (McHardy *et al*., 2006).

Very young players are rarely exposed to extreme overuse conditions, although no real epidemiological data are available until now. On the other hand, they are more likely to develop risk behaviors while using golf equipment, particularly boys between 5 and 9 years of age (Fradkin *et al*., 2005; Rahimi *et al*., 2005). Injuries in children and adolescents typically occur during unobserved play with golf clubs, and while standing too close to the golf player hitting the ball. The incurred injuries are generally severe head injuries and may even lead to death (Brian & Glazer, 2005; Finch *et al*., 1999; Fountas *et al*., 2006; Fradkin *et al*., 2005; Macgregor, 2002; Rahimi *et al*., 2005). Adults should be aware that there is a need for early tuition on the safety components of the game. Some studies have shown that in the younger groups injuries occur outside the golf course and, that the main motive is the unsupervised experimentation with golf clubs (Pennycook, Morrison & Ritchie, 1991; Ridenour, 1998).

Players using motorized golf carts should also be concerned with respect to the pediatric population, since careless driving and its inadequate use has been reported to result in serious traumatic injuries (Rahimi *et al*., 2005). Attention to community safety and awareness of correct storage of golf equipment, together with education of children regarding handling of the material used, are thought to be useful in preventing pediatric golf injuries (Fradkin *et al*., 2005).

An additional group that may be at a higher risk is composed of the golf course employees, especially when their tasks include heavy lifting or working in close proximity of a game. Furthermore, the use of toxic products for the maintenance of the golf course may present an additional health hazard, also (Knopper & Lean, 2004). However, this issue goes beyond the scope of the present review.

3.3. Injuries by Anatomical Location

An outline of injury distribution by anatomical location obtained from different published studies is provided in Table 1. From the overview of Table 1, it becomes clear that the most commonly injured location of the amateur golfer was respectively, the low back, the elbow, the wrist and the hand, and the shoulder. Conversely, the professional golf player injures himself more often at other anatomical locations. According to a more recent study (Gosheger *et al*., 2003), the anatomical regions where professional golfers showed a significantly higher percentage of injury were the head (50% higher!), the lumbar spine, and the wrist or the hand. In addition, at the professional level, the “handicap” or ranking seems not to make a significant difference in the injury rate.

Another remarkable observation is the fact that lower limb injury occurrence is far lower than upper limb and back problems, although a greater moment of force is reported both in the leading and the trailing leg (Gatt, Pavol, Parker & Grabiner, 1998).

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From the data from Gosheger *et al*. (2003), one may perceive that the main causes for the "absence of play" can be appointed to the injuries of the thoracic and lumbar spine, followed by elbow problems. A high percentage of chronic problems (lasting longer than one year) were localized at knee level and lower back.

Finch *et al*. (1999) revealed that low back pain in elite golfers is responsible for a reduction in participation or unsatisfactory play level of 55%. However, most of the injuries caused absence from no more than one month, and the most common injuries were minor ones, with less than one week of cessation of practice.

An overall picture of the number of days lost due to injuries by anatomical region was given by Gosheger *et al.* (2003). It is evident that injuries of the thoracic spine force the longest absence of play, expressed as time lost due to injury (137.4 days), followed by injuries of the elbow (73.8 days), and the lumbar spine (69.0 days). Wrist/hand and ankle/foot injuries cause an absence of respectively 55.2 and 55.9 days. Ribs, cervical spine and shoulder injuries require resting periods of 36.1 to 39.2 days, whereas hip and knee injuries inflict less time lost (20.5 and 21.9 days) (Gosheger *et al*., 2003).

3.3.1. Low back and trunk

Low back injuries range from 15.2% to 34 % of all golf injuries, and thus represent the most common musculoskeletal complaint experienced by both amateur and professional golf players (McCarroll, 1996; Vad *et al.*, 2004). The number of golfers with a history of low back pain may be as high as 55% (Sugaya, 1999), but it is not clear whether this prevalence is only related to the practice of golf (Fradkin *et al*., 2007; Lindsay & Horton, 2002; McCarroll *et al*., 1990; Vad *et al.*, 2004).

There seems to exist a significant higher prevalence of low back pain in professional golfers (Gosheger *et al.*, 2003; Sugaya, 1999), although inferior values were found in an older study (McCarroll, 1996). Symptoms or other type of subjective complaints are predominantly reported as coming from the right side (i.e. leading side for right handed players) of the spine, and symptom aggravation of right-side complaints usually occurs from ball impact until the follow-through.

Golfers with low back pain tend to flex their spines to a larger degree when addressing the ball, and use significantly more left side bending on the backswing, compared to healthy players (Lindsey & Horton, 2002). Furthermore, golfers with chronic low back pain tend to report increases in pain after a practice session, although abdominal muscle activity and muscle fatigue characteristics during the golf swing are quite similar compared with asymptomatic golf players after measuring repetitive swings (Horton, Lindsay & Macintosh, 2001).

Right-sided vertebral osteophyte formation at L3/L4 levels, as well as facet joint changes at L3/L4 and L4/L5 levels, are significantly higher in professional golfers, compared to a control group, indicating asymmetric degeneration of the spine (Sugaya, 1999). Golfers can also suffer from thoracic pain that appears due to stress fractures of the rib cage (postero-laterally), which can typically be found on the leading side (Metz, 1999). This injury can be related to a dramatic increase of playing and/or practice times, but may also be due to the constant activation of the (leading) serratus anterior muscle, producing extra stress to the ribs and possibly leading to fracture (Lord, Ha & Song, 1996).

