

7: Does stretching help prevent injuries?

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Introduction

Over the past 30 years, sport medicine professionals have promoted stretching as a way to decrease the risk of injury.¹⁻⁶ Two potential mechanisms are often proposed by which stretching could decrease injury: a direct decrease in muscle stiffness via changes in passive visco-elastic properties, or an indirect decrease in muscle stiffness via reflex muscle inhibition and consequent changes in visco-elastic properties due to decreased actin-myosin cross bridges. These changes in muscle stiffness would allow for an increased range of motion (ROM) around a joint (i.e. “flexibility”*), which is believed to decrease the risk of injury.

Despite these claims, new research has challenged some of these concepts. First, stretching must be differentiated from range of motion. There are many individuals who have excellent range of motion but never stretch, and many individuals who stretch but continue to have limited range of motion. Therefore, different injury rates in people with different ranges of motion may not be related to the effect of stretching but rather occur because of underlying variations in tissue properties (for example strength), anatomy, etc. To understand the specific effect of stretching, then one should limit the review to studies that directly look at that intervention.

Second, stretching immediately before exercise may have different effects than stretching at other times. These should be considered separate interventions, and completely different from studies on flexibility. Whereas there is a considerable amount of clinical data on stretching immediately before exercise, there is much less data on stretching at other times.

* Within this paper, I will use the term flexibility as a synonym for range of motion (ROM) because that is the common use of the term by clinicians. However, the reader should realise that “flexibility” has other meanings in other domains, and is often used as a synonym for compliance, i.e. the ease with which the shape of a material can be deformed as in “a piece of metal is flexible if you can bend it easily”. Mathematically, compliance is the reciprocal of stiffness, and is equal to change in length produced by a given force.

Third, to decrease the risk of injury, one must either increase the stress a tissue can absorb, or decrease the stress applied to the tissue. Stretching may decrease the stress applied to a tissue both locally (i.e. decrease the risk of injury to the muscle being stretched) and at a distance from the muscle being stretched (i.e. decrease the risk of injury to a muscle or joint that is not being stretched). One example of a distant effect is that stretching the hamstring muscles may decrease the stress on the low back during toe touching. This is because toe touching is achieved through both hip and lumbar flexion. If hip flexion is limited because of stiff hamstrings, then more motion must come from, and more stress must be applied to the lumbar spine to achieve the same range of motion.

In this chapter, I will first review new findings that have changed our understanding of what stretching actually does to muscle. This will include changes at the level of the whole muscle (for example compliance) and at the level of the myofiber. Next, I will review the clinical evidence surrounding the protective effect of stretching both immediately before exercise, and at other times. Finally, I will then review some of the basic science evidence to see whether it supports or contradicts the clinical evidence. The use of stretching as performance enhancement will not be discussed.

Physiology of stretching

Immediate effects

Stretching is believed to increase the range of motion around a joint through decreases in visco-elasticity and increases in compliance of muscle. What is compliance and visco-elasticity? Compliance is the reciprocal of stiffness and, mathematically, it is equal to the length change that occurs in a tissue divided by the force applied to achieve the change in length. A tissue that is easy to stretch is compliant because it lengthens with very little force. Visco-elasticity refers to the presence of both elastic behaviour and viscous behaviour. An elastic substance will exhibit a change in length for a given force, and will return to its original length immediately upon release (for example a regular store bought elastic). The effect is not dependent on time. However, a viscous substance exhibits flow and movement (for example molasses), which is dependent on time.⁷ Experimentally, viscous behaviour produces “creep” if the force is held constant (i.e. the length continues to increase slowly even though the applied force is constant) or “stretch relaxation” if the length is held constant (i.e.

the force on the tissue decreases if the tissue is stretched and then held at a fixed length). When the force is removed, the substance slowly returns to its original length. This is different from plastic deformation in which the material remains permanently elongated even after the force is removed (for example plastic bag⁷). The reader should note that stretching affects tendons and other connective tissue in addition to muscle. However, within the context of normal stretching, the stiffness of a muscle-tendon unit is mostly related to the least stiff section (i.e. resting muscle) and is minimally affected by the stiffness of tendons.

Stretching appears to affect the visco-elastic behaviour of muscle and tendon, but the duration of the effect appears short. In one study, canine gastrocnemius muscle was repeatedly stretched to a fixed length and the force measured. The force required to produce the length change declined over 10 repetitions and was fairly stable after four stretches.⁸ The authors did not measure how long the effect lasted. In humans, Magnusson originally found that increased ROM was lost by 60 minutes if the subjects remained at rest after stretching. Because they did not take measurements at intervals, the effect could have lasted anywhere from 1–60 min.⁹ In a later study designed to further narrow the interval for the effect, the same group found that the increased ROM lasted less than 30 minutes even if the person warmed up prior to the stretch and continued to exercise.¹⁰ More studies are needed to see exactly how long the effect does last, for example 1 min, 5 min, 15 min, etc.

