

IOC consensus paper on the use of platelet-rich plasma in sports medicine

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INTRODUCTION

Acute and chronic musculoskeletal injuries in sports are common and problematic for both athletes and clinicians. A significant proportion of these injuries remain difficult to treat, and many athletes suffer from decreased performance and longstanding pain and discomfort.¹

In 2008, the International Olympic Committee (IOC) published a consensus document on the importance of molecular mechanisms in connective tissue and skeletal muscle injury and healing.² This document predicted an increase in the use of autologous growth factors, as it has indeed happened following that publication.

Platelet-rich plasma (PRP) (also referred to as platelet-rich in growth factors, platelet-rich fibrin matrix, platelet-rich fibrin, fibrin sealant, platelet concentrate) is now being widely used to treat musculoskeletal injuries in sports and draws widespread media attention despite the absence of robust clinical studies to support its use.³ Of the few studies on the effectiveness of PRP in clinical settings published, very few are of sufficient methodological quality that would enable evidence-based decision-making.

PRP and its variant forms were originally used in clinical practice as an adjunct to surgery to assist in the healing of various tissues. PRP has also been used in prosthetic surgery to promote tissue healing and implant integration, and to control blood loss.^{4,5} Furthermore, the application of activated PRP has an effect on pain and pain medication use following open subacromial decompression surgery.⁵

Initially, PRP was mainly used in oral surgery.^{6,7} Subsequently, PRP has also been used at the time of surgery involving shoulder,⁸ hip⁹ and knee joint procedures,^{10,11} including anterior cruciate ligament (ACL) reconstruction,¹² and it has been used to improve bone healing.¹³ More recently, PRP in an injectable form has been used for the management of common muscle,¹⁴ tendon¹⁵ and cartilage injuries.¹⁶ As predicted by the 2008 IOC consensus document on the molecular mechanisms in connective tissue and skeletal muscle injury and healing,² there is significant anecdotal evidence that the use of PRP for treating musculoskeletal injuries has increased in recent times. Currently, PRP is not considered as a drug or a therapeutic substance, and so it does not have the usual regulatory requirements that would generally be needed for a substance used in regular clinical practice.

To discuss the use of PRP in a clinical setting, and the need for further research, the IOC assembled an expert group in May 2010 to critically review the current

state of PRP treatment among athletes, aiming to provide recommendations for clinicians, athletes and individual sports governing bodies. The purpose of this consensus paper is furthermore to review the evidence for the clinical effectiveness of PRP, its ergogenic potential and safety, and attempt to reconcile any possible disparity between its increasing popularity and the underlying science supporting its use. After an introduction into the basic science of PRP (i), the group considered the following issues regarding PRP use in clinical practice; (ii) the role of PRP in muscle injuries; (iii) the role of PRP in tendon injuries; (iv) the role of PRP in cartilage injuries and the healing of other tissues; (v) suggested techniques for the application of PRP and postinjection recommendations; (vi) potential adverse effects of PRP use; (vii) developing a randomised controlled trial (RCT) on PRP; (viii) PRP and antidoping regulations; and (ix) summary and recommendations.

Basic science of PRP

In broad terms, PRP may be defined as a volume of the plasma fraction of autologous blood having a platelet concentration above baseline,⁷ and is therefore a concentrated source of autologous platelets. Platelets contain a number of growth factors that play an important role in the healing of injured tissue.¹⁷ PRP is prepared from a volume of autologous blood using extracorporeal blood processing techniques such as blood cell savers/separators, table-top devices (centrifuges) and filtration methods. This volume may contain variable concentrations of red and white cells depending on the specific preparation technique that is used.

Not only can PRP be prepared in a variety of methods, but it can be administered in various forms; this diversity is reflected by the number of terms used to describe the product (table 1). These variations will inevitably influence the composition and potential effectiveness of the biologically active material.

Allogenic fibrin glue was originally described in 1970, and is formed by polymerising fibrinogen with thrombin and calcium.¹⁸ The first reference in the scientific literature to the use of PRP in clinical practice dates back to 1987, when PRP was used as an autologous transfusion component after open heart surgery to prevent the need for a homologous blood product transfusion.¹⁹ In 1990, an autologous fibrin gel (fibrin sealant or fibrin glue) was introduced; a biomaterial with

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Table 1 Names of production devices and products

Technology summary	Device name	Name of product	Increase in platelet no per ml above baseline	Platelet recovery (%)	Prepared product content
Floating buoy or shelf	Biomet GPS	PCP	3.2×	70	Buffy coat product: concentrated platelets, WBC fractions and minimal amount of RBC
	Harvest	PRP	4.6×	72	
	SmartPrep2		4.0×		
	BMACDepuy Symphony II		4.0×		
Cell-saver-based systems	Electa, Haemonetics, CATS, BRAT	PRP	4–6×	75	Platelet concentrate only
Computer aided system	Sorin Angel	PRP	4.3×	70	Buffy coat product: concentrated platelets, WBC fractions and minimal amount of RBC
	Arteriocyte Medical (Magellan)	PRP	5.1×	76	
Standard centrifugation	Autogel system	PRP	1–2×	78	Platelet in plasma suspension with minimum white cells and low concentration of platelets
	Smart PRP				
	Cascade PRFM fibrinet system	PRFM	1–2×	78	Platelet-rich fibrin membrane
Direct siphoning	Choukroun's PRF	PRF	1–2×	70	Leucocyte and platelet rich fibrin
	Genesis CS	PRP	6×	68	concentrates of platelets, leucocytes through siphoning device
Direct aspiration	Secquire Arthrex ACP	PRP ACP	1.6×	31	Manual aspiration of platelet and plasma after centrifuging
Platelet separation	Vivostat	PRF Fibrin sealant	6×	65	Platelet-rich fibrin Fibrin sealant without platelet
Platelet filtration	Caption	Platelet concentrate	4.3×	–	Concentrated platelets without plasma

ACP, autologous concentrated plasma; PCP, platelet concentrated plasma; PRF, platelet-rich fibrin; PRFM, platelet-rich fibrin matrix; PRGF, plasma-rich in growth factors; PRP, platelet-rich plasma; RBC, red blood cells; WBC, white blood cells.

haemostatic and adhesive properties.¹⁸ In 1999, the first autologous PRP prepared from a small quantity of blood was described.⁶

Despite limited scientific support, musculoskeletal practitioners began using PRP for the management of cartilage problems as early as 2003.¹⁵ The use of PRP in many fields of medical practice has recently expanded rapidly, with many articles being published. This results in part from its relative ease of use, relatively low cost and a strong commercial industry investment,²⁰ with the yet unsubstantiated promise that it may prove to be highly effective. In particular, in athletes with sporting injuries, especially in elite athletes where there is a relative urgency to facilitate a rapid return to competition, the use of PRP has expanded rapidly.

Platelets are cytoplasmic fragments of megakaryocytes that are formed in the bone marrow. They are the smallest of the blood components, with an irregular shape and a diameter of 2–3 µm. They lack nuclei, but contain organelles and structures such as mitochondria, microtubules and three forms of granules (α , δ and λ). The α granules, bound by a membrane, are formed during megakaryocytes maturation and are about 200 to 500 nm in diameter. There are approximately 50 to 80 granules per formed platelet.²¹ They contain more than 30 bioactive proteins,

many of which play a role in haemostasis or tissue healing.²² However, the entire and exact function of these proteins remains to be elucidated. These proteins are accumulated in α granules, and platelets contain distinct subpopulations of α granules that undergo differential release during activation,²³ a potentially important point in understanding how PRP is activated and acts. Platelets contain, synthesise and release large amounts of biologically active proteins that promote tissue regeneration. Researchers have identified more than 1100 types of proteins inside platelets or on their surface.¹⁸ The most commonly studied platelet proteins include platelet-derived growth factor (PDGF), transforming growth factor (TGF- β), platelet-derived epidermal growth factor (PDEGF), vascular endothelial growth factor (VEGF), insulin-like growth factor 1 (IGF-1), fibroblastic growth factor (FGF), epidermal growth factor (EGF) and cytokines including proteins such as platelet factor 4 (PF4) and CD40L. Chemokines and newly synthesised metabolites are also released (tables 2, 3).