3.3.2. Upper extremity

Shoulder injuries overall can range from 4% to nearly 19%. Most often, the injury is related to overuse and due to an excessive shoulder rotation, both at the beginning (external rotation) and at the end of the golf swing (internal rotation) (Theriault & Lachance, 1998). In many cases, the leading shoulder is the most affected, and shoulder pain may be the result of acromioclavicular problems such as impingement, rotator cuff tendonitis or tear, posterior glenuhumeral subluxation or arthritis. Instability resulting from isolated labrum tears has also been described, also (Faustin *et al*., 2007; Hovis *et al.*, 2002).

Elbow injuries may account for 7 to 27% of all injuries, and are considered to be the second most frequent anatomical region to be injured. Elbow injuries secondary to golfing are more common in the amateur than the professional players. The flexor and extensor tendons of the forearm are particularly prone to injury at their sites of attachment to the medial and lateral humeral epicondyles (Sutcliffe *et al*., 2008). Medial epicondylitis occurs most often in the right arm of a right handed golfer after excessive, repetitive muscular contractions or after sudden deceleration or forceful resistance is encountered by hitting the turf instead of the ball with the club head (Sutcliffe *et al*., 2008; Theriault & Lachance, 1998). Lateral epicondylitis also affects the amateur golfer more than the professional, and occurs in the leading elbow with equal frequency to medial epicondylitis in the lagging arm (Sutcliffe *et al*., 2008; Theriault & Lachance, 1998). The incidence seems to increase with age and the number of rounds played, with more than two to three rounds per week as a threshold for increased incidence (Gosheger *et al*., 2003). “Golfers elbow” or medial epicondylitis in the trailing arm, and “tennis elbow” or lateral epicondylitis in the leading arm are common elbow injuries (Grimshaw *et al.*, 2002; McCarroll, 1996, 2001; Stockard, 2001). It is interesting to note that, in amateurs, lateral epicondylitis is five times more prevalent than medial epicondylitis (Stockard, 2001).

Injuries at the level of the hand and wrist have also been described to occur in golf players: from subluxations of fingers (thumb), tenosynovitis of thumbs adductor and extensor tendons to (hair) fractures may occur, as a result of either overuse or through (repeated) forceful swings or swings with high impact on the ground (Mueller *et al.*, 2000; Rettig, 2004; Stockard, 2001).

3.3.3. Lower extremity

In general, lower limb injuries do not have a high prevalence in golf players. Hip injuries are not very common (see Table 1), although a high degree of rotation may occur during the golf swing. Trochanteric bursitis may be observed mostly in women (McCarroll, 1996) and is probably caused by walking on the uneven surfaces of a golf course. However, the reason why a higher incidence is found in women is not clear.

With respect to knee and ankle/foot injuries, most of the published studies are inconclusive as to their prevalence, despite the fact that some biomechanical studies demonstrated high torsional and compressive forces during the golf swing (Gatt *et al*., 1998), which may explain some of the mechanisms of lower limb injury (Theriault & Lachance, 1998). One study observed that golfers, having a knee or hip joint endo-prosthesis, may maintain their handicap and may even improve it after surgery (Suckel & Best, 2006). It must be stated here that the literature concerning lower extremity injuries and its mechanisms of occurrence in golf is rather scarce and that further studies in this field need to be encouraged.

3.4. Injury Distribution by Age

The average age for occasional golfers in the US is around 45 years, and one third of all American golfers are 50 years old or more (Stover & Stoltz, 1996). The professional golfer, on average, reaches its peak ability to score in Majors at 32 years of age, with the best scores being observed between 30-35 years (Berry & Larkey, 1999).

Golf players from 50 to 65 years old have a higher injury prevalence or distribution (Soto-Quijano, *et al*., 2004). However, this fact is questioned regarding its statistical significance (Gosheger *et al*., 2003). It is believed that players with an increased risk of osteoporosis should be cautioned about playing golf. Those who continue playing should participate in an appropriate exercise program and possibly utilize a thoraco-lumbar support while playing (Lindsay, Horton & Vandervoort, 2000) because of case studies published with multiple acute vertebral compression fractures and of stress fractures in golfers over 50. A study in older patients (mean age: 70 yrs) with total hip replacement (arthroplasty) demonstrated no significant change from pre-disease state to the 1-year postoperative golf performance and level of participation (Arbuthnot *et al.*, 2007). Furthermore, in the same study, Harris hip scores (a clinical tool for the evaluation of patients' hip condition) were significantly higher for the golfing population, both preoperatively and at all stages of follow up, in comparison to a sedentary group, indicating that elderly golfers may benefit from this low impact activity already 6 months after surgery.

The senior golfer is susceptible to additional factors related to the specific changes in the musculoskeletal, cardiovascular, and neural systems. Declines of strength, flexibility, coordination and ability to deal with stress effectively, as well as the increase of body fat, may well result in a possible increase rate and severity of injury, although more studies need to be conducted to confirm this statement (Cann, Vandervoort & Lindsay, 2005). For example, because ageing is related to changes in the cardiovascular system, one might consider advocating specific exercise programs in order to reduce risks of coronary heart disease. However, there is encouraging evidence from the literature that many of the age-related changes affecting older players, as well as the injuries they incur, are preventable or treatable through exercise.

Clinically relevant regions such as the lumbar spine or the femoral neck are thought to be prone to fractures with ageing. It is shown that long-term professional golf participation is not associated with significant increments in regional or whole body bone mass or bone mineral density. Therefore, it can be assumed that bone mass or density cannot be altered by long-term professional golf participation, and injuries such as lumbar spine and femoral neck fractures probably have other origin types than playing golf (Dorado *et al.*, 2002).

