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# Intermittent pneumatic compression in fracture and soft-tissue injuries healing

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**Introduction**: Current methods of fracture care use various adjuncts to try and decrease time to fracture union, improve fracture union rates and enhance functional recovery. Intermittent pneumatic compression (IPC), one such modality, is used in the management of both fractures and soft-tissue injuries.

**Methods and results**: A search of PubMed, Medline, CINAHL, DH data and Embase databases was performed using the following keywords 'intermittent pneumatic compression', 'fracture healing' and 'soft tissue healing'. Sixteen studies on the use of IPC in fracture and soft-tissue healing were identified. These studies demonstrated that IPC facilitates both fracture and soft-tissue healing with rapid functional recovery.

**Conclusions**: IPC appears to be an effective modality to enhance fracture and soft-tissue healing. However, the number of subjects in human studies is small, and adequately powered randomized controlled trials in humans are required to produce stronger clinically relevant evidence.

*Keywords:* intermittent pneumatic compression/fracture healing/soft tissue healing

## Introduction

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Modern fracture care aims to achieve union and to restore function as soon as possible. This has led to the introduction of several treatment modalities to enhance healing and expedite recovery.[1] Intermittent pneumatic compression (IPC) is one of them. The concept of IPC has been experimented with since the nineteenth century, when physicians tried to improve circulation by exerting external pressure on the legs.[2] Cyclic positive and negative pressure improved arterial circulation in patients with arteriosclerosis and tromboangitis obliterans.[3] IPC is used mainly to prevent deep vein thrombosis, but its potential role in fracture and soft-tissue healing has also been investigated. IPC has the potential of enhancing the fracture and soft-tissue healing process with early return to functional activities.[4,5]

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This review explores the rationale of use of IPC, and investigates the role of IPC in fracture and soft-tissue healing.

## Methods

A search of PubMed, Medline, CINAHL and Embase databases was performed using the following keywords 'intermittent pneumatic compression', 'fracture healing' and 'soft tissue healing'. Studies detailing the use of IPC in fracture and soft-tissue healing were identified, and their bibliographies thoroughly reviewed to identify further related articles. This search identified 16 studies which investigated the use of IPC in fracture and soft-tissue healing.

## Exclusion criteria

Studies in language other than English and those published as abstracts only were excluded from the present investigation.

## Mechanism of action of IPC treatment

Human and animal studies have been performed (Tables 1 and 2), but the exact mechanism by which IPC enhances fracture and soft-tissue healing is unknown. Several hypotheses have been postulated.

### *Mechanical effect*

#### Improvement in vascularity

When compression is applied, the sudden pressure gradient at the compression zone accelerates the blood forward with subsequent collapse of the lumen of the vessel at the compression zone, effectively facilitating venous return. The accelerated blood moves forward as a pulsatile volume that causes distension of the compliant lumen. If the pressure is applied sequentially, the accelerated blood flow could increase the peak flow velocity by over 200% within the lumen. The higher flow velocity increases the shear stress[6] on the endothelial cells lining the lumen, which may also facilitate clearance of the valve sinuses. The improved emptying of lower extremity veins and lowered venous pressure lead to an increase in arteriovenous pressure gradient and decreased peripheral resistance.[7] This increased disparity of pressure induces an increase in lower extremity arterial blood flow.[8] This increase in blood flow not only improves