The basic premise of PRP use in clinical practice is to facilitate the application of autologous plasma and platelet-derived proteins, in addition to developing at the desired location a fibrin scaffold that can act as a temporary matrix for cell growth and differentiation to assist repair in the injured tissue.²⁴

PRP can be prepared in a laboratory, an operating theatre or an appropriate room in the outpatient clinic from blood collected in the immediate pretherapeutic period. A sterile technique is followed when blood withdrawing, preparing and applying PRP. PRP can be applied percutaneously or during an open surgical procedure as fluid injections, gel or releasate serum, or mixed with other biological active materials such as bone and ligament grafts. During open procedures, PRP is activated to form a gelatinous mass to facilitate ease of application.⁸ During closed procedures, more applicable to sporting injuries such as soft tissue muscle and tendon injuries, PRP is injected by a syringe in a fluid form. It is recommended that the injections are administered under ultrasound guidance, thus ensuring the exact location of the product placements.

Platelets begin to actively secrete these proteins within 10 min of clotting, and more than 95% of the presynthesised growth factors are secreted within 1 h.²⁵ After the initial burst of growth factors, the platelets synthesise and secrete additional growth factors for the remaining several days of their life span.^{26,27}

When using anticoagulated PRP, activation is critical, as clotting results in the release of growth factors from the α -granules (degranulation) of the platelets. PRP may be activated immediately

Table 2 Growth factor release and their possible roles

Growth factor	Effect
Platelet-derived growth factor	Angiogenesis, macrophage activation Fibroblasts: proliferation, chemotaxis, collagen synthesis Enhances the proliferation of bone cells
Transforming growth factor-β	Fibroblasts proliferation Synthesis of type I collagen and fibronectin Induce deposition of bone matrix, inhibits bone resorption
Platelet-derived epidermal growth factor	Stimulates epidermal regeneration Promotes wound healing by stimulating the proliferation of keratinocytes and dermal fibroblasts Enhances the production and effects of other growth factors
Vascular endothelial growth factor	Vascularisation by stimulating vascular endothelial cells
Insulin-like growth factor 1	Chemotactic for fibroblasts and stimulates protein synthesis Enhances bone formation
Platelet factor 4	Stimulate the initial influx of neutrophils into wounds Chemoattractant for fibroblasts
Epidermal growth factor	Cellular proliferation and differentiation

Table 3 Growth factor receptors expression in musculoskeletal tissues²

Growth factor	Muscle	Tendon/ligament	Cartilage	Bone
Growth hormone	+	+	+	+
Insulin-like growth factor-1	2+	+	+	+
Mechano growth factor	3+	+	?	?
β-Fibroblast growth factor	+	±	+	+
Platelet-derived growth factor	-	±	-	±
Vascular endothelial growth factor	+	±	-	-
Transforming growth factor-β	±	±	+	+
Bone morphogenic protein	+	-	+	-

before application. Alternatively, activation can occur in vivo, that is, with or after the injection in the tissue of interest. There is no consensus on the timing of PRP activation, or even whether activation is necessary at all. Furthermore, there is currently no consensus on whether the PRP is better activated in vitro and placed in vivo, or whether we allow the local environment (in vivo) to activate. Originally, bovine thrombin was used as an activating agent, but the rare and major risk of coagulopathy from antibody formation has restricted the routine use of bovine thrombin. Calcium chloride and autologous prepared thrombin offer an alternative preinfiltration, in vitro activation means.⁶ Soluble type 1 collagen is equally effective as bovine thrombin in activating PRP.²⁸ By relying on this pathway of activation of PRP by soluble type 1 collagen, PRP can be injected inactivated and thus be activated by the presence of type 1 collagen in vivo in the tissue, the same principle followed when PRP is used at time of surgery.^{25 28 29}

In vitro, the application of PRP enhances gene expression of the extracellular matrix proteins,³⁰ collagen production²⁷ and tenocyte proliferation.²⁷ ³¹ Studies demonstrated the mitogenic

activity of PRP, and also that stimulated tenocytes synthesise important growth factors such as VEGF and HGF, suggesting a beneficial effect for the management of tendon injuries by inducing cell proliferation and promoting the synthesis of angiogenic factors during the healing process.³² Animal studies have confirmed the usefulness of platelet concentrate in acute tendon injury,³³ but this benefit of PRP is negated if the tendon is immobilised, and hence no mechanical stimuli are applied to the tendon during the critical healing period.³⁴

Many PDGFs are also involved in the homeostasis of articular cartilage. These growth factors have been studied in vitro and in vivo in animal models, and demonstrate some benefit for their potential in assisting cartilage repair, although the evidence of their efficacy in humans is still lacking.^{35 36} The growth factors described in most of the studies include the TGF-β super-family, PDGF, IGF and FGF.³⁷ Basic science studies have also documented the important role of growth factors in ligament and meniscus homeostasis and repair.¹¹ For example, PDGF, TGF-β1 and βFGF are actively involved during the early stage of medial collateral ligament and ACL healing,³⁸ and several growth

factors are also effective for meniscal regeneration.¹¹

In human tenocyte culture studies, PRP, but also platelet-poor plasma (PPP), stimulates cell proliferation and total collagen production. PRP, but not PPP, slightly increases the expression of matrix-degrading enzymes and endogenous growth factors.³⁹ This demonstrates the complex nature of PRP with more in vitro and in vivo studies being required to delineate the clinical practicality of such findings.

In addition to healing ability, PRP may also contain antibacterial effects that could demonstrate clinical benefits. PRP or platelet-leucocyte rich plasma prepared by two-step centrifugation of whole blood contains high concentrations of platelets and leucocytes. Both platelets and leucocytes play an important role in antimicrobial defence by performing opsonophagocytosis, chemotaxis and oxidative microbicidal activity.⁴⁰⁻⁴² Furthermore, platelets and leucocytes can release a variety of small cationic peptides (antibacterial peptides) that, upon contact with pathogens, exert bactericidal activity via a non-oxidative mechanism.⁴³ Another potential advantage is that in vitro and in vivo data have shown that these peptides possess potent microbicidal activities with minor cytotoxicity for relevant mammalian cells.⁴⁴ Thus, PRP may act in cooperation with the host immune defence system to defend invasion of pathogens.

At present, there are no published applications of the antibacterial effect of PRP in sports medicine. However, in a study evaluating the effect of PRP on the postoperative wound-healing process in patients receiving total knee prosthesis, 5% of patients not treated with PRP developed a superficial wound infection compared with none in the PRP group.⁴⁵ PRP eliminated superficial and deep wound infections in a study on the use of PRP in cardiac surgery.⁴⁶ In vitro, PRP gel displays antibacterial activity toward several bacterial strains, especially, methicillin sensitive and resistant *Staphylococcus aureus*. The antibacterial effects of PRP are transient, lasting for only 2-6 h.^{47 48}

In summary, the antimicrobial effect of PRP and its use in clinical practice is, as its role in healing and repairing cells and tissue, yet to be fully elucidated. However, there could be a future use for PRP in both the prophylaxis of infection, in particular for surgical wounds, and as adjuvant to normal treatment regimes.