With respect to pediatric golf related injuries, most of the studies published report, although relatively uncommon, accidental head trauma as a result of an object impact (ball, club, etc.) (Brian & Glazer, 2005; Fountas *et al*., 2006; Fradkin *et al.*, 2005; Macgregor, 2002; Rahimi *et al*., 2005). The majority of children hurt are boys between 5 and 9 years of age (Fradkin *et al.*, 2005; Macgregor, 2002). Education of children (and their parents) to properly use golf equipment and etiquette is thought to be useful in the prevention of such injuries.

3.5. Golf Injury Mechanisms

The above reviewed literature may enable us to make some speculations concerning mechanisms which may inflict injuries in golf. For example, the predominance of overuse injuries found in most of the published studies, especially in the (low) back, may point out that some of the activities used in golf movements comprise high forces on the lumbar segments above biomechanical tolerance levels of the structures. Single trauma events were typically present on the head and the ankle. High percentages of excessive play (overuse) were found to cause shoulder, knee and elbow injuries, with similar trends in terms of gender (Gosheger *et al.*, 2003; Theriault & Lachance, 1998).

In amateurs who play an average of two rounds a week, injuries are most often due to overuse, striking the ground with the club (hitting a "fat shot"), and poor swing mechanics (McCarroll, 1996). "Over-swinging" (swinging harder and/or faster than is appropriate for a golfer's capabilities), poor warm-up, twisting the trunk during the swing, and gripping or other swing changes may also contribute to amateurs' injuries. In professionals who play many hours a day on most days, overuse accounts for 80% of injuries, hitting a fat shot for 12%, and twisting the trunk during the swing for 5%. Professional golfers report no injuries due to poor swing mechanics, over-swinging, poor warm-up, and grip or swing changes (McCarroll, 1996; Metz, 1999).

Some of the mechanisms reported by both professional and amateur golf players are discussed in various older (review) articles (McCarroll, 1996; McHardy & Pollard, 2005). In general, professional golf players complain about the fact that they practice too much (98%), whereas amateur players do not refer any complaint. Other reported reasons were: poor swing mechanics (including over-swinging), hitting the ground, being hit by a ball, etc.

Occasionally, fractures were reported in a younger population (i.e. hamate hook fractures) (Evans, 2004; Evans, Gilbert & Norton, 2006). Several case studies also point out the importance of ageing factors on injury prevalence (osteoporosis, stress factures, cardiovascular problems, skin cancer) (Lindsay *et al*., 2000).
It is suggested that a higher risk for injury is likely to occur during the swing at the moment of hitting the ball (Theriault & Lachance, 1998), although injuries may also come from lifting and transporting heavy equipment. In other words, a bad golf swing technique is supposed to be prejudicial for the integrity of the human tissues under loading.

There is also the potential that changing the habit of wearing metal spikes on the course could have an influence on musculoskeletal complaints of the lower extremity and might optimize functional performance (Stude *et al.*, 2008).

3.6. Injury versus Handicap.

As mentioned previously, there are certain differences between professional and amateur golfers, and some of them might be related to the type of injuries that usually are reported by the two groups. These differences are extensive to other important aspects. For the purpose of this paper, it is important to mention that the workloads and physical background to support them are very different in the two groups of players.

Professional players are involved in regular competition and follow intense and organized schedules of practice. They are submitted to intense practice effort that may implicate hundreds or even thousands of swing movements daily. On the other hand, they are usually engaged in carefully structured conditioning programs, and have better strength and flexibility indicators than recreational or high handicap players (Sell *et al*., 2007). Also, they do not complain as frequently as amateurs because they usually play in better shape.

Adult recreational players are an intrinsically variable group. Some recreational players may play occasionally, and have a restricted amount of practice, but some others may participate in organized golf programs of moderate or high intensity. As they behave differently, they may also experience a diversity of problems, physical impacts and injuries.

Injury patterns of elite and recreational golfers are different. Elite players tend to experience overuse related injury, while recreational golfers have their injuries associated with poor or deficient aspects of the swing technique. Many problems detected in amateur players will probably disappear if a new and improved technique is adopted.

At the peak of the backswing, professional players exhibited significantly higher left shoulder horizontal adduction and right shoulder external rotation. Professionals also showed higher trunk rotation values at the peak of the backswing and at the moment of ball contact. Significantly higher values were also observed in professionals concerning maximum angular velocity of the right shoulder internal rotation, left and right wrist action, and right elbow extension (Zheng *et al*., 2008).

Low-handicap golfers who suffer low back pain tend to demonstrate reduced erector spinae activity at the top of the backswing and at impact, but greater external oblique activity throughout the swing. This was associated with a reduced capacity to protect the spine at the moment where the torsional loads are the highest (Cole & Grimshaw, 2008a). It is hypothesized that low-back-pain golfers use their erector spinae muscle as a primary spinal stabilizer instead of the stronger deeper muscles (transversus abdominis and multifidus) (Cole & Grimshaw, 2008a, 2008b). The side bending at the moment of impact and at the peak of the backswing is also different - amateurs exhibit a deeper left side bending in the backswing, and less side bending in the downswing. Bending is probably a poor compensation for a limited trunk rotation, frequently observed in recreational players (Grinell, 1999). Golfers who have a lower handicap (0 to 9) are to some extent more likely to be injured in comparison with those who have a handicap above 18 (67.5% vs. 59%), indicating that training volume may be a risk factor, especially in amateur golfers. The injury rate in golfers older than 50 is slightly higher than that in younger golfers (64.9% vs. 58.3%) (McCarroll, 1996).

