REVIEW

Blood boosting

S Leigh-Smith

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This article reviews the history, technique, effects, side effects, and detection of blood boosting. It also considers whether or not this particular performance enhancement technique is a thing of the past or a continuing form of abuse among athletes.

The term "blood boosting" is used in this article to refer to infusion of blood or blood products into an athlete to increase performance.[1] Although this technique has also been previously referred to as "blood doping", the latter term is now more commonly associated with recombinant human erythropoietin (rHuEpo) induced erythropoiesis and so will not be used further in this article.

RECENT USAGE

In March 2002 at the Salt Lake City Olympics, the International Olympic Committee (IOC) investigated the discovery of discarded blood transfusion equipment at the quarters of the Austrian cross country skiers. The Austrian Ski Federation claimed that the equipment had been for treating blood. They described the method as being exclusively for the prevention of colds and flu, not doping, indicating that it was common among non-medical practitioners and at spas. The technique apparently involved treatment of small volumes of blood with ultraviolet light and magnetic fields before reinjection, along with giving the athlete a vitamin C dose, but their team doctor was not aware that the skiers were using this method. After DNA testing, two Nordic skiers (who had been placed in the 40s and not the Austrian team's three medallists) were disqualified and had their results cancelled. Their coach and chiropractor were banned from the next two Winter Games. The IOC later dismissed the claims because the Austrians had failed to produce any satisfactory evidence of therapeutic use, adding that any manipulation of blood is considered a form of blood doping (banned by the IOC). The IOC expressed surprise at the potential use of traditional blood boosting by the Austrians, as it had been assumed to be virtually obsolete since the advent of rHuEpo induced erythropoiesis.[2]

With increasing numbers of athletes being caught in rHuEpo scandals—for example, in the 1998 Tour de France—and with rHuEpo in the process of being brought under control,[3] athletes' interest may turn back to more traditional forms of blood boosting that are more difficult to detect.[4] Indeed critics of the IOC's rHuEpo testing during the Sydney games in 2000 said these would probably not make a significant impact on doping because athletes would just switch to other undetectable methods, such as blood boosting.

HISTORY

The first alleged use of blood boosting in sport was in the 1960s, when a French four times winner of the Tour de France (1961–1964) was named as one of the first cyclists to use the technique. Widespread use among endurance athletes (especially running, cycling, and cross country skiing) started after the 1968 Olympic Games, in Mexico City which is situated at an altitude of 2300 m.[1] Here the athletes from higher altitudes performed better in the endurance events because of various physiological acclimatisation adaptations, including increased red blood cell (RBC) mass.[5] Blood boosting was the method adopted by many athletes after Mexico to increase their aerobic performance.[6] It did not come to general public attention until the early 1970s when it was termed "blood doping" by the media.[7 8] This followed a Finnish steeplechaser using the technique before winning two gold medals in endurance runs at the 1972 Munich Olympics.[1] The technique became more popular during the 1980s and was used by distance runners (5000 m, 10000 m, marathon runners), cyclists, and skiers.[1 9–11] Specific accusations were made against the Russians, Italians, Finns, Americans, and East Germans, particularly during the 1980 and 1984 Olympics.[1 9 10] Athletes who admitted using the technique included the Italian cyclist who beat the one hour world record in 1984 and a Russian distance runner who specifically admitted to autologous transfusion with two units by team doctors in 1980.[1] The US Olympic cycling team also admitted to having received homologous transfusions from friends and family before achieving outstanding results in the 1984 Olympic games, winning a record nine medals despite not having performed well in past Games.

The IOC forbade blood boosting after the 1984 Olympics, despite the fact that no methods had been devised for unequivocal detection.[7]

Blood boosting became less widespread after 1987 (despite admitted use by a US Nordic skier in that year)[9] with the invention of rHuEpo to stimulate erythropoiesis in patients with renal failure. rHuEpo was soon adopted as the standard drug by which athletes could illegally

Correspondence to:
S Leigh-Smith, Defence Medical Services, Edinburgh EH9 1EB, Scotland, UK;
simonlsuk@aol.com

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Abbreviations: Hb, haemoglobin; IOC, International Olympic Committee; RBC, red blood cell; rHuEpo, recombinant human erythropoietin; VO_{2MAX}, maximal oxygen uptake

boost their RBC mass, and the need for blood boosting diminished.