Role of PRP in muscle injuries

Muscle strain and contusion injuries are common in sports, and result in time loss from training and competition. In many sports, particularly the football codes, muscle injuries are the single largest cause of time loss from injury.^{49–50} However, despite advances in rehabilitation programmes,⁵¹ reinjury rates for muscle injury remain high.^{52–54} Historically, the management of muscle injuries has involved the use of various stretching and strengthening regimes underpinned by a graduated return to activity and subsequent return to sporting competition. These management strategies lack sound scientific support. The rapid return to functional activity and minimisation of recurrence is the goal of any management intervention. In the past, there has been little direct intervention. However, to facilitate an earlier return to sporting competition and with less risk of injury recurrence, invasive techniques using various substances are currently being considered for use. These include traumeel (a homeopathic anti-inflammatory), actovegin (protein-free extract obtained from filtered calf blood), growth factors such as IGF-1 and PRP.⁵⁵ None of these proposed interventions, however, have any evidence base for their use in the treatment of muscle injuries.⁵⁶ While the use of recombinant growth factors for muscle injuries has a strong theoretical and scientific basis, cost, side effects and prohibition by World Anti-Doping Agency (WADA) contraindicate their use in athletes.⁵⁷ While acknowledging that the mode of delivery of growth factors (bolus vs sustained release) may impact significantly upon the clinical outcome in injured muscle tissue,⁵⁸ the recognised physiological benefits of recombinant growth factors include the enhancement of muscle regeneration and minimisation of scarring.⁵⁷

By contrast, while anecdotally being widely used in elite sport, the use of PRP for acute muscle injuries has little scientific support with very few studies in either animals or athletes.

In one study, 100 µl of PRP was repeatedly injected into the rat tibialis anterior muscle, which had been injured by superimposing a maximal isometric contraction onto either a single lengthening (large strain) or a series of multiple lengthening contractions (small strain). This resulted in a functional improvement in large strain injury rats at day 3, and small strain injury rats at days 7 and 14 when compared with the rats that had a similar injury

but with no PRP injected. Furthermore, evidence of elevated myogenesis was observed in the PRP treated group, but only in the small muscle strain injury model. Notwithstanding the observed outcome variability depending on the injury model utilised, and the unknown transferability of rat data to humans, this early research provides some support for the use of PRP in promoting muscle injury regeneration.⁵⁹

While not strictly PRP, another study investigated the potential of autologous growth factors to enhance recovery from muscle strain injury using autologous conditioned serum (ACS).¹⁴ By injecting 5 ml of autologous ACS, they compared the return to play time of 18 professional athletes with muscle strain injuries treated with ACS, with 11 athletes treated with traumeel and actovegin. While the authors report a significant reduction in return to play time for the treated group (16 vs 22 days), the large number of methodological concerns, including choice of control, lack of randomisation, lack of blinding and potential bias of the MRI, limits its interpretation. These two studies are the only studies present in the published scientific literature demonstrating the paucity of evidence for use of PRP in muscle-strain injury.^{14–59}

There are also two case reports utilising PRP for treating muscle-strain injuries.^{60–61} One described the use of serial PRP injections in a 35-year-old professional body builder with an ultrasound confirmed adductor longus muscle injury.⁶⁰ While the authors suggest that the recovery of this athlete was assisted by the PRP injections, the data presented provide only limited evidence for this. In the second case report, a single dose of injected PRP resulted in the rapid resolution, both clinically and at MRI, of a grade II semimembranosus muscle strain injury.⁶¹ This case also shows growth factor levels within the PRP consistent with previous reports, with the athlete experiencing no adverse effects from the procedure at a 12-month follow-up.

In summary, at present there is little scientific support for the use of PRP for the management of muscle strain injuries. This provides challenges for clinicians hoping to utilise this technology to treat this common sporting injury. Optimal timing, dose, volume, frequency, content and postinjection rehabilitation techniques require future clarification in order to provide any coherent guidelines, and future research should address these areas. However, as basic science supports the

use of specific growth factors in muscle regeneration with minimisation of muscle scarring, further investigation of the utility of PRP injection is warranted.

Role of PRP in tendon injuries

Chronic painful tendon disorders are common invalidating conditions in athletes, who can also suffer from acute and chronic, partial and complete, tendon tears.⁶² Tendinopathic lesions can occur along the entire course of the tendon (osteotendinous junction, main body of the tendon, musculotendinous junction). The surrounding tissues such as the tenosynovium and the peritendon can be affected alone or in combination with the main body of the tendon.⁶² Tendinopathy is characterised by swelling, pain and inability to perform at full capacity.

Despite the morbidity associated with tendon problems in athletes and an abundance of therapeutic options, management is far from scientifically based, and many of the therapeutic options in common use lack scientific support.⁶³ Although tendon biopsies show an absence of inflammatory cell infiltration, anti-inflammatory agents (non-steroidal anti-inflammatory drugs and corticosteroids) are commonly used,¹⁵ but their efficacy and effectiveness are dubious. In most instances, the rate of success using anti-inflammatory agents, defined as an improvement of symptoms and return to sport, is in the region of 65%, and the time to return to sport ranges from several weeks to several months.¹⁵

PRP is one treatment that is a considered option for management of chronic tendon injuries in athletes, with a positive effect of PRP on tendon healing having been established in several animal studies.²⁴ In one of these studies, PRP was percutaneously injected into the transected rat achilles tendon. This increased tendon callus strength and stiffness by about 30% after 1 week, and mechanical testing indicated an improvement in maturation of the tendon callus when compared with controls.³³ Another study showed that locally injected PRP in the rat patella tendon increased the activation of circulation-derived cells and the immunoreactivity for types I and III collagen at the early stages of tendon healing.³² Finally, the osteoinductive effect of PRP on tendon-to-bone healing was evaluated on a sheep infraspinatus repair model using MRI scan and histology. This study demonstrated an increased formation of new bone and fibrocartilage at the healing site.⁶⁵

Most of the scientific publications involving the use of PRP on human tendons are case studies, with the majority of them being of poor methodological quality (table 4). Studies on Achilles tendons,^{66 67} patellar tendons,^{68 69} wrist extensors²⁰ and supraspinatus tendons⁷⁰ have been published. At the moment, only a few level I studies (RCTs) have been published or are in press.^{71–74} One of these studies demonstrated a positive effect on human wrist extensor tendons following the injection of PRP,⁷¹ whereas the other study performed on achilles tendinopathy did not demonstrate any significant benefit from the injection of PRP.⁷² There is limited evidence that PRP exerts a beneficial effect in surgical repair achilles tendon, with earlier recovery from the procedure.^{67 73} In the rotator cuff, the evidence is contrasting.^{73 74} Two investigations suggest that injected PRP is beneficial in patients with chronic patellar tendinopathy.^{68 69}

It is difficult to formulate indications for the use of PRP on tendon injuries in a clinical setting based on the available scientific evidence. In a recent review investigating the use of autologous blood products, including PRP, in the management of tendinopathy, only three studies on PRP had adequate methodology.⁷⁵ All these three studies considered to have adequate methodology did not demonstrate any significant benefit from the injection of PRP into injured tendons.⁷⁵

In summary, there is a lack of well-designed studies to support the use of PRP in clinical settings in the management of tendon injuries. More research on basic science and the clinical application of PRP

needs to be undertaken before there is any comprehensive recommendation for PRP administration in injured human tendons. For each individual athlete and circumstance, a risk/benefit analysis should be performed before embarking on this as yet scientifically unproven therapeutic modality.

Role of PRP in cartilage injuries and the healing of other tissues

Cartilage, ligament, meniscal and labral injuries are common in athletes. Treatment options vary from traditional conservative management, to minimally invasive techniques, for example corticosteroid injections, to surgery. Sports-medicine physicians are faced with the additional challenge of high expectations regarding the resolution of these difficult athletic injuries in an accelerated fashion.