As one observes the people around them, it becomes clear that some people are naturally flexible even though they never stretch, whereas others remain inflexible no matter what they do. The effect of stretching also appears to be individual specific and muscle specific. For instance, within every study, some individuals have large increases in range of motion with stretching whereas others do not, both in animal⁸ and human studies.^{11,12} In addition, stretching appears less effective in increasing hip external rotation and abduction compared to hip flexion.¹³ If true, the optimal duration and frequency for stretching may be different for different muscle groups. This appears logical given that different muscles have different temperatures (superficial muscles are colder than deep muscles) and different amounts of pennation (i.e. angle of sarcomeres to the direction of force when the muscle contracts, for example gastrocnemius muscle). More research is needed on which variables are responsible (and to what degree) for the variation observed in response to stretching protocols.

Stretching also appears to increase the pain threshold during a muscle stretch, i.e. it acts like an analgesic.^{14–16} In these series of

studies, subjects' muscles were stretched until they felt pain, and the stretch stopped. After the subjects stretched, the expected increased ROM before pain was felt was associated with both an increased length and force across the muscle. Had the increased ROM been limited to visco-elastic changes, the muscle length would have increased but the force applied would have been less or unchanged. The only explanation for an increase in force before pain is felt is that stretching acts like an analgesic. Finally, the analgesia is at least partially due to the effects at the spinal cord or cerebral level because during unilateral proprioceptive neuromuscular facilitation (PNF) stretching, the range of motion in the non-stretched leg also increases.

PNF stretching is also an interesting example of how myths can be propagated within the medical literature. When it was first proposed in the early 1970s, PNF techniques were based upon the basic science finding that stretching/activity of the antagonist muscle creates reciprocal inhibition of the agonist muscle.¹⁷ When tested, PNF techniques were indeed shown to increase ROM more than static stretching. However, these initial studies did not measure muscle activity so the reason for the increased ROM was not known. In fact, when EMG was recorded in 1979, the reciprocal inhibition theory was disproved.¹⁸ Although these results have been confirmed more recently,^{15,19,20} the myth of reciprocal inhibition continues to be promoted in textbooks and the medical literature. In fact, muscles are electrically silent during normal stretches until the end ROM is neared. Surprisingly, PNF techniques actually increase the electrical activity of the muscle during the stretch,¹⁸⁻²⁰ even though the range of motion is increased.^{15,18,21} This suggests that:

- PNF stretching is associated with a more pronounced analgesic effect
- the muscle is actually undergoing an eccentric contraction during a “PNF stretch”.

Although stretching may affect the visco-elastic properties of resting muscle, it does not affect the compliance of *active* muscle. Compliance of resting muscle is almost exclusively due to the muscle cytoskeleton^{22,23} whereas compliance of active muscle is directly dependent on the number of active actin-myosin cross bridges.²⁴⁻²⁷ Because injuries are believed to occur when the muscle is active (i.e. during eccentric contractions),²⁸ compliance during activity should be more important than compliance at rest.

In summary, stretching decreases visco-elasticity of muscle for less than 30 min, and the increased ROM is at least partially due to an analgesic effect mediated at the level of the spinal cord or higher.

Long-term effects

Although the immediate effects of a single stretching session produce a decrease in visco-elasticity and an increase in stretch tolerance, the effect of stretching over 3–4 weeks appears to affect only stretch tolerance with no change in visco-elasticity.^{21,29} In this case, a second explanation for the increased stretch tolerance besides an analgesic effect is possible; regular stretching may induce muscle hypertrophy.

Animal research has shown that muscles that are stretched for 24 hours per day for several days will actually increase in cross sectional area (or decrease in cross sectional area less than if casted without stretch) even though they are not contracting.^{30–32} This is known as stretch induced hypertrophy. These studies all used cast immobilisation^{30,32} or weights to continuously stretch the muscle 24 hours/day over 3–30 days.³¹ This is of course very different from human stretching programmes that involve stretching for only 30–60 sec/day for any particular muscle group. Still, if the shorter duration human stretches are continued over months, there remains the possibility that some hypertrophy will occur.