TECHNIQUE

Blood boosting uses intravenous infusion of blood to produce an increase in the blood's oxygen carrying capacity[12] and is either from a matching donor (homologous) or by reinfusion of one's own blood (autologous). This can produce an increase in RBC mass of up to 10%,[13] whereas it may take many months of natural training to increase it by just 5%.

In autologous transfusion, 1 to 4 units (450–1800 ml) of blood are withdrawn then centrifuged. The plasma components are immediately reinfused while the packed RBCs are placed in cold storage.[14] This involves removing blood 8–12 weeks before the event, as it takes this long for the body to re-establish RBC mass to the levels that existed before withdrawal.[15] The withdrawn blood is then stored for reinfusion one to four days before competition.[6 16]

The disadvantage of this is the decrease in maximal oxygen uptake ($V_{O_2}MAX$), which occurs as a result of decreased exercise intensity while waiting for the venesection induced anaemia to correct.[10 17] A second problem is the RBC haemolysis at roughly 1% a day when the blood is refrigerated at 4℃.[6 13 18] Lack of increased athletic performance in the early days of the technique were due to either the athletes not allowing eight weeks for their own anaemia to revert to normal, or waiting too long, by which time very few of the stored RBCs were still viable. However, when the venesection is carried out 16 weeks before the event and reinfusion is performed about eight weeks before the competition, the haemoglobin (Hb) concentration is raised, as well as allowing time for high intensity training, which further increases $V_{O_2}MAX$ above the athlete's normal levels.[10] This still has a performance effect, as, although maximal Hb increase occurs in the two weeks after infusion, high concentrations remain for two to three months.[18]

The technique is further refined with the use of glycerol freezing of the RBCs at −80℃, which almost halts the haemolysis and allows blood storage for up to 10 years with only 10–15% RBC loss.[19] Before reinfusion, the cells are thawed, washed to remove the glycerol, and suspended in a saline solution with a packed cell volume of about 0.50.[10]

Homologous transfusion avoids all these difficulties but has the major risk of cross infection[19] and is easier to detect with partial agglutination reaction tests.[4]

EFFECTS

A brief review of early work into the role of cardiac output, $V_{O_2}MAX$, blood volume, and RBC mass on athletic performance is provided in a recent article in this journal.[20]

Increased performance after blood transfusion was first shown as early as 1947,[21] but the first pivotal results came from the experiments of Ekblom *et al*[22] on human volunteers in 1972. These clearly showed considerable overnight increases in performance with autologous transfusion of packed RBCs from an earlier 800 ml venesection. There was a strong positive correlation between Hb concentration and $V_{O_2}MAX$ ($r = 0.97$) and total Hb and $V_{O_2}MAX$ ($r = 0.79$), along with a 23% increase in maximal work time.[22]

Since this early work, increased $V_{O_2}MAX$ along with performance in endurance sports, from blood boosting, has been widely reported.[10 11 18 23–25] Robertson *et al*[26] showed a 12.8% increase in $V_{O_2}MAX$ 24 hours after reinfusion of 750 ml packed RBCs, but, in contrast with Ekblom *et al*[22] they found that any performance improvement did not show a direct relation to the changes in haematological variables. Berglund *et al*[11] showed a 4–6% decrease in 15 km time, when compared with controls, for six well trained cross country skiers at both three hours and 14 days after reinfusion of 1350 ml autologous blood. A double blind field study showed a 69 second improvement in runners' 10 km race time after blood boosting.[27] Faster and/or longer treadmill endurance tests have also been shown.[24 25 28] Other work has shown that $V_{O_2}MAX$ and time to exhaustion (on a maximal treadmill run) is increased in relation to the increased Hb concentration, whether this is achieved through acute (blood boosting) or slow (rHuEpo) techniques.[29]

The major effect of blood boosting is related to the increase in total RBC mass, as the transient increase in blood volume and cardiac output after reinfusion is too short lived to be of any real importance.[10] Any substantial increase in Hb will increase the $V_{O_2}MAX$ of an athlete,[30 31] and, as each fully saturated gram of Hb carries 1.34 ml oxygen, a 20 g/l increase in Hb will raise the oxygen carrying capacity of 1000 ml blood by 25 ml. In an athlete with a mixed venous saturation of about 50%, half would be available to the working muscle, and, at a cardiac output of 24 litres per minute, 300 ml extra oxygen would be available for the tissues per minute.[6 10] This assumes that the additional oxygen can be used by the exercising muscle and that the cardiac output is not decreased by increased blood viscosity resulting from the raised packed cell volume.[32]

Blood boosting has also been shown to increase heat tolerance in athletes.[10 33 34] This may be due to the lower exercise intensity with lower muscle blood flow for a set work rate, which will increase the skin blood flow.[32] Immediately after reinfusion, however, it may be through the increased blood volume, which serves as a reserve to support thermoregulation.