PRP injection has been proposed as a novel treatment modality for the management of articular cartilage injuries of the knee, hip and ankle. Even though clinical evidence is lacking some basic research supports the use of PRP-derived growth factors to improve tissue healing.⁷⁶ As articular cartilage injuries are such a large cause of athlete morbidity, and morbidity in the wider general community, any procedure or method that may assist in the reduction in morbidity in these athletes would be most welcome. Hence, this has produced an increased interest in PRP application for injured joints. The most common reported method of clinical application consists of multiple intra-articular injections of PRP.^{10 68 69}

There are few published clinical studies on the use of PRP in cartilage pathology. In a pilot study of 100 patients with osteoarthritis of the knee receiving intra-articular PRP injections, favourable results with pain reduction and improved function were reported.⁷⁷ Potential side effects of the injections were also monitored. Only minor adverse events, such as a mild pain reaction and effusion after the injections, have been reported. Patients were followed up at 2, 6, 12 and 24 months. Statistically significant improvement was observed in all the variables evaluated. However, these positive beneficial effects of pain reduction and improved function were reduced at the 12- and 24-month follow-up with a median duration of the beneficial effect of 9 months.⁷⁷

In another study, a larger and longer beneficial effect in pain reduction and improved function after PRP injection into affected knees was documented in young males with a low BMI and a low degree of cartilage degeneration. Other patients in this study demonstrated less durable results.⁶⁸

The intra-articular injection approach for the management of degenerative joint disease has also been compared with another treatment commonly used in clinical practice. An observational retrospective cohort study in patients with knee osteoarthritis that compared PRP injections with hyaluronan injections demonstrated better pain control and an improvement in physical function in the intraarticular PRP group.¹⁰ Philippon *et al* have published two papers on the use of PRP in the hip joint.^{78 79} However, no long-term follow-up is available.

Table 4 Studies on platelet-rich plasma and tendinopathy

Reference	Level of evidence	Tendon	Patients (n)	Follow-up	Outcome	Complications
Peerbooms <i>et al</i> ⁷¹	Prospective randomised study (level I)	Elbow extensor or flexor tendon	100	52 weeks	DASH score improved in both groups, but sign. much more in the platelet-rich plasma group	No
De Vos <i>et al</i> ⁷²	Prospective randomised study (level I)	Achilles tendon	54	24 weeks	Mean VISA-A score improved in both groups; however, no significant group differences	No
Randelli <i>et al</i> ⁷³	Prospective randomised study (level I)	Rotator cuff tendon	55	104 weeks	Significantly better external rotation strength, and higher SST, UCLA, constant scores 3 months after surgery, but no group differences after 2 years (only for subgroups)	No
Castricini <i>et al</i> ⁷⁴	Prospective randomised study (level I)	Rotator cuff tendon	88	65 weeks	No significant difference in total Constant Score or in MRI tendon score PFRM	No
Mishra & Pavelko ²⁰	Prospective cohort study (level II)	Elbow extensor or flexor tendon	20	25.6 months (12–38 months)	Reduction in visual analogue pain score (93% of treated patients)	No
Filardo <i>et al</i> ⁶⁸	Prospective cohort study (level III)	Patellar tendon	31	6 months	Significant improvements in Tegner score, EQ-5D VAS score and pain level	No
Gawedal <i>et al</i> ⁶⁶	Case-control study (level III)	Achilles tendon	14	18 months	AOFAS scale improved from 55 to 96 points VISA-A scale improved from 24 to 96 points	No
Sánchez <i>et al</i> ⁶⁷	Case-control study (level III)	Achilles tendon	12	32–50 months	Earlier regain of RO, and less time to start running and training	In the control group (wounds)
Kon <i>et al</i> ⁶⁹	Cohort study (level IV)	Patellar tendon	20	6 months	Improvements in Tegner, EQ-5D VAS and Short Form (36) Health Survey scores	No

AOFAS scale, American Orthopaedic Foot Ankle Society (AOFAS) midfoot score; DASH score, disabilities of the arm, shoulder and hand score; EQ-5D, EuroQol-5D; SST, simple shoulder tests; UCLA, University of California Los Angeles (UCLA) rating scale; VAS, visual analogue scale; VISA-A, Victorian Institute of Sport Assessment-Achilles.

Several growth factors may improve meniscal regeneration with the regenerative effect of PRP on meniscal cells having been documented both *in vitro* and *in vivo*,¹⁰ but there is a lack of clinical studies to prove its efficacy in human applications. One study has explored the role of PRP to augment meniscal repair and reported favourable outcomes,⁸⁰ though scientific evidence for the clinical efficacy of this approach is limited to this single study, and any clinical use in this context has been limited.

Some preliminary findings reported results with the use of PRP to augment ACL reconstruction. PRP was used with hamstring double bundle ACL reconstruction aiming to accelerate tendon-to-bone integration in the femoral tunnel, and therefore allow an earlier and safer return to sport.⁸¹ MRI performed 3 months after surgery failed to demonstrate an acceleration of PRP on tendon-to-bone integration. Other investigations using PRP on ACL reconstructions have demonstrated theoretical benefits on the use of PRP. One study showed no significant effects of the platelet concentrate on the osteoligamentous interface or tunnel widening evolution. However, the graft maturation as evaluated by MRI signal intensity was enhanced.⁸² Another recent study demonstrated a 48% shortening of the time required to achieve a complete homogeneous graft signal, measured by MRI, when PRP was added.¹²

The available clinical studies on PRP as a treatment option for articular injuries to the ankle, knee and hip are listed

in table 5. These reports on the use of PRP through intra-articular injections suggest a good potential in favouring pain reduction and improved function, but the methodology of these studies is questionable. The best procedure and proper application modalities still need to be defined. The procedures may vary widely among different groups not only for the type of platelet concentrate used, but also for many other aspects, such as number and frequency of injections, activation methods, storage modalities and associated treatments. At present, it is also not known how applicable the results of PRP being used for treating degenerative articular injuries in non-athletes would be for the active athletic population.

Suggested techniques for the application of PRP and postinjection recommendations

It is difficult to give guidelines on the application of PRP using scientific evidence, as there is not enough research comparing the different techniques. The following represents the majority viewpoint of the consensus committee on the current best practice administration of PRP.

Following appropriate clinical examination, imaging will assist in establishing the exact location and extent of the injury. As PRP is considered to act best when placed at the site of injured tissue, we recommend the use, if possible, of ultrasound guidance to verify accurate needle placement. With respect to tendon

administration, there is no agreement on whether the needle should be placed inside the tendon or in the surrounding tendon sheath. In the presence of exudates around the tendon, we suggest that this is evacuated before PRP is injected. If PRP is administered at arthroscopy, we suggest that the injection be performed after emptying the joint of arthroscopic fluid. In the case of open surgery, application of PRP can be undertaken using one of the gel and semisolid forms. At all times and in all situations, the preparation and administration of PRP should be performed under strict asepsis. Disagreement exists on the use of concomitant NSAIDs before the PRP treatment and during the first 2 weeks following its application. Although there are published data on the role of NSAIDs and the healing of various tissue such as bone, tendon and muscle, there are no data on concomitant use with PRP. Controversy also exists regarding the concomitant use of local anaesthesia for the application of PRP: with no available evidence, it is difficult to give a reasonable recommendation on whether using local anaesthetic will be detrimental to the final clinical outcome.

There is no general agreement on postinjection treatment. Most studies have allowed exercises after 2–5 days. Patients should follow general recommendations after an injection with rest, ice and limb elevation for 48 h. Depending on the site of treatment and extent and duration of the condition, patients could follow an accelerated rehabilitation protocols under appropriate supervision.