3.7. The Evolving Golf Swing

The golf swing as a very complex skill involves accurate body perception and well-coordinated muscular actions. The golf swing encloses three main components: the backswing, the downswing and the follow-through phase. The backswing is a slow component with an average duration between 800 and 1000 ms, while the downswing is a fast component of a much shorter duration (around 300 ms). The backswing duration is a subject of minor importance, but the two sub-components of the downswing are quite different. The first downswing component – the early acceleration phase – has a duration of about 250 ms, and the second sub-component, just before hitting the ball, is extremely short (40 to 60 ms duration) (Zheng *et al*., 2008), leaving no opportunity for trajectory corrections. Even in slow unskilled players, with moderate peak velocities, the duration of the final phase is not sufficient to introduce changes in club movement.

In order to maximize distance, the golfer performs movements of great amplitude in the spine and shoulders, in addition to very short and powerful movements with the arms, shoulders, back and hips. This is the most frequent action in golf, followed by putting and other short game techniques. The purpose of the golf swing is to propel the ball to a certain point in the golf course, and for competitive purposes this may frequently imply hitting the ball as far as possible.

3.7.1.Changes in Speed

Many different aspects of the game have changed, as exemplified by the swing technique, which was adapted through continuous changes in both the composition of the golf balls and the design of golf club materials. In the thirties, the best players could reach a club head speed of 100-120 $Km.h^{-1}$ and averaged 200-220 m in distance. In 1997, the ten best players in the US PGA Tour had an average distance of more than 260 m and a club head speed around 150 $Km.h^{-1}$. In some exceptional cases, club head speeds of nearly 200 $Km.h^{-1}$ have been registered (Stewart, 1999).

Tour professionals nowadays can easily create initial ball speeds of more than 200 $Km.h^{-1}$, and this value may surpass 250 $Km.h^{-1}$ for “long” players. Although all players can not experience these performances, many golf players may exhibit swing speed and acceleration values that are only about 50% of those reported for top-level athletes. However, the increased speed values are the result not only of changes in swing technique, but also due to improved development of design of the material used. However, an increase of swing speed as a result of strength training could also cause more injuries if the body is not prepared to handle these higher forces (Hellström, 2002).

Between the ages of 40 to 59 years, a decline in the maximum club head speeds occurs. The center of pressure is an important factor in producing fast club head speeds. Increased age combined with declines in center of pressure parameters may contribute to decrease in club head speeds (Brown *et al*., 2002). It is suggested that older male golfers may benefit more from strengthening exercises than flexibility exercises to increase club head speed (Thompson, 2002).

3.7.2. Changes in Material

New adjustable and flexible materials, as the golf club shafts, offered an increased shooting power (i.e. better ball flight and additional distance) to all players. Clubs are also becoming "friendly", optimizing the performance of players of different handicap and characteristics. The new clubs and shafts do not break easily, even under extreme impacts. Its stiffness is related to the club head speed (Worobets & Stefanyshyn, 2007). Although shaft stiffness for maximal performance depends on the individual's characteristics, the complete nature of this relationship is not clear yet**.** It may be hypothesized that muscles, tendons, ligaments and bones may suffer not only from a bad swing technique, but also from the use of inappropriate material. Furthermore, the last time clubs were changed is significantly associated with the risk of golf injury (McHardy *et al*., 2007), indicating that not only the equipment itself but the *change* of material used plays an important role in injury occurrence (e.g. lighter clubs may lead to a more aggressive swing, which may result in higher musculoskeletal strain; technical adaptation to or experimenting with new equipment may induce alterations in swing characteristics, like movement amplitude or peak acceleration with inherent increased injury risk).

3.7.3. Changes in Movement

The consistency of the ball strike improved through the stabilization of the lower part of the body, i.e. by keeping the feet in close contact to the ground with minor variation. For this reason, the rotation of hips during the backswing remained small in amplitude, at least of a smaller range than the shoulder rotation. This technical detail of differential amplitude of hip and shoulder angles has been referred as the X-factor (see Lindsay *et al*., 2000, for a review). The main argument that supports this technical evolution of the swing is the storage of potential energy during the backswing that allows an increased rotational velocity in the downswing (Lindsay *et al*., 2000; Bulbulian *et al*., 2001, Cole & Grimshaw, 2008a).
However, the differential rotation of hips and shoulders also increases the torsional load in

the spine (Gluck *et al*., 2008), and increased flexion may increase disc pressure and low back injury risk (Lindsay & Horton, 2002). Empirical evidence indicates that the stretching of viscoelastic components experienced by male top-level golfers may be related to low back pain (McHardy *et al*., 2006).

Despite the above, golf players seem to have developed some kind of protective mechanism, because the comparison between golfers and sedentary subjects has shown that the occurrence of disc problems is clearly higher in sedentary subjects than in golfers (McHardy *et al*., 2006).

Another critical aspect of the modern swing techniques, especially those that are observed in professional players, is the final hyperextension (the reversed "C") on the follow-through phase. While the dynamic X-factor refers to the backswing, related to a supra-maximal rotation at low movement speed, the reversed "C" problem is associated with the fast breaking components of the swing. In fact, it takes less than a second to reduce the club head speed from its peak value to zero. The reversed "C" position allows the golfer to absorb part of the power released during the downswing, and the hyperextension in the spine is considered to be responsible for the increased shear forces on the lumbar spine. In order to reduce the aforementioned shear forces, some players are trying to reduce the reversed "C" problems, especially in low back pain golfers, as a solution to avoid repetitive compression of specific spine regions (Gluck *et al*., 2008).