**Table 1** Human studies

| Study | Year | | Type of study | Number of subjects |
|---|---|---|---|---|
| Challis | 2007 | Distal radius fractures | Prospective Randomized controlled trial | 21 participants (11 study and 10 controls) |
| Albertazzi | 2005 | Bone mineral density in women with low bone mass | Prospective study | 37 recruited 24 completed |
| Morris | 2005 | Bone uptake of (99 m)Tc-labelled MDP in the lower limbs | Prospective study | 24 participants |
| Caschman | 2004 | Ankle fractures | Prospective Randomized controlled trial | 64 recruited, 10 excluded with 27 study patients and 27 controls |
| Thordarson | 1999 | Calcaneal fractures | Prospective Randomized controlled trial | 38 recruited (13 study and 15 controls) |
| Thordarson | 1997 | Ankle fractures | Prospective Randomized controlled trial | 30 recruited (15 study and 15 controls) |
| Myerson | 1993 | Trauma and major surgery to the foot and ankle | Prospective study | 55 recruited Group A consisted of 19 patients and 19 controls with acute swelling of the foot and ankle after major elective or post-traumatic surgery. Group B comprised 18 patients and 16 controls with chronic post-surgical or post-traumatic swelling |
| Airaksinen | 1990 | Acute ankle sprains | Prospective study | 44 recruited (22 study and 22 controls) |
| Airaksinen | 1989 | Lower leg fractures | Prospective study | 34 recruited (22 study and 12 controls) |

**Table 2** Animal studies

| Study | Year | Animal model | |
|---|---|---|---|
| Park | 2008 | Rabbits | Mid-diaphysis on the right tibia blood flow |
| Challis | 2007 | Sheep | Distal-radius osteotomy |
| Dhal | 2007 | Rat | Achilles tendon rupture |
| Hewitt | 2005 | Male Beagles | Right-radius osteotomy |
| Park | 2003 | Rabbits | Mid-tibial osteotomy |
| Goodship | 1985 | Sheep | Tibial diaphysial osteotomy |
| Panjabi | 1979 | Rat | Long-bone osteotomies |

cutaneous circulation but also increases the vascularity of bone and soft tissues.[5,9] The increased blood flow to the bone is likely to improve blood flow to the fracture site, thereby increasing the supply of essential elements such as growth factors, proteins, oxygen and other components necessary for fracture repair. This finding has been supported by the formation of abundant callus at the fracture site, increased bone mineral density and bone mineral content following IPC treatment.[10–13]

In a study involving 30 skeletally mature male beagles, intermittently increased venous pressure proximal to a bone defect enhanced the formation of new bone without soft-tissue complications.[11]

Park and Silva[12] performed a mid-tibial osteotomy with a 3 mm gap in 30 rabbits, and stabilized it with a double-bar external fixator. There was an increase in callus area and mineral content at the osteotomy gap in the study group, compared with the values in the control group, starting from 4 weeks after the index procedure. At 6 weeks, the rabbits treated with IPC exhibited, on the average, a 32.2% larger callus area ($P = 0.035$) and a 49.7% higher mineral content ($P = 0.01$) at the osteotomy site compared with the values in the control group. The torsional stiffness, maximum torque, angular displacement at maximum torque and energy required to failure of specimens in the study group were an average of 27.0 ($P = 0.05$), 61.5 ($P = 0.0001$), 35.4 ($P = 0.0003$) and 110.8% ($P = 0.0001$) higher, respectively, than those in the control group at 8 weeks.

### Redirection of blood flow

The venous channels in the long bones may act as collateral channels to restore outflow in the presence of compression. Therefore, general blood flow through bone would increase when compression is applied to the limb. The above observation has been supported by the fact that, under pressure from a thigh tourniquet, blood from the popliteal vein can be shunted via the inferior metaphyseal veins to central venous sinus to superior metaphyseal vein to medial and lateral circumflex femoral to gluteal veins to internal iliac to inferior vena cava. This, in turn, is due to the absence of valves in venous sinus of the bone.[14] The hypothesis has been confirmed by experiments in cats, where, after femoral vein ligation, an increase in metaphyseal blood flow was measured using heated thermocouples.[15,16]

In a study on 21 rabbits, laser probes were inserted at three different sites of the mid-diaphysis on the right tibia: in the medullary canal, outside the periosteum on the lateral side and outside the periosteum on the medial side. IPC was applied for 30 min through cuffs placed around the feet and the lower part of the calf. There was a 47 ($P = 0.002$) and 89% ($P = 0.02$) increase in total amount of blood flow outside the lateral and medial periosteum, respectively.[5] IPC resulted in a significant local increase in total blood flow to the bone.