Table 5 Studies on platelet-rich plasma (PRP) and intra-articular lesions

Reference	No	Study design	Inclusion criteria	Intervention	Control group	Primary outcome measures	Follow-up (months)	Outcome intervention group (percentage improvement)	Outcome control group (percentage improvement)
Orrego <i>et al</i> ⁶²	108	RCT (level I)	ACL tear	PRP clotted around the graft and ACL reconstruction with bone plug	ACL reconstruction without PRP	MRI	3.6	Graft signal intensity 6 m: 100% mature with PRP, 93% mature with PRP+BP	Graft signal intensity 6 m: 78% mature with control, 89% mature with control+BP
Radice <i>et al</i> ¹²	50	Case control trial (level III)	ACL tear	PRP in a synthetic gelatin sutured on the ACL graft	ACL reconstruction without PRP	MRI	6	Homogeneity: 1.1 (0–4)	Homogeneity: 3.3 (0–4)
Sánchez <i>et al</i> ¹⁰	60	Case control trial (level III)	Knee OA	Three PRP injections	Hyaluronan injections	WOMAC	5 weeks	Pain subscale success: 34%	Pain subscale success: 10%
Silva <i>et al</i> ⁸¹	40	Case control trial (level III)	ACL tear	PRP in femoral tunnel PRP in femoral tunnel and intraarticular at 2–4 weeks PRP activated with thrombin in femoral tunnel	ACL reconstruction without PRP	MRI	3	NA	NA
Kon <i>et al</i> ⁷⁷	100	Case series (level IV)	Knee OA and cartilage lesions	3 PRP injections	No control group	IKDC subject (0–100) EQ-VAS score (0–100)	12	Mean IKDC score: 40.5 to 62.5 (34%) Mean EQ-VAS score: 50.3 to 69.5 (39%)	–

ACL, anterior cruciate ligament; EQ, EuroQol; Knee OA, knee osteoarthritis; IKDC, International Knee Documentation Committee; RCT, randomised controlled trial; VAS, visual analogue scale.

Potential adverse effects of PRP use

Oral and maxillofacial surgery is the medical field where the pioneering use of PRP was initiated. Based on long-term clinical experience in this field and thousands of patients being treated, the use of PRP is safe.^{83 84} In musculoskeletal tissues, although no long-term clinical studies with PRP exist, a large number of patients have been treated worldwide. Recently, Wang-Saugusa *et al*⁸⁵ reported that no adverse effects were observed when plasma rich in growth factors was infiltrated in more than 800 patients, many of whom suffered from knee osteoarthritis.

As, theoretically, PRP is an autologous preparation, immunogenic reactions or disease transmission should be prevented. As discussed above, the use of bovine thrombin for activation hypersensitivity may be a concern and is therefore avoided in modern preparation techniques. Indeed, development of antibodies against clotting factors V and IX leading to life-threatening coagulopathies has been reported.^{86–88}

To date, there is no compelling evidence of any systemic effect of local PRP injection. Furthermore, there are no scientific reports suggesting potential cause–effect relationships between growth factors present in PRP and carcinogenesis. Some potential arguments for these considerations include the limited need of PRP injections in clinics (as PRP is not chronically administered) and the short *in vivo* half-lives and local bioavailability of growth factors produced by PRP.

Developing an RCT on PRP

In general, most available clinical studies on PRP lack scientific stringency, making it difficult for the clinicians to assess the efficacy of using this new treatment modality. Much of what is known about the basic function of PRP and the effect on healing tendons, ligament, muscle and cartilage has been obtained from animal studies. Given the paucity of existing studies, the clinical applicability and safety of PRP need to be proven in humans for all forms of tissue pathology.

The production of scientific evidence may be pursued using different study designs. Case series, cohort studies and non-randomised trials provide some insight but provide limited compelling evidence.⁸⁹ RCTs provide the most compelling evidence as to whether a given intervention is effective and safe. Finally, the strongest evidence will be provided when sufficient data are available from different RCTs on the same topic and analysed using meta-analytical methods.

The best study to investigate the efficacy and safety of PRP in musculoskeletal injury would therefore be a double-blind, placebo-controlled RCT. In designing an RCT, the following elements are of major importance.

Clear inclusion and exclusion criteria

Particular attention should be given to any confounding variables that may affect healing response including age, gender, past treatment, concomitant medical conditions, lifestyle factors such as smoking and use of medication.

Study population

The study population should be as homogenous as possible. This can be difficult when considering the demands for an early and effective return to competition for high-level (elite) athletes. The natural history of the condition under study should be taken into account, and appropriate patient selection effected accordingly.

Clear diagnosis of the injury

The diagnosis of the injury should be based on standard clinical assessment, and must be confirmed using suitable imaging techniques.

Production of PRP

It should be clear which type of PRP product is used and how it has been prepared, validated and tested (table 1).

Delivery of PRP

It is considered critical that PRP is administered in the correct location. Therefore, any study should ensure that PRP is injected into the injured area. The amount injected and the number of injections must be clearly defined. Ideally, the platelet concentration should be determined, together with the content of growth factors.

Definition of outcome measures and end points

A robust study design would require well-defined outcome measures and end-points with follow-up measurements for at least 2 years. This is often poorly done in studies using athletes, where return to sport measure is often the only included outcome criteria. Nearly all athletes, particularly professional athletes, will attempt to return to sport irrespective of their underlying condition. Several rating scales and outcome measures can be used according to the body part and tissue studied.

Standardised post-treatment protocol

A standardised post-treatment protocol should be used in both treatment and control groups and the adherence to it assessed at equal intervals. This protocol

should be consistent with current best-practice guidelines for that particular condition.

Follow-up

The flow of the study participant should be carefully documented using the CONSORT 2010 flow chart.⁸⁹ The period of appropriate follow-up should be assessed according to the treated tissue.

Documentation of adverse events

All adverse events should be documented for the participants during the period of follow-up for several years.

Alternative to an RCT

The consensus group acknowledges that research in this field could also benefit from studies other than RCTs, such as prospective cohort studies. However, the consensus group cautions from basing therapeutic decisions uniquely on the lower level of evidence produced by such studies. Multicentre trials may be required to reach the large number of patients required to achieve a meaningful statistical analysis. Randomisation of centres in a cluster trial could offer a logistically acceptable solution for variation in practice between centres, but the intrinsic lack of equipoise in the different centres should be explicitly acknowledged, accounted for and built into the statistical model.

PRP and antidoping regulations

WADA publishes a list of prohibited substances and methods every year. According to the World Anti-Doping Code, a substance or method is considered for the list when two out of three criteria are fulfilled: (i) potential for performance enhancement, (ii) risks to health and (iii) violates the spirit of sport.

In 2010, PRP was specifically mentioned in the prohibited list for the first time.⁹⁰ Intramuscular PRP injections were prohibited. All other routes of administration, such as intra-articular, intra- or peritendinous were permitted and required only a declaration of use. Note that specific purified or recombinant growth factors (eg, IGF-1, VEGF, PDGF) are explicitly prohibited elsewhere in the list.⁹⁰ Growth factors are permitted only when part of platelet-derived preparations from the centrifugation of autologous whole blood.

There was concern by the WADA List Expert Group that growth factors contained in PRP may stimulate muscle satellite cells and increase muscular size and strength (beyond normal healing).

However, the different PRP formulations and treatment methodologies, as

they exist now, have not been found to increase muscle growth beyond return to a normal physiological state. There are some animal studies that show faster muscle regeneration and recovery to full function following experimentally induced injury, but no enhancement of performance beyond normal.¹⁴ There is a suggestion, but no compelling evidence, of systemic effects.^{58,91} The risk of adverse reactions (fibrosis, infection, carcinogenesis) are theoretical and have not been documented clinically. The use of PRP injections for therapeutic purposes only does not violate the spirit of sport.