If stretch induced hypertrophy does occur, it should be associated with an increase in stiffness because of the increased muscle cross sectional area. For example, the stiffness of an elastic band doubles if you double the cross sectional of an elastic band by folding it upon itself, even though the elastic itself has not changed. Therefore, a thicker muscle should also be stiffer. However, the stiffness of human muscles does not change over time with stretching.^{21,29} Therefore, if stretch induced hypertrophy is occurring in this situation, then there must be associated changes in the visco-elastic properties of the individual muscle fibers to explain the lack of increase in whole muscle visco-elasticity. Much more research is needed to answer these questions.

Does stretching immediately before exercise prevent injury?

Methods

The Medline database was searched for all clinical articles related to stretching and injury using the strategy outlined in Table 7.1. All titles were scanned and the abstracts of any potentially relevant articles were retrieved for review. All studies that used stretching as an intervention, included a comparison group, and had some form of

Table 7.1 Medline Search Strategy using a PubMed Search engine, which searches all fields including Medline Subject Headings (MeSH) and textwords (tw) between 1996 and the present. Textword strategy will retrieve any article which includes the word in the title, or abstract (if abstract is included in Medline). The symbol “*” in the search acts as a wildcard for any text

Item	Search	Results
1	stretch*	21 984
2	sprain OR strain OR injur*	488 228
3	sport OR athlet* OR activ*	760 034
4	1 AND 2 AND 3 (limited to human studies)	293

injury risk as an outcome were included for this analysis. In addition, all pertinent articles from the bibliographies of these papers were also reviewed. Finally, a Citation Search was performed on the key articles.

Results

Every study has limitations. This does not usually invalidate the research but only limits the interpretation of the study. This chapter summarises the main weaknesses of the studies and illustrates how the data can still be interpreted for clinical usefulness.

Of the 293 articles retrieved from the search, only 14 articles used a control group to analyse whether pre-exercise stretching prevents injury and all were included in this analysis. Of these, five articles suggested it is beneficial (Table 7.2),^{33–37} three articles suggested it is detrimental (Table 7.3),^{38–40} and six articles suggested no difference (Table 7.3).^{41–46}

Figure 7.1 shows the relative risks or odds ratios (with 95% CI) for all the prospective studies. A close examination of these studies suggests that the clinical evidence does not support the hypothesis that stretching before exercise prevents injury.

Positive studies

When grouped together, three of the five studies that showed a positive effect actually evaluated a complete programme that included many co-interventions in addition to stretching and the remaining two studies were very weak methodologically. For example, Ekstrand *et al* found that elite soccer teams that were part of an experimental group (pre-exercise warm-up, leg guards, special shoes, taping ankles, controlled rehabilitation, education, and close supervision) had 75% fewer injuries compared to the control group of soccer teams.³⁷

Table 7.2 Brief summary of the clinical studies that suggest stretching immediately before exercise may prevent injury. For the relative risk (RR) or odds ratios (OR), a value above 1 means a higher rate of injury in people who stretch

Reference	Population	Study Design	Results	Comments
Ekstrand <i>et al</i> ³⁷	180 elite male soccer players	RCT intervention of warm-up, stretch, leg guards, prophylactic ankle taping, controlled rehabilitation, information, supervision	The group that received the combined intervention had a RR of 0.18 (0.6 injuries/month versus 2.6 injuries/month)	The multiple interventions prevent one from concluding that pre-exercise stretching is beneficial
Bixler & Jones ³⁵	5 High School Football teams	Pseudo-RCT intervention of half-time stretching and warm-up	Intervention group had 0.3 injuries per game vs 0.8 injuries per game for control group	If an intervention team did not stretch at half-time, they were considered as part of the "control data". No numbers given for changes in exposure. With increased exposure and constant risk, frequency of injuries is expected to increase. Therefore, risks cannot be calculated. Also, there was a co-intervention of warm-up
Ekstrand <i>et al</i> ³⁶	180 elite male soccer players	1-year prospective cohort study	"All seven quadriceps strains affected players of teams in which shooting at the goal occurred before warm-up (p < 0.058)". "Hamstring strains were most common in teams not using special flexibility exercises (t = 2.1)"	No real analysis of stretching before exercise. Multiple co-interventions
Wilber <i>et al</i> ³⁴	518 recreational cyclists	Survey of overuse injuries and other related factors	Only results available are "stretching before cycling (1 vs. 2 minutes, p < 0.007) ... had a significant effect on those female cyclists who sought medical treatment for groin/buttock conditions".	Response rate of 518/2500. The association between stretching and injuries to other body parts (knees, back) was not reported, even though data available. Not clear if people stretched before injury, or because of injury. Effect only in women and not in men
Cross <i>et al</i> ³³	195 Division III College football players	Chart review, prepost stretching intervention using historical controls. Stretching immediately before exercise	43/195 injuries pre-intervention, and 21/195 post-intervention (p < 0.05)	Use of historical controls is poor design. Likely to have had high rate of injuries and decided to introduce stretching. If true, results are likely by chance due to "regression towards the mean"