A third aspect of the modern swing is known as the "crunch" factor (Cole & Grimshaw, 2008; Sugaya, 1999), an intense lateral bending during the downswing and impact, which usually occurs at very high rotational speed. The crunch factor was defined as the instantaneous product of lumbar lateral bend and axial rotation velocity and has also been related with low back problems (Cole & Grimshaw, 2008; Gluck *et al*., 2008; Morgan *et al*., 1999). Both components of the crunch factor reduce with age, which seems to be a protective solution for the lumbar spine (Mitchell, Banks, Morgan & Sugaya, 2003).

3.8. Swing Phases and the Incidence of Injuries

Bearing in mind that the speed of the club head may reach high velocities during a very short time, which is related to high biomechanical stress on the musculoskeletal system, it is not difficult to understand that injuries can occur either through overuse (many repetitions during e.g. training sessions) or through severe trauma (high impact during e.g. a “fat” hit).
Most injuries occur at the final downswing phase, mainly when the club head hits the ball or the ground (17.8 %), and in the follow-through phase (41.6%) (McHardy *et al*., 2007). The injuries that have been reported in the follow through phase are probably related to the deceleration because of divot or ball contact, as they require counteracting forearm muscle participation to keep the ongoing control of the club (Grinell, 1999). The counterforce, i.e. the force of the impact of the ball, is transmitted by the club head and shaft to the hand and arm. The counterforce can be very high if the club hits any hard surface. Impact forces may be damaging for the wrist, elbow and shoulder.

The follow-through phase, that is basically a vigorous deceleration phase, has been reported as a potential injury source for the spine (hyperextension) and lower limbs, as the body weight is shifted to the left foot.

By studying the biomechanics of the golf swing in relation to the lumbar spine, it is understandable how both acute and chronic injury can occur. Although the human body may not be designed to handle the forces generated by swinging a golf club, there are measures one can take to prevent injury in the lower back by doing so. Strength training with a focus on dynamic lumbar stabilization techniques, rotational flexibility training, assuming a more upright stance, and warming up have all been shown to be beneficial (Gluck *et al.*, 2008).
From a biomechanical point of view, the different phases of the swing may cause different patterns of injury, due to the biomechanical stresses the musculoskeletal tissues may undergo, especially when the movement is carried out with anomalies of posture and technique (McHardy *et al*., 2007). An overview of the musculoskeletal regions prone to injury and the related swing phases is depicted in Figure 2.

------ Insert Figure 2 about here ------

3.8.1. Ball address and backswing

The first phase of the golf swing, the ball address, is characterized by adopting an optimal pre-stroke posture or starting position: equal weight distribution on the feet, feet on shoulder width, slight forward inclination of the trunk, straight back, and extended relaxed arm position. This posture should allow the golfer to generate maximal potential (kinetic) energy with the club. Ball address starts with a weight shift to the trail foot (right foot for right-handed golfers) while keeping the back and trunk perpendicular to the ground in the frontal plane.

Some of the structures that may be harmfully stressed due to a compromised starting position are: excessive loading on the spine through over-extension of over-rotation, shoulder injuries through compression of the rotator cuff or bursa subacriomiodeltoidea (Theriault & Lachance, 1998). Potential risk for injury of the elbow and wrist during striking of the ball also exists when elbow, forearm and wrist are held too tight, especially of the left arm.

At the end of the backswing, one should take care of not over-rotating the trunk. The backswing should be adapted to individual characteristics (height, flexibility, corpulence, etc.) of the player in order to prevent pathology of the hips and spine. Reducing the backswing, also known as the protective swing often observed in older golfers, in some cases one solution may be to decrease muscle activity of the trunk muscles, without compromising accuracy (Bulbulian *et al*., 2001).

The dorsal shoulder instability and secondary impingement is often attributed to the fact that the backswing phase involves a maximum adduction of the trailing arm at the end of this phase (Hovis *et al*., 2002). It was observed that recreational golfers do not show any dorsal instability, leading to the presumption that shoulder instability is related to professional golfers, only (Michael *et al*., 2008).

3.8.2. Forward swing and ball impact

The third phase of the swing is typically the phase of acceleration of the club head in order to achieve maximal club speed at ball impact. The sequence starts with a weight shift to the left foot by a linear and parallel movement of hips and shoulders and by keeping the spine perpendicular to the ground. At the same time, the knees, hips and trunk start to rotate to the left side, demanding high muscular activity of the abdominal muscles, acting as powerful trunk rotators. Some figures explain the importance of the loading of the musculoskeletal system during this phase (Pink, Jobe & Perry, 1990; Pink, Perry & Jobe, 1993; Pink *et al*., 1996), compared to the backswing phase:

- the external oblique muscles generate three times more activity (expressed as the percentage of the maximal voluntary electromyographic activity)
- the erector spinae, acting as spinal stabilizers, produce 4 to 5 times of muscle activity
- the right shoulder adductors exert 3 to 4 times of muscle activity
- the right shoulder internal rotators produce 5 to 7 times of muscle activity.

During the fourth phase, the wrists and hands complete acceleration of the club at ball impact. This whip-like action is characterized by the right (trailing) hand turning gradually in pronation and the left (leading) hand turning in supination during hitting (Metz, 1999).

Risks for injuries in the forward swing and at ball impact occur in the range of movement of greatest muscular activity (Theriault & Lachance, 1998). Players who are technically less skilled or older players may have up to 50% less trunk rotational capacity in comparison to younger or highly skilled players. This means that, in order to compensate this “shortcoming” and to be able to hit the ball as far, the former group will demonstrate higher muscular activity. Thus, higher loading on the spine is the result of a reduction of flexibility, strength and articular stability of the trunk and spinal structures, and may be important determinants for risk of injuries (Pink *et al*., 1993).