The prohibition for intramuscular injections of PRP has been deleted in the 2011 Prohibited List.⁹² PRP is now permitted by all routes of administration. WADA will continue to review PRP use as new medical and scientific information becomes available.

Summary and recommendations

There is a limited amount of basic science research on the influence of PRP on the inflammation and repair of connective tissue and skeletal muscle. There is an even greater paucity of well-conducted clinical studies on the use of PRP to manage sport injuries. For clinicians, the generalisability of basic science must be tempered by clinical studies that inherently contain factors controlled for in basic science experiments. For these reasons, the design of robust clinical studies is essential for conclusions to be assigned sufficient validity to be used in clinical practice.

Although PRP has been in clinical use for decades, some basic science issues still require further investigation. Several techniques are available to prepare PRP; however, there is no evidence of standardisation of preparation (in terms, for example, of length and speed of centrifugation) and use of PRP. In addition, different methods of preparation may produce different platelet concentrations such as storing the PRP for differing lengths of time before use, using different anticoagulants and variable degrees of other cells such as red and white cells in the PRP preparation. It is therefore possible that each preparation method may lead to a different product with different biology and potential uses.

As stated, all these variables may produce PRPs in which the amount and type of growth factors are different. Therefore, a classification system for different PRPs should be developed and should be used to define the PRPs used by different research and treatment groups. For

clinical applications, based on different clinical conditions, the best time to inject PRP must be determined according to the different tissues and body districts. The kinetics of cytokine release from various PRPs with/without other biomaterials needs further investigation, as this may ultimately determine the best time for injection for a given PRP formulation. Furthermore, the tissue-specific effects of PRP should be compared, as the underlying cellular and molecular processes for a particular tissue healing may be markedly quite different. For instance, muscle and bone healing need vascularisation. However, a high degree of vascularisation may not be required for tendon and articular cartilage injuries. In fact, it is plausible that the effect of PRP on a given tissue is influenced by the microenvironment within that tissue, and therefore PRP activation may not be required prior its use. Lastly, the optimal use of PRP for regenerative medicine is still under investigation. Although application of the PRP may enhance mesenchymal stem cell proliferation and migration, exposure of cells to PRP may also limit differentiation of those cells into the appropriate cell lineages.¹⁷

The question arises in this consensus statement as to whether we as clinicians should use a treatment with very little scientific evidence supporting its clinical efficacy and with limited evidence supporting its safety. Medical ethics is anchored by the concepts of beneficence (doing good) and non-maleficence (do no harm). Medical ethics includes the concept of patient autonomy (self-determination). Western medicine tends to hold to the principle that patients can determine their treatment themselves, even if beneficence or non-maleficence is not proved. For the doctor, non-maleficence is the principal determinant of medical practice. While limited, current evidence suggests the use of PRP to be safe, and therefore the non-maleficence principle is probably upheld; however, there are few if any studies that document adverse or serious adverse events, and there are no studies at all looking at long-term effects. As there is little scientific evidence that PRP injections are of clinical benefit, beneficence is at this time not proven. Current medical ethics generally allows clinicians to make an individual choice to prescribe treatments that have not shown beneficence as long as the treatment is non-maleficent. With respect to PRP, its increasing popularity appears to have outreached in some respects the principle of medical ethics and the usual

conservatism that new treatments are taken up by the clinicians. Part of the answer to this would be that PRP is presently marketed and widely perceived as a natural healing method with the implications of minimal maleficence.

The role of PRP in tissue healing and regeneration may open a new area in regenerative medicine, but there remains a large amount of work required toward understanding the mechanism of action of PRP in the regeneration and repair process of a given tissue. Firm recommendations on the effectiveness of PRP in the clinical setting to support the healing processes of muscle, tendon, ligament and cartilage injuries cannot be given. Results of studies on PRP are difficult to interpret, as the methodological quality of published investigations varies substantially. More attention should be paid to methodological quality when designing, performing and reporting clinical trials.

The final recommendation of this consensus group would be to proceed with caution in the use of PRP in athletic sporting injuries. We believe more work on the basic science needs to be undertaken, and greater rigour should be implemented in developing robust clinical trials to demonstrate the efficacy or otherwise of PRP.

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REFERENCES

1. **Rompe JD**, Nafe B, Furia JP, *et al*. Eccentric loading, shock-wave treatment, or a wait-and-see policy for tendinopathy of the main body of tendo Achillis: a randomized controlled trial. *Am J Sports Med* 2007;**35**:374–83.
2. **Ljungqvist A**, Schweltnus MP, Bachl N, *et al*. International Olympic Committee consensus statement: molecular basis of connective tissue and muscle injuries in sport. *Clin Sports Med* 2008;**27**:231–9, x–xi.
3. **Mei-Dan O**, Mann G, Maffulli N. Platelet-rich plasma: any substance into it? *Br J Sports Med* 2010;**44**:618–9.
4. **Berghoff WJ**, Pietrzak WS, Rhodes RD. Platelet-rich plasma application during closure following total knee arthroplasty. *Orthopedics* 2006;**29**:590–8.
5. **Everts PAM**, Devilee RJJ, Brown-Mahoney Ch, *et al*. Platelet gel and fibrin sealant reduce allogenic blood transfusions and in total knee arthroplasty. *Acta Anaesthesiol Scand* 2006;**50**:539–90.
6. **Anitua E**. Plasma rich in growth factors: preliminary results of use in the preparation of future sites for implants. *Int J Oral Maxillofac Implants* 1999;**14**:529–35.
7. **Marx RE**, Carlson ER, Eichstaedt RM, *et al*. Platelet-rich plasma: Growth factor enhancement for bone grafts. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 1998;**85**:638–46.
8. **Everts PAM**, Devilee RJJ, Brown Mahoney C, *et al*. Exogenous application of platelet-leukocyte gel during open subacromial decompression contributes to improved patient outcome. A prospective randomized double-blinded study. *Eur Surg Res* 2008;**40**:203–10.
9. **Everts PA**, Jakimowicz JJ, van Beek M, *et al*. Reviewing the structural features of autologous platelet-leukocyte gel and suggestions for use in surgery. *Eur Surg Res* 2007;**39**:199–207.
10. **Sánchez M**, Anitua E, Azofra J, *et al*. Intra-articular injection of an autologous preparation rich in growth factors for the treatment of knee OA: a retrospective cohort study. *Clin Exp Rheumatol* 2008;**26**:910–3.
11. **Ishida K**, Kuroda R, Miwa M, *et al*. The regenerative effects of platelet-rich plasma on meniscal cells in vitro and its in vivo application with biodegradable gelatin hydrogel. *Tissue Eng* 2007;**13**:1103–12.
12. **Radice F**, Yáñez R, Gutiérrez V, *et al*. Comparison of magnetic resonance imaging findings in anterior cruciate ligament grafts with and without autologous platelet-derived growth factors. *Arthroscopy* 2010;**26**:50–7.
13. **Kawasumi M**, Kitoh H, Siwicki KA, *et al*. The effect of the platelet concentration in platelet-rich plasma gel on the regeneration of bone. *J Bone Joint Surg Br* 2008;**90**:966–72.
14. **Wright-Carpenter T**, Klein P, Schäferhoff P, *et al*. Treatment of muscle injuries by local administration of autologous conditioned serum: a pilot study on sportsmen with muscle strains. *Int J Sports Med* 2004;**25**:588–93.