Table 7.3 Brief summary of the clinical studies that suggest stretching immediately before exercise does not prevent injury. For the relative risk (RR), odds ratio (OR) or hazard ratio (HR), a value above 1 means a higher rate of injury in people who stretch

Reference	Population	Study Design	Results	Comments
Pope <i>et al</i> ⁴⁶	1538 male military recruits	12 week RCT	Univariate HR = 0.95 (95% CI: 0.77, 1.18) Multivariate HR = 1.04 (95% CI: 0.82, 1.33)	Large sample size. Military recruits do not perform same activities as elite athletes, but the activity is probably very similar to recreational athletes. Compliance and follow up is easy in this group
Pope <i>et al</i> ⁴⁷	1093 male military recruits	12 weeks RCT stretch calves	HR = 0.92 (95% CI: 0.52, 1.61)	Although stretching did not reduce risk, there was a 5-fold increased ankle injury if ankle ROM only 34 deg (p < 0.01).
van Mechelen <i>et al</i> ⁴⁵	421 male recreational runners	16 week RCT matched on age and weekly running distance	RR: 1.12	Intervention was warm-up and pre-exercise stretching. There was a lot of "non-compliance" in each group
Macera <i>et al</i> ⁴²	583 habitual runners	1-year prospective cohort	OR for men = 1.1, for women = 1.6	Response rate 966/1576. Stretching data was only controlled for age. Stretching was not included in the multiple regression analysis because it was insignificant in the univariate analysis
Walter <i>et al</i> ⁴³	1680 community road race runners	1-year prospective cohort	Comparison group is people who always stretch RR: Never stretched: 1.15, 1.18, Sometimes stretch: 0.56, 0.64, Usually stretch: 1.05, 1.25	To be consistent with other articles, the RR was converted so that the numbers reflect the risk of people who always stretch. These numbers are controlled for running distance and frequency, type of runner, use of warm-up, injuries in past year
Howell ³⁸	17 elite women rowers	Cross sectional	Stretching associated with injuries	Not clear if people stretched before injury, or because of injury
Brunet <i>et al</i> ⁴⁴	1505 road race recreational and competitive runners	Survey of past injuries and other related factors	Similar frequencies of injuries among those who stretch and those who do not	Response rate unknown. Cross sectional study design but injury profile was "any injury" and not recent injury. Not clear if people stretched before injury, or because of injury
Blair <i>et al</i> ⁴¹	438 habitual runners	Survey of past injuries and other related factors	Only results available are "frequency of stretching ... were not associated with running injuries"	Response rate 438/720. This article comprises three studies. Only the cross sectional study directly looked at stretching habits. Not clear if people stretched before injury, or because of injury
Kerner ⁴⁰	540 people buying running shoes	Survey of past injuries and other related factors	Only results available are "A comparison of subjects who warmed up prior to running (87.7%) and those who did not (66%) revealed a higher frequency of pain in the former"	Response rate 540/800. No data available to determine clinical relevance. Not clear if people stretched before injury, or because of injury
Jacobs ³⁹	451.10-kilometre race participants	Survey of past injuries and related factors	~90% of injured people stretched, compared to ~80% of non-injured people	Response rate 451/550. Not clear how 550 were chosen from potential 1620. Univariate analysis only. Not clear if people stretched before injury, or because of injury