There is also a risk for injury of the elbows, wrist and hand, especially when the downward club trajectory is poor, and ground contact is made. In this case, severe injuries such as sprains and fractures may occur (Theriault & Lachance, 1998). At the moment of ball impact, compressive forces on the leading leg and hip are significant and can become a risk for injury, particularly for older players who may already have been affected by osteochondral degeneration or osteoarthritis (Gatt *et al*., 1998).

3.8.3. Early and late follow through

The fifth and sixth phases of the golf swing are the follow through after ball impact. Characterized by a progressive deceleration of the club rotation of the body towards the left around the axis of the spine, it is the natural momentum of the continuing swing (Metz, 1999). There is also a superimposed and parallel left rotatory motion of both the hips and the shoulders; a movement which ends when the body faces the target (Theriault & Lachance, 1998).

The danger of injuries to the lumbar dorsal zone arises if the deceleration stops too brusquely or if the final range of motion of spinal rotation is too pronounced. To minimize excessive spinal load, the spine should be as vertical as possible at the end of the sixth phase. In the follow-through, muscular activity is predominantly that of the muscles of the spine and the shoulders; however, the abdominal, dorsal, pectoral and anterior portion of the deltoid muscles are also implicated (Pink *et al*., 1990; Pink *et al*., 1993). As for the rotator cuff muscles, the supraspinatus and infraspinatus on the left side are activated mainly during the follow-through, while the subscapularis muscle remains active to a similar extent during the forward swing and ball impact. Thus, these muscles are of great importance in stabilizing the shoulders during the golf swing, but also during the follow-through. Because of the fact that the aforementioned muscles are demonstrating high activity during the follow-through, it may not be surprising that injury may also occur during this phase.

4. Conclusions.

The available literature on golf injuries leads to the observation that the amount of variation (age, level of play, training volume, and so on) is so high that the prevalence of injury and possible mechanisms are matter of controversy. Nevertheless, it was possible to identify some of the most frequent injury sites: the low back, elbow, wrist and hand, and shoulder.

The general nature of golf injuries is quite similar among golfers, but occasional and recreational golfers are more likely to suffer from traumatic injuries and various ill-known behaviors, such as absence of warming-up and insufficient physical condition.

The consequences of using a poor swing technique were also more evident among occasional golfers. On the other hand, the competitive player is often affected by overuse injuries in muscles and joints. Low back pain is the most common complaint experienced by both amateur and professional golfers, but it is not clear whether this is necessarily related to golf practice. Professional golfers may also report spine asymmetry complaints. In this case there is evidence that the right side is more affected than the left side.

Shoulder problems, although not predominant, can account for some of the reported complaints. The leading shoulder is generally more affected, and some of the identified causes are acromioclavicular problems, rotator cuff tendonitis, posterior glenohumeral subluxation and joint instability. The elbow is also a leading injury area: medial epicondylitis of the trailing arm and the lateral epicondilitys of the leading arm are frequently reported by experienced golfers. Wrist and hand problems include subluxation of fingers, tendon problems and even fractures. Part of these injuries is associated with club head impacts on the ground.

Traumatic and impact injuries are more frequent in young players and in the elderly. This high incidence is probably due to a systematic lack of preparation for safety aspects of the game and attention deficits. Poor supervision and information concerning safety aspects of practice are the main reasons for most of the traumatic episodes.

The impact of injuries is not the same in different anatomical regions. Spine (thoracic and lumbar) and elbow/wrist/hand injuries may lead to significant perturbation of golf practice. Hip and knee injuries, on the contrary, are rare and also the least persistent types of injury.

Golf is a sport for all ages and the persistence of practice for long periods is probably the main reason for the prevalence of injuries in the age group between 50 and 65 years. In this population some effects of musculoskeletal, cardiovascular and neural degeneration are to be expected. Some relevant changes include reduced strength, flexibility, coordination and balance, which may affect golf performance and increase the potential for injuries. However, the benefits of golf practice seem unquestionable in the domains of reduction of coronary disease risk and development of active lifestyles. A combination of physical conditioning and golf practice is recommended as a positive contribution to the reduction of injuries and the improvement of the quality of the golf experience in the elderly. The adoption of more protective swing techniques, particularly in the elderly population or in players having poor physical conditioning, is a matter of great concern.

Overuse injuries deserve some special attention. The concept of overuse is more than a single sum of days or hours of practice: it is relative to each subject's potential and capability. Overuse accounts for most of the injuries in professionals and for a large amount of occasional and recreational players' injuries. While recreational players complain about poor swing and insufficient warm-up, professional players emphasize overuse-related injuries. The main reason for injuries presented by professionals is too much play or practice.

The technical quality of the swing is associated with the prevalence of injuries, in particular in recreational golfers. The repetition of a poor swing may be a leading cause for overuse injuries in players of this level. Many complaints will disappear just by changing the swing pattern and adjusting it to physical and morphological characteristics and individual limitations. Excessive shoulder amplitude and rotation, excessive swing velocity, side bending in the downswing and backswing, and limited trunk rotation are some aspects of the swing technique that deserve special attention.

In conclusion, it can be stated that the literature available on golf injuries is merely descriptive and needs more inferential objective data. With respect to the mechanisms of golf injuries, as well as the factors which may put the golfers to risk, are either ill-known or still controversial because of the many influencing factors (age range, level of skill, conditions of play, cultural aspects) which affect both internal and external validity of the studies published.

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Figure Captions:

Figure 1: Flow chart of methodology used for article search

Figure 2: Possible locations for golf injuries (shaded areas) in (1) ball address, (2) backswing, (3) forward swing, (4) ball impact, (5) early follow-through and (6) late follow-through.