15. **Magra M**, Maffulli N. Nonsteroidal antiinflammatory drugs in tendinopathy: friend or foe. *Clin J Sport Med* 2006;**16**:1–3.
16. **Sánchez M**, Azofra J, Anitua E, *et al*. Plasma rich in growth factors to treat an articular cartilage avulsion: a case report. *Med Sci Sports Exerc* 2003;**35**:1648–52.
17. **Bachl N**, Derman W, Engebretsen L, *et al*. Therapeutic use of growth factors in the musculoskeletal system in sports-related injuries. *J Sports Med Phys Fitness* 2009;**49**:346–57.
18. **Gibble JW**, Ness PM. Fibrin glue: the perfect operative sealant? *Transfusion* 1990;**30**:741–7.
19. **Ferrari M**, Zia S, Valbonesi M, *et al*. A new technique for hemodilution, preparation of autologous platelet-rich plasma and intraoperative blood salvage in cardiac surgery. *Int J Artif Organs* 1987;**10**:47–50.
20. **Mishra A**, Pavelko T. Treatment of chronic elbow tendinosis with buffered platelet-rich plasma. *Am J Sports Med* 2006;**34**:1774–8.
21. **Harrison P**, Cramer EM. Platelet alpha-granules. *Blood Rev* 1993;**7**:52–62.
22. **Anitua E**, Andia I, Ardanza B, *et al*. Autologous platelets as a source of proteins for healing and tissue regeneration. *Thromb Haemost* 2004;**91**:4–15.
23. **Italiano JE Jr**, Battinelli EM. Selective sorting of alpha-granule proteins. *J Thromb Haemost* 2009;**7** Suppl 1:173–6.
24. **Marx RE**. Platelet-rich plasma (PRP): what is PRP and what is not PRP? *Implant Dent* 2001;**10**:225–8.
25. **Andia I**, Sanchez M, Maffulli N. Tendon healing and platelet-rich plasma therapies. *Expert Opin Biol Ther* 2010;**10**:1415–26.
26. **Marx RE**. Platelet-rich plasma: evidence to support its use. *J Oral Maxillofac Surg* 2004;**62**:489–96.
27. **de Mos M**, van der Windt AE, Jahr H, *et al*. Can platelet-rich plasma enhance tendon repair? A cell culture study. *Am J Sports Med* 2008;**36**:1171–8.
28. **Fufa D**, Shealy B, Jacobson M, *et al*. Activation of platelet-rich plasma using soluble type I collagen. *J Oral Maxillofac Surg* 2008;**66**:684–90.
29. **Foster TE**, Puskas BL, Mandelbaum BR, *et al*. Platelet-rich plasma: from basic science to clinical applications. *Am J Sports Med* 2009;**37**:2259–72.
30. **Schnabel LV**, Mohammed HO, Miller BJ, *et al*. Platelet rich plasma (PRP) enhances anabolic gene expression patterns in flexor digitorum superficialis tendons. *J Orthop Res* 2007;**25**:230–40.
31. **Zhang J**, Wang JH. Platelet-Rich plasma releasate promotes differentiation of tendon stem-cells into active tenocytes. *Am J Sports Med* 2010; PMID 20802092; (In press).
32. **Kajikawa Y**, Morihiro T, Sakamoto H, *et al*. Platelet-rich plasma enhances the initial mobilization of circulation-derived cells for tendon healing. *J Cell Physiol* 2008;**215**:837–45.
33. **Aspenberg P**, Virchenko O. Platelet concentrate injection improves Achilles tendon repair in rats. *Acta Orthop Scand* 2004;**75**:93–9.
34. **Eliasson P**, Fahlgren A, Pasternak B, *et al*. Unloaded rat Achilles tendons continue to grow, but lose viscoelasticity. *J Appl Physiol* 2007;**103**:459–63.
35. **Saito M**, Takahashi KA, Arai Y, *et al*. Intraarticular administration of platelet-rich plasma with biodegradable gelatin hydrogel microspheres prevents osteoarthritis progression in the rabbit knee. *Clin Exp Rheumatol* 2009;**27**:201–7.
36. **Wu W**, Chen F, Liu Y, *et al*. Autologous injectable tissue-engineered cartilage by using platelet-rich plasma: experimental study in a rabbit model. *J Oral Maxillofac Surg* 2007;**65**:1951–7.
37. **O'Keefe RJ**, Crabb ID, Puzas JE, *et al*. Effects of transforming growth factor-beta 1 and fibroblast growth factor on DNA synthesis in growth plate chondrocytes are enhanced by insulin-like growth factor-I. *J Orthop Res* 1994;**12**:299–310.
38. **Lee J**, Harwood FL, Akeson WH, *et al*. Growth factor expression in healing rabbit medial collateral and anterior cruciate ligaments. *Iowa Orthop J* 1998;**18**:19–25.

39. **Tsay RC**, Vo J, Burke A, *et al*. Differential growth factor retention by platelet-rich plasma composites. *J Oral Maxillofac Surg* 2005;**63**:521–8.
40. **Lehrer RI**, Ganz T, Selsted ME, *et al*. Neutrophils and host defense. *Ann Intern Med* 1988;**109**:127–42.
41. **Yeaman MR**. The role of platelets in antimicrobial host defense. *Clin Infect Dis* 1997;**25**:951–68; quiz 969–70.
42. **Hammer JH**, Mynster T, Rosendahl S, *et al*. Bacterial antigen-induced release of white cell- and platelet-derived bioactive substances in vitro. *Int J Gastrointest Cancer* 2002;**31**:165–79.
43. **Zander DM**, Klinger M. The blood platelets contribution to innate host defense—what they have learned from their big brothers. *Biotechnol J* 2009;**4**:914–26.
44. **Stallmann HP**, Faber C, Nieuw Amerongen AV, *et al*. Antimicrobial peptides: review of their application in musculoskeletal infections. *Injury* 2006;**37** Suppl 2:S34–40.
45. **Everts PAM**, Knappe JTA, Weibrich G, *et al*. Platelet rich plasma and platelet gel. *J Extra Corp Techn* 2006;**38**:174–87.
46. **Trowbridge CC**, Stammers AH, Woods E, *et al*. Use of platelet gel and its effects on infection in cardiac surgery. *J Extra Corpor Technol* 2005;**37**:381–6.
47. **Moojen DJ**, Everts PA, Schure RM, *et al*. Antimicrobial activity of platelet-leukocyte gel against *Staphylococcus aureus*. *J Orthop Res* 2008;**26**:404–10.
48. **Bielecki TM**, Gazdzik TS, Arendt J, *et al*. Antibacterial effect of autologous platelet gel enriched with growth factors and other active substances: an *in vitro* study. *J Bone Joint Surg Br* 2007;**89**:417–20.
49. **Ekstrand J**, Häggglund M, Waldén M. Injury incidence and injury patterns in professional football—the UEFA injury study. *Br J Sports Med* Published Online First: 23 June 2009 doi:10.1136/bjism.2009.060582.
50. **Orchard J**, Seward H. Epidemiology of injuries in the Australian Football League seasons 1997–2000. *Br J Sports Med* 2002;**36**:39–44.
51. **Sherry MA**, Best TM. A comparison of 2 rehabilitation programs in the treatment of acute hamstring strains. *J Orthop Sports Phys Ther* 2004;**34**:116–25.
52. **Orchard J**, Best TM, Verrall GM. Return to play following muscle strains. *Clin J Sports Med* 2005;**15**:436–41.
53. **Malliaropoulos N**, Ntessalen M, Papacostas E, *et al*. Reinjury after acute lateral ankle sprains in elite track and field athletes. *Am J Sports Med* 2009;**37**:1755–61.
54. **Malliaropoulos N**, Papacostas E, Kiritsi O, *et al*. Posterior thigh muscle injuries in elite track and field athletes. *Am J Sports Med* 2010;**38**:1813–9.
55. **Orchard JW**, Best TM, Mueller-Wohlfahrt HW, *et al*. The early management of muscle strains in the elite athlete: best practice in a world with a limited evidence basis. *Br J Sports Med* 2008;**42**:158–9.
56. **McCroly P**, Franklyn-Miller A, Etherington J. Sports and exercise medicine—new specialisms or snake oil salesmen? *Br J Sport Med* Published Online First: 29 November 2009 doi:10.1136/bjism.2009.068999.
57. **Menetrey J**, Kasemkijwattana C, Day CS, *et al*. Growth factors improve muscle healing in vivo. *J Bone Joint Surg Br* 2000;**82**:131–7.
58. **Borselli C**, Storie H, Benesch-Lee F, *et al*. Functional muscle regeneration with combined delivery of angiogenesis and myogenesis factors. *Proc Natl Acad Sci USA* 2010;**107**:3287–92.
59. **Hammond JW**, Hinton RY, Curl LA, *et al*. Use of autologous platelet-rich plasma to treat muscle strain injuries. *Am J Sports Med* 2009;**37**:1135–42.
60. **Loo WL**, Lee DY, Soon MY. Plasma rich in growth factors to treat adductor longus tear. *Ann Acad Med Singap* 2009;**38**:733–4.
61. **Hamilton B**, Knez W, Eirale C, *et al*. Platelet enriched plasma for acute muscle injury. *Acta Orthop Belg* 2010;**76**:443–8.