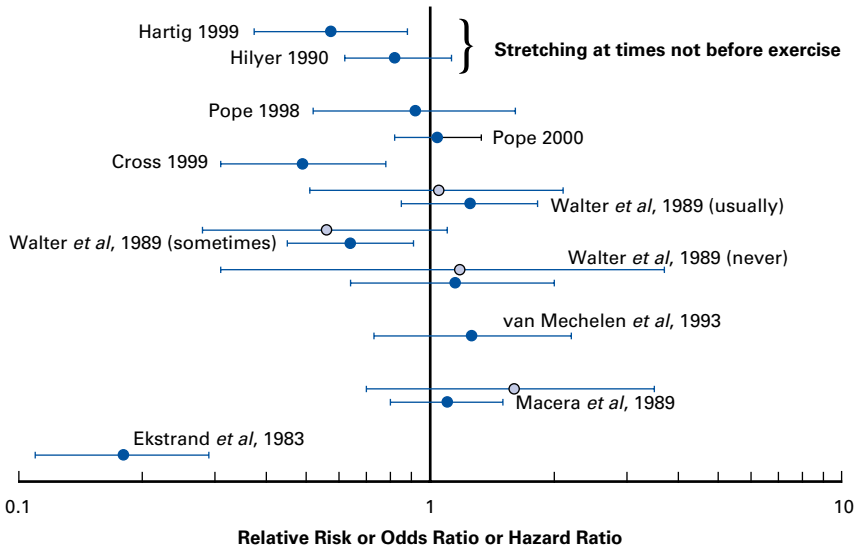


Figure 7.1 The relative risk or odds ratio or hazards ratio ($\pm 95\%$ confidence intervals) from all the prospective studies are shown (men [filled circles], women [open circles]). A value greater than 1 means an increased risk for people who stretch before exercise, and a value below 1 means a decreased risk of injury for people who stretch before exercise. There were three studies in which there was a lack of data in the article to calculate the relative risk or odds ratio.^{35,36,38} The study by Ekstrand *et al*³⁷ was calculated for strains and sprains only, and as if each person was only injured once. The study by Walter *et al*⁴³ compared several groups to “Always stretched before exercise” (a relative risk above 1 means the “always” groups had a higher injury rate). This figure was adapted with permission from the *Clinical Journal of Sport Medicine*.

However, it is impossible to determine which of the interventions might be responsible for the decrease in injury rates. In a similar study completed one year earlier, Ekstrand *et al* found less hamstring and quadriceps strains in elite soccer players³⁶ who performed warm-up, skill, and stretching exercises presoccer.

In the remaining multiple intervention group, high school football teams were pseudorandomised to stretching and warm-up during half-time.³⁵ The hypothesis was that athletes become stiff during half-time and that stretching at half-time would decrease third quarter injuries. This study had problems with randomisation and it used multiple interventions. Finally, if an intervention team did not stretch at half-time, injuries during that game were considered as part of the control group. For statistical reasons, it is considered more appropriate to use an “intention-to-treat” analysis, which means that

groups are analysed according to their randomisation and not according to their compliance.

Cross *et al* used a cohort design with historical controls and found pre-exercise stretching decreased injuries.³³ Basically, the authors compared injury rates during the year prior to instituting a pre-exercise stretching routine, and again during the first year of its use. The problem with interpreting this study is that the following scenario is very likely. First, the medical staff noticed a high injury rate one year and asked themselves what could be done to prevent injuries. Stretching was proposed, and the rates of injury dropped. This may sound like cause and effect, but in reality, is likely to have occurred by chance. This is because injury rates will always vary from year to year. If there is a high rate one year, then by chance, the rate is likely to be lower the next year. In fact, this second year rate may still be higher than average but the reader would not know because the only comparison available is with the very high rate of the previous year. Statistically, this is called regression towards the mean. Studies using historical controls only provide strong evidence when the rates are stable over a number of years, and then fall (or rise) for a few years following the introduction of an intervention. Therefore, without knowing the rates of injury for several seasons before and after the intervention, nor the reason why the intervention was applied during that particular year, the most likely reason for the drop in injury rates in the Cross *et al* study is regression towards the mean.

Finally, in a cross sectional study, women cyclists who stretched before exercise had less groin and buttock pain but the effect was not observed in men.³⁴ Because the physiological effect of stretching is similar in both groups, these results are difficult to interpret.

In summary, although there are some strong studies for which pre-exercise stretching was associated with a reduction in injury rates, the presence of probable effective co-interventions means that the interpretation might be that we cannot ascribe the beneficial results to stretching unless there is supporting evidence from other types of studies.

Negative Studies

There have been three studies (all cross sectional) that suggested stretching before exercise may increase the risk of injury.³⁸⁻⁴⁰

In a cross sectional study, Howell found that 13/13 elite rowers who stretched had back pain, and only one of four athletes who didn't stretch had back pain.³⁸ Interestingly, of the study subjects with hyperflexibility of the lumbar spine, the only two who did not have back pain did not stretch. However, it is again unclear if these athletes

became injured because they were stretching, or stretched because they were injured.

In the two other cross sectional studies that showed stretching might increase injury rates,^{39,40} the authors did not control for any other factor such as training distance, experience, etc. In summary, conclusions based upon these studies should be guarded.