There is a theoretical risk of blood boosting increasing the susceptibility to peripheral cold injury. This may occur when the increased blood viscosity is combined with the physiological cold induced vasoconstriction.

Another effect is an ''altitude lowering'' effect for those competing at altitude. Pace *et al*[21] showed that subjects infused with 1000 ml RBCs exhibited lower heart rates while walking at a simulated altitude of 4712 m than control subjects.

Blood boosting can also help athletes in anaerobic sports, as Hb provides 70% of proton buffering.[4] The extra Hb and proton buffering capacity will raise the lactate threshold[10 32] and lower lactate concentrations during submaximal exercise.[23]

SIDE EFFECTS

Hyperviscosity is a particular risk in athletes trying to maximise their RBC mass, and the risk rises exponentially as packed cell volume increases above 30%.[27] The deaths of 18 Dutch and Belgian cyclists with very high packed cell volumes between 1987 and 1990 has never been fully explained, but may have been due to blood boosting or rHuEpo use causing hyperviscosity.[1] A raised viscosity may decrease peripheral blood flow (Poiseulle's law) and cardiac output by increasing the cardiac work. This would have the opposite effect to that sought by the athlete and would decrease their aerobic capacity.[14]

All RBC transfusions carry the risks of phlebitis, septicaemia, hyperviscosity syndrome, bacterial infections, and air embolism.[19] Homologous transfusion carries the added risk of viral infection (predominantly hepatitis C/hepatitis B/HIV), major transfusion reactions from blood type incompatibility, minor transfusion reactions including fever/myalgia, and transfusion related acute lung injury.[19 35]

Even autologous transfusion carries infusion related morbidity associated with clerical error.

What is already known on this topic

Blood boosting as a method of performance enhancement gives a recognised physiological advantage to the athlete. It was probably widely used during the 1970s and 1980s, although exact usage levels may never be known. rHuEpo was thought to have replaced it as the main mechanism for illegally increasing haemoglobin concentration.

What this study adds

This review suggests that blood boosting may not be obsolete. It gives a history of its original usage as well as potential recent uses. It reminds readers of the technique used, its physiological basis, complications, and potential means of detection.

SUMMARY

Performance in sport through autologous blood transfusion may not be a thing of the past. The combination of rHuEpo and autologous blood transfusion may allow enhanced autologous transfusion,[2] which may explain the blood transfusion bags found at Salt Lake City. Correct timing of rHuEpo injections along with the use of intravenous iron would allow larger blood deposits to be made[36–38] while keeping RBC mass, Vo_2max, and training intensity constant.

Detection is so important that a multinational collaboration (Science and Industry Against Blood Doping) of researchers, pharmaceutical companies, and haematologists exists dedicated to the subject. Techniques have been developed for detection of non-autologous (allogenic) blood transfusions and were used at the 1994 Winter Olympics.[39] However, autologous RBC transfusion remains notoriously difficult to detect.[7 23] Recent attempts at blood doping detection relying on upper limits for Hb concentration and packed cell volume may unfairly disqualify some athletes, as about 5% genetically have high readings and others may legitimately use altitude training/living.[4]

A suggested way of detecting all types of blood doping is the ''haematological passport'', which involves regular blood testing and enables a trend for an athlete's haematological values to be established.[4] Any unexpected or sudden deviation from the norm would lead to further investigations or banning. To detect sudden autologous transfusion requires mobile blood testing facilities at competition sites, as used at the Sydney 2000 Olympics. Haematological passports and testing after competitions are gaining support from others[8] and are already used by the Italian Cycling Federation, the International Cycling Union, and the International Ski Federation. The Finnish Ski Federation is even putting the haematological values of its skiers on its web site!

Far from being consigned to the history books, blood boosting may still be a current topic worthy of a sports physician's attention.

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Notes