62. **Maffulli N**, Khan KM, Puddu G. Overuse tendon conditions: time to change a confusing terminology. *Arthroscopy* 1998;**14**:840–3.
63. **Maffulli N**, Longo UG. Conservative management for tendinopathy: is there enough scientific evidence? *Rheumatology (Oxford)* 2008;**47**:390–1.
64. **Rees JD**, Maffulli N, Cook J. Management of tendinopathy. *Am J Sports Med* 2009;**37**:1855–67.
65. **Kovacevic D**, Rodeo SA. Biological augmentation of rotator cuff tendon repair. *Clin Orthop Relat Res* 2008;**466**:622–33.
66. **Gawedal M**, Tarczynska W, Krzyzanowska C. Treatment of achilles tendinopathy with platelet-rich plasma. *Int J Sports Med* 2010;**31**:577–83.
67. **Sánchez M**, Anitua E, Azofra J, et al. Comparison of surgically repaired Achilles tendon tears using platelet-rich fibrin matrices. *Am J Sports Med* 2007;**35**:245–51.
68. **Filardo G**, Kon E, Buda R, et al. Platelet-rich plasma intra-articular knee injections for the treatment of degenerative cartilage lesions and osteoarthritis. *Knee Surg Sports Traumatol Arthrosc* 2010;**18**:472–479.
69. **Kon E**, Filardo G, Delcogliano M, et al. Platelet-rich plasma: new clinical application: a pilot study for treatment of jumper's knee. *Injury* 2009;**40**:598–603.
70. **Randelli PS**, Arrigoni P, Cabitza P, et al. Autologous platelet rich plasma for arthroscopic rotator cuff repair. A pilot study. *Disabil Rehabil* 2008;**30**:1584–9.
71. **Peerbooms JC**, Sluimer J, Bruijn DJ, et al. Positive effect of an autologous platelet concentrate in lateral epicondylitis in a double-blind randomized controlled trial: platelet-rich plasma versus corticosteroid injection with a 1-year follow-up. *Am J Sports Med* 2010;**38**:255–62.
72. **de Vos RJ**, Weir A, van Schie HT, et al. Platelet-rich plasma injection for chronic Achilles tendinopathy: a randomized controlled trial. *JAMA* 2010;**303**:144–9.
73. **Randelli P**, Arrigoni P, Ragone V, et al. Platelet Rich Plasma (PRP) in arthroscopic rotator cuff repair. A prospective RCT study, 2 years follow-up. *JSES* 2010; (In press).
74. **Castricini R**, Longo UG, De Benedetto M, et al. Platelet-rich fibrin matrix augmentation for arthroscopic rotator cuff repair: a randomised controlled trial. *Am J Sports Med* 2010; (In press).
75. **de Vos RJ**, van Veldhoven PL, Moen MH, et al. Autologous growth factor injections in chronic tendinopathy: a systematic review. *Br Med Bull* 2010;**95**:63–77.
76. **Milano G**, Sanna Passino E, Deriu L, et al. The effect of platelet rich plasma combined with microfractures on the treatment of chondral defects: an experimental study in a sheep model. *Osteoarthr Cartil* 2010;**18**:971–80.
77. **Kon E**, Buda R, Filardo G, et al. Platelet-rich plasma: intra-articular knee injections produced favorable results on degenerative cartilage lesions. *Knee Surg Sports Traumatol Arthrosc* 2010;**18**:472–9.
78. **Philippon MJ**, Schroder e Souza BG, Briggs KK. Labrum: resection, repair and reconstruction sports medicine and arthroscopy review. *Sports Med Arthrosc* 2010;**18**:76–82.
79. **Philippon MJ**, Briggs KK, Hay CJ, et al. Arthroscopic labral reconstruction in the hip using iliotibial band autograft: technique and early outcomes. *Arthroscopy* 2010;**26**:750–6.
80. **Arnoczky SP**, Anderson L, Fanelli G, et al. The role of platelet-rich plasma in connective tissue repair. *Orthopedics Today* 2009;**26**:29.
81. **Silva A**, Sampaio R. Anatomic ACL reconstruction: does the platelet-rich plasma accelerate tendon healing? *Knee Surg Sports Traumatol Arthrosc* 2009;**17**:676–82.
82. **Orrego M**, Larrain C, Rosales J, et al. Effects of platelet concentrate and a bone plug on the healing of hamstring tendons in a bone tunnel. *Arthroscopy* 2008;**24**:1373–80.
83. **Anitua E**, Orive G. Short implants in maxillae and mandibles: a retrospective study with 1 to 8 years of follow-up. *J Periodontol* 2010;**81**:819–26.
84. **Anitua E**, Orive G, Aguirre JJ, et al. 5-year clinical experience with BTI dental implants: risk factors for implant failure. *J Clin Periodontol* 2008;**35**:724–32.
85. **Wang-Saegusa A**, Cugat R, Ares O, et al. Infiltration of plasma rich in growth factors for osteoarthritis of the knee short-term effects on function and quality of life. *Arch Orthop Trauma Surg* 2010; (In press).
86. **Spero JA**. Bovine thrombin-induced inhibitor of factor V and bleeding risk in postoperative neurosurgical patients. Report of three cases. *J Neurosurg* 1993;**78**:817–20.
87. **Cmolik BL**, Spero JA, Magovern GJ, et al. Redo cardiac surgery: late bleeding complications from topical thrombin-induced factor V deficiency. *J Thorac Cardiovasc Surg* 1993;**105**:222–7; discussion 227–8.
88. **Ortel TL**, Mercer MC, Thames EH, et al. Immunologic impact and clinical outcomes after surgical exposure to bovine thrombin. *Ann Surg* 2001;**233**:88–96.
89. **Schulz KF**, Altman DG, Moher D. CONSORT 2010 statement: updated guidelines for reporting parallel group randomized trials. *Ann Intern Med* 2010;**152**:726–32.
90. WADA, The World Anti-Doping Code. *The Prohibited List 2010. International Standard 2009*. Montreal: World Anti-Doping Agency.
91. **Banfi G**, Corsi MM, Volpi P. Could platelet rich plasma have effects on systemic circulating growth factors and cytokine release in orthopaedic applications? *Br J Sports Med* 2006;**40**:816.
92. WADA The World Anti-Doping Code. *The Prohibited List 2011*. Montreal: World Anti-Doping Agency.