Table Title:

Table 1: Injury distribution by site (a), showing number of reports (when given) and percentages (in parenthesis). Modified from (Lindsay, Horton & Vandervoort, 2000).

Fig. 1

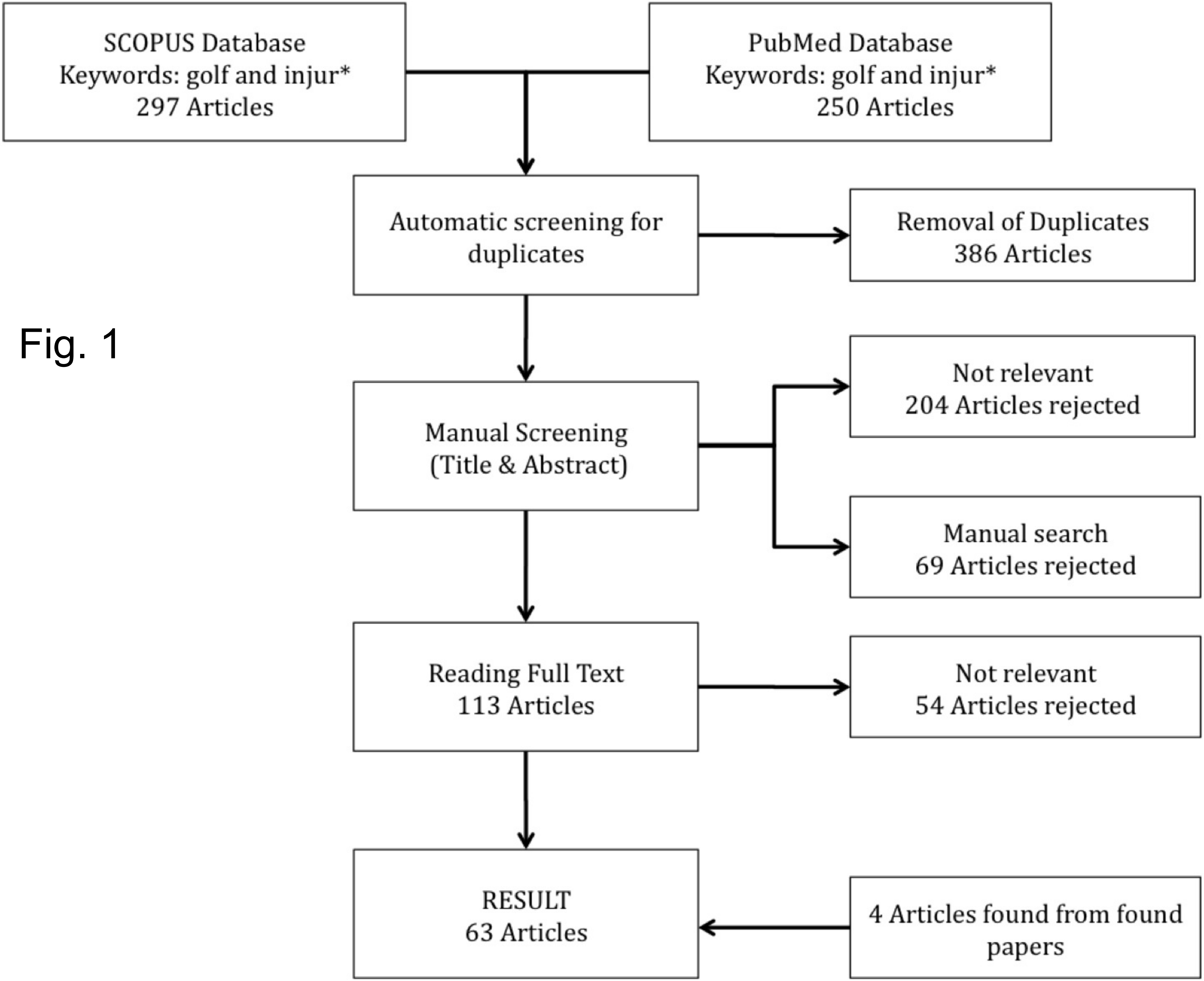
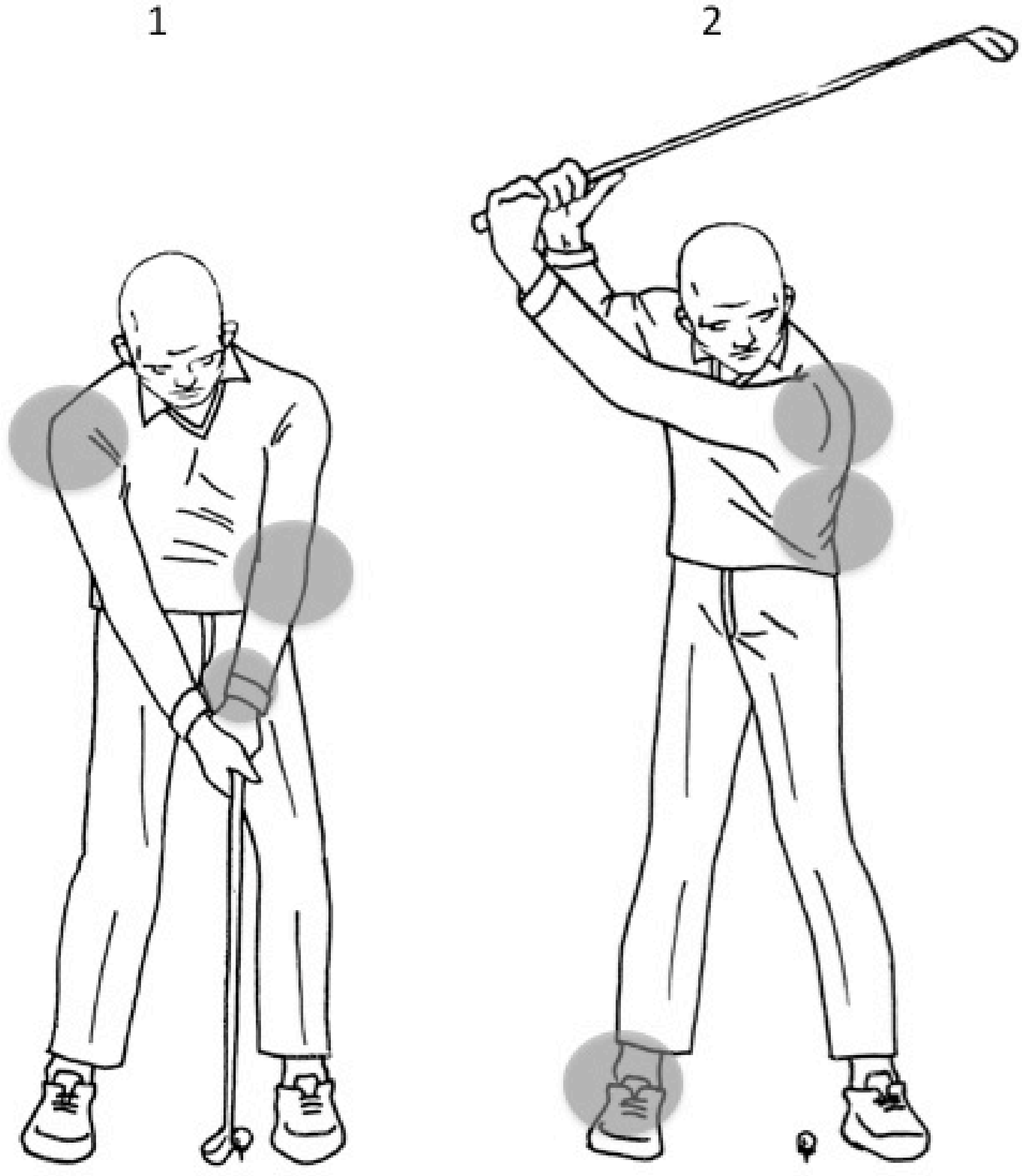