Equivocal Studies

There have been six studies (three RCT, two prospective, two cross sectional) that found no difference in injury rates between people who stretch before exercise and those who do not.^{41–46}

In the most recent large RCT, Pope and colleagues randomised 1538 military recruits to either warm-up and then stretch immediately before exercise, or simply warm-up and exercise.⁴⁶ The hazard ratio (equivalent to an odds ratio but takes into account different follow up times) was 1.04 (95% CI: 0.82–1.33) after controlling for height, weight, day of enlistment, age and 20 meter shuttle run test score. This study was consistent with a previous study by the same authors that used only calf stretching immediately before exercise (HR: 0.92, 95% CI: 0.52, 1.61)⁴⁷. Interestingly, this same study still showed an increased risk if the baseline ankle ROM was decreased but stretching over 11 weeks was still an ineffective intervention. With respect to sport injury prevention, the main limitation of this study is that it occurred in military recruits, who may not be doing the same type of activity as recreational or elite athletes. The importance of this limitation is questionable.

Van Mechelen randomized 421 persons to an intervention group that included six minutes of warm-up, and 10 minutes of stretching.⁴⁵ The relative risk for injury for those in the intervention group was 1.12 compared to controls. Of note, only 47% of those in the intervention programme actually stretched according to the instructions outlined in the study. In addition, many of the runners in the control group also performed some type of pre-exercise stretching. This type of non-compliance (or “misclassification”) would be expected to “bias towards the null” and minimise the odds ratio obtained. However, it should not reverse the direction of the odds ratio, which showed more injuries in the group randomised to stretch. Although one could re-analyse the data according to whether the actual intervention was performed, most statistical consultants believe the intention-to-treat analysis (as was done in the paper) is more appropriate.

In a prospective cohort study by Walter *et al*,⁴³ the authors found that stretching was unrelated to injury after controlling for previous

injuries and mileage. Macera *et al*⁴² found that stretching before exercise increased the risk of injury but the differences were not statistically significant (males: OR 1.1; females OR 1.6). Although not RCTs, these were good studies with few limitations.

Finally, two cross sectional studies showed no protective effect of pre-exercise stretching.^{41,44} In fact, Brunet *et al* reported that non-stretchers had fewer injuries even though they had higher mileage per week and fewer previous injuries.⁴⁴ The cross sectional design limits the conclusions that can be drawn from these studies.

Summary of clinical evidence

Overall, the only studies to suggest that pre-exercise stretching might prevent injuries included a warm-up programme as a co-intervention. All other studies suggested that pre-exercise stretching has no benefit or may be detrimental. Thus, the clinical evidence available does not support the hypothesis that pre-exercise stretching prevents injury.

Does stretching after or outside periods of exercise prevent injuries?

There have only been two studies (Table 7.4) examining the effect of stretching after or outside periods of exercise. One suggested injury risk is decreased and the other suggested that only injury severity is decreased. Much more research is needed in this area before definitive conclusions can be made.

Positive studies

In support of this hypothesis, a recent study using basic training for military recruits found that the companies of soldiers who stretched three times per day besides their normal pre-exercise stretching regimen had fewer injuries than a control group who stretched only before exercise.⁴⁸ Although there were problems with baseline comparisons and a lack of control for previous injuries, fitness levels, etc, the study represents a good beginning. This is an area that requires further research.

Hilyer *et al* randomised firefighters from two out of four fire districts to perform 12 daily stretches for six months, and the firemen from the other two districts not to stretch (total 469 firemen)⁴⁹ Although the change in flexibility was greater in the experimental group, this

Table 7.4 Brief summary of the clinical studies that suggest stretching immediately before exercise may prevent injury. For the relative risk (RR) or odds ratios (OR), a value above 1 means a higher rate of injury in people who stretch

Reference	Population	Study Design	Results	Comments
Hilyer <i>et al</i> ⁴⁹	469 firefighters	Cluster randomisation by fire district. Stretching at work; obviously not possible immediately before fire	48/251 injuries in stretching group and 52/218 injuries in control group (RR = 0.82, 95% CI: 0.57, 1.14). \$950 per injury for lost-time in stretching group and \$2838 in control group (p = 0.026)	Reviewed exercises with subjects but not clear how closely. Medical cost difference also greater in control group, but not significantly (p = 0.19). Because medical costs more similar than lost time costs, total cost not significantly different (0.56)
Hartig <i>et al</i> ⁴⁸	298 basic training recruits	Cluster randomisation by company	25/150 injuries in stretching group and 43/148 in control group (RR: 0.57, 95% CI: 0.37, 0.88)	Stretching group more flexible prior to training and not controlled for in analysis. Almost twice the loss to follow-up in stretch group, which means less people available to be injured. This would make stretching appear more effective

was due to loss of flexibility in the control group and not gain in flexibility in the experimental group, even though exercise physiologists visited the various stations during the first month to correct improper technique. The number of injuries was not different between groups, but the costs due to lost time from work were less in the group that stretched.

Discussion

A review of the clinical evidence strongly suggests that pre-exercise stretching does not prevent injury, and that the evidence on stretching at other times is too limited to make any realistic recommendations. Considering these results are contrary to many people's beliefs, it seems prudent to review why some people ever believed stretching was so beneficial. There appear to be five general arguments that have been proposed in the past.

First, *paraphrasing an old Zen saying, "that which does not bend, breaks"*. If true, increasing compliance should decrease the risk of injury. However, even though a balloon will stretch before it bursts (high compliance), a sphere made of metal with the same thickness as the balloon might never stretch (low compliance) and still withstand extremely high pressures. Therefore, compliance refers to the length change that occurs when a force is applied but is not necessarily related to a tissue's resistance to injury. Furthermore, the basic science evidence suggests that an increase in compliance is associated with a decrease in the ability of the muscle to absorb energy. For example, if muscle compliance is increased with warming from 25°C to 40°C, the muscle ruptures at a longer length.⁵⁰ Although this may appear beneficial, the muscle actually ruptured under less force, and absorbed less energy.⁵⁰ Ligaments that have been immobilised are also more compliant but absorb less energy.⁵¹ In addition, resting muscle is more compliant than a contracting muscle^{26,27} but again absorbs less energy.^{52,53} Finally, sarcomeres directly attached to the tendon are the least compliant and remain undamaged, but adjacent sarcomeres are stretched beyond actin-myosin overlap and become injured.⁵⁴⁻⁵⁶ These results are consistent with Garrett's whole muscle studies in which the sarcomeres attached to the tendon remain intact, but more of the compliant adjacent sarcomeres rupture.⁵² Taken together, this evidence suggests that an increased compliance is associated with an inability to absorb as much energy, which may increase the risk of injury during an eccentric load.

Although more compliant tissue is less able to absorb force, the Zen saying is not necessarily incorrect, just an inappropriate example for muscle. Using the example of a bamboo tree that bends with the

wind, one realises that by bending, the direction of the force applied to the tree changes. When the tree is upright, the force is perpendicular to the tree, but when the tree bends, the force is applied longitudinally to the tree. However, when we stretch muscle or exercise, the force on the muscle is always longitudinal and never changes direction, and therefore the analogy is inappropriate.

Second, some people believe injuries occur when the muscle is stretched beyond its normal length. Although this can occur in some situations, most authors believe an injury occurs when the muscle cannot absorb the force applied to it and that the most important variable with respect to muscle injury is the energy absorbed by the muscle.^{52,57,58} For example, a hamstring strain would occur during eccentric activity if the muscle is unable to prevent excessive sarcomere lengthening caused by the force of the leg coming forward during the swing phase of gait, even though the joint is still within its normal ROM. When sarcomeres are stretched so that the actin and myosin filaments no longer overlap, the force is transmitted to the cytoskeleton of the muscle fiber and damage occurs. This can occur within the normal ROM because sarcomere length within the muscle is heterogeneous; some sarcomeres lengthen during a contraction at the same time others are shortening.^{55,56,59,60} Therefore, it appears that it is the sarcomere length that is related to most exercise related muscle strains, rather than total muscle length. Under this hypothesis, an increase in total muscle compliance is irrelevant.

Third, because injuries are believed to occur when the muscle is active (i.e. during eccentric contractions)²⁸ compliance during activity should be more important than compliance at rest. However, we have seen that these two compliances are unrelated. This is because compliance of resting muscle is almost exclusively due to the muscle cytoskeleton^{22,23} whereas compliance of active muscle is directly dependent on the number of active actin-myosin cross bridges.²⁴⁻²⁷ Furthermore, active muscle has a much lower compliance than resting muscle,^{26,27} but absorbs significantly more energy.^{52,53} This data again supports the argument that an increase in compliance does not mean a decreased risk of injury.

Fourth, over-stretching a muscle can certainly produce damage. However, even strains as little as 20% beyond resting fibre length, as one would expect with “correct” stretching techniques, can produce damage in isolated muscle preparations.⁵⁸ Therefore, the basic science evidence suggests that “correct” stretching techniques may be more difficult to define than previously thought.