SCOPUS Database
Keywords: golf and injur*
297 Articles
PubMed Database
Keywords: golf and injur*
250 Articles
Automatic screening for duplicates
Removal of Duplicates
386 Articles
Manual Screening
(Title & Abstract)
Not relevant
204 Articles rejected
Manual search
69 Articles rejected
Reading Full Text
113 Articles
Not relevant
54 Articles rejected
RESULT
63 Articles
4 Articles found from found papers

Fig. 2



3

4

5

6

Table 1. Injury distribution by site (a), showing number of reports (when given) and percentages (in parenthesis). Modified from (Lindsay, 2000).

Study	Spine (%)			Upper limb (%)				Lower limb (%)				Other (%)
	cervical (neck)	thoracic	lumbar	shoulder	elbow	wrist	hand	hip/groin	knee	ankle	feet	
McCarroll & Gioe (1982) in (Lindsay et al., 2000) n = 393 P; mean age (age range) = 30 (23-72)	12 (3)	8 (2)	93 (24)	37 (9)	26 (7)	106 (27)	41 (10)	9 (2)	26 (7)	8 (2)	13 (3)	14 (4)
McCarroll et al. (1990) n = 708 A; mean age (age range) = 52 (15-86)	28 (3)		244 (27)	84 (9)	234 (26)	144 (16)		22 (2)	66 (7)	18 (2)	12 (1)	34 (4)
Batt (1993) n = 53 A; mean age (age range) = 49.5 (17-85)	2 (4)	13 (25)		2 (4)	4 (8)	15 (28)	2 (4)		4 (8)	3 (6)	2 (4)	(11)
Thériault et al. (1998) n = 528 A; age range = 12-70	(40)			(42)				(18)				
Sugaya et al (1999) n = 283 P; mean age (age range) = 35 (21-54)	93 (20)		154 (34)	44 (10)	45 (10)	42 (9)	7 (2)		26 (6)	20 (4)	6 (3)	14 (3)
Finch et al (1999) n = 34 A; median age (age range) = 40.5 (24-65)	(15)		(24)	(6)	(18)		(6)		(18)			(13)
McNicholas et al (1999) n = 286 A and P; age range = 0-70		(21)		(45)					(13)	(4)	(4)	(13)
Gosheger et al. (2003 n = 643 A and 60 P; mean age 46.2 ± 17.3 y	A: 45 (8.5) P: 11 (10)	5 (1.0) 3 (2.7)	80 (15.2 24 (21.8)	98 (18.6) 14 (12.7)	131 (24.9) 11 (10.0)	68 (12.9) 22 (20.0)		15 (2.9) 3 (2.7)	17 (3.2) 6 (5.5)	28 (5.3) 1 (0.9)		

Vad et al. (2004) n = 42 P; mean age (age range) = 30.7 (21-38)			14 (33)									
McHardy et al. (2007) n = 588 A; mean age 59.1 (SD = 12.9)			(18.3)	(11.8)	(17.2)					(12.9)		
Parziale et al. (2002) n = 145; (age range 14-80 yr) A and P;	14	1	65	20	15				12		1	2
Fradkin et al. (2007) n = 304 A (median age = 53 yr)	2	4	40	15	13	6	6	4	8	6	3	4

(a) Percentages are represented as a proportion of all reported injuries

A = amateur; P = professional.