Fifth, we have seen that the increased range of motion with stretching is partly due to an analgesic effect.^{15,16,18,21} This explains why stretching may provide short-term relief for muscle aches and pains but does not mean that the risk of injury is decreased. Nor does it mean that

stretching shortens rehabilitation time and prevents re-injury following an injury. In the only clinical study directly comparing stretching to strengthening after injury,⁶¹ 23/34 male athletes with over two months of groin pain who participated in a strengthening programme returned to pre-activity levels within four months, compared to only 4/34 of athletes who participated in a stretching program (multiple regression OR: 12.7, 95% CI 3.4–47.2). Further, the group that strengthened had the same increase in ROM as the stretching group even though they never stretched. Whether this is also true for acute injuries, or whether stretching adds additional benefit to a strengthening programme remains to be determined.

Given these arguments about pre-exercise stretching, the reader should remember that stretching at other times may theoretically induce hypertrophy,^{30–32} and if future evidence suggests this occurs, an increase in strength is likely to decrease injuries. This may explain the results of Pope *et al* which showed an increased risk if ankle ROM was decreased, but no effect of pre-exercise stretching over 11 weeks.⁴⁷ The effect of stretching might simply require a much longer period of time.

In conclusion, the clinical evidence is consistent with the basic science evidence and theoretical arguments; stretching before exercise does not reduce the risk of injury and stretching at other times may or may not be beneficial.

Further Note: In a recent article (*Br J Sports Med* 2001;35:103–108), the authors suggested in the text that ankle injuries are more frequent in people who did not stretch immediately before a game. However, the results (Tables 3 & 4) suggest the opposite: people who stretch immediately before a game had 2.6 times the risk of injury. The simplest way to understand this is that the coding is Yes = 1 for stretching, which is the same as that for “history of ankle sprains”. Both history of sprain and stretching before exercise had odds ratios above 1. If the authors say a previous sprain increases the risk of injury, then so must stretching before exercise. The authors did not reply to a request for clarification.

Sample examination questions

Multiple choice questions (answers on p 561)

- 1 The original study by Ekstrand *et al* suggested that stretching immediately prior to exercise is associated with a decrease in injuries. Which of the following interventions that are likely to prevent injury were also included in the experimental group as co-interventions?

- A Shin guards
 - B Supervised rehabilitation
 - C Warm-up
 - D Education
 - E All or none of the above
- 2 With regards to the number of studies examining whether stretching outside periods of exercise prevent injury or minimise the severity of injury:
- A 2 found it does and 2 found it does not
 - B 0 found it does and 2 found it does not
 - C 2 found it does and 0 found it does not
 - D All studies used a cohort design
 - E All or none of the above
- 3 Theoretical reasons why stretching prior to exercise would not decrease injuries include all of the following EXCEPT:
- A Tissues that are more compliant are associated with a decreased ability to absorb energy
 - B The compliance of active muscle is related to the compliance of muscle during normal stretches
 - C Most injuries occur during eccentric activity of the muscle, within its normal range of motion
 - D Overstretching a muscle is known to be a cause of muscle injury
 - E All or none of the above

Essay question

- 1 Discuss the evidence for and against the use of stretching immediately prior to exercise as an intervention to prevent injuries.
 - 2 Explain the theoretical reasons why stretching immediately prior to exercise was thought to prevent injuries, and why they do not apply to regular exercise such as jogging.
 - 3 Describe how stretching increases range of motion.
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Summarising the evidence

Comparison	Results	Level of evidence*
Does stretching before exercise prevent injury?	5 RCTs, 3 prospective cohorts, 1 historical cohort, 6 cross sectional studies. Conflicting results explained in Table 2 and 3. <i>Overall, stretching before exercise does not prevent injury.</i> Note that most studies done on recreational athletes or military personnel. According to the basic science of injury, there is no reason why elite athletes would be expected to have different results.	A1
Does stretching outside periods of exercise prevent injury?	2 RCTs (n = 300–470), weaknesses in follow-up and differences in baseline characteristics. <i>One study suggested a decreased injury rate and the other only decreased severity of injury.</i>	A1

* A1: evidence from large RCTs or systematic review (including meta-analysis) †

A2: evidence from at least one high quality cohort

A3: evidence from at least one moderate sized RCT or systematic review †

A4: evidence from at least one RCT

B: evidence from at least one high quality study of non-randomised cohorts

C: expert opinion

† Arbitrarily, the following cut-off points have been used; large study size: ≥ 100 patients per intervention group; moderate study size ≥ 50 patients per intervention group.

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