A study in 24 patients evaluated the effect of IPC of the thigh and calf on the uptake of (99 m) Tc-methylene diphosphonate (MDP).[17] All were undergoing routine bone imaging for medical conditions not involving their lower limbs, and received 1 h IPC at 60 mmHg on one limb only, after injection of the radiopharmaceutical. Three hours after injection, the median differences in uptake in the intermittently

compressed limb compared with the contralateral limb were +7.6% ($P < 0.0005$) for the anterior aspect of the femur; +11.7% ($P < 0.0005$) for the posterior aspect of the femur; +10.5% ($P < 0.0005$) for the anterior aspect of the tibia and +10.6% ($P < 0.0005$) for the posterior aspect of the tibia. IPC significantly increased the uptake of (99 m) Tc-MDP in long bones.

### Cyclical loading

Fracture healing is largely dependent on the prevailing mechanical environment of the fracture.[18,19] Compressive forces probably impart the greatest positive influence on the mechanical environment of healing.[18–21] Several studies have demonstrated the positive effect of cyclic loading on osteogenesis,[22,23] and cyclic loading, which enhances fracture healing in animal models, may also positively influence fracture healing in humans.[13,24]

Challis *et al.*,[24] in an experiment using distal radii of 10 fresh sheep foreleg, showed that application of IPC to the proximal foreleg musculature produced a corresponding increase in load at the osteotomy site. For the cuff pressures tested (109.8–238.4 mmHg), there was a linear correlation ($r = 0.99$) with the load at the osteotomy site with a gradient of 12 mmHg/N. It was postulated that predominantly compressive load applied to muscles proximal to the fracture site may help produce cyclic loading at the fracture site which may in turn enhance fracture healing. This effect of IPC may have a role in the management of upper limb fractures.

Albertazzi *et al.*[13] studied 37 postmenopausal women with low bone density (T score $< -1$). Women applied intermittent compression for 2 h a day for 6 months to each leg in turn. The women also took 1 g of Calcium and 800 IU of vitamin D daily. At 12 months, the bone mineral density of the right femoral neck increased by 3% compared with baseline (mean 0.811 +/− 0.08, $P = 0.22$), while the left increased 2% (0.783 +/− 0.06, $P = 0.16$). There was no change in bone mineral density at the distal tibia or heels, and no local effect. IPC may have a role in osteoporosis prevention, and may inhibit a decline in the bone mineral density of the femoral neck, particularly in sedentary women.

## *Chemical effect*

### Generation of nitric oxide

IPC may produce shear stresses on endothelium. This shear on the endothelial cells produces nitric oxide.[25] Nitric oxide is a potent inhibitor of smooth muscle cell contractions, causing vasodilatation. When cultured endothelial cells were exposed to 24% cyclic strain at 60 cycles/min,

they exhibited significant increased endothelial nitric oxide synthase activity when compared with controls.[26] Also, in a study of 80 male rats, vasodilatation was maximal 30 min after initiation of IPC, and was completely blocked by an inhibitor of nitric oxide (NG-monomethyl-L-arginine).[27]

### Increase in inflammatory mediators

Sensory neuropeptide, calcitonin gene-related peptide (CGRP) and substance P (SP) are among the cascade of mediators which are not only pro-inflammatory but also promote healing by encouraging proliferation of fibroblasts and endothelial cells.[8, 28] IPC enhances their presence at the site of injury.

Dhal *et al.*[9] studied the effects of IPC on healing of Achilles tendons in rat models with daily 1-h IPC treatment during 2 and 4 weeks post-rat Achilles tendon section. The tendons were subjectively and semi-quantitatively analysed for collagen organisation, fibroblast density, angiogenesis and the occurrence of sensory neuropeptides, SP and CGRP, as well as for a nerve regeneration marker, growth associated protein 43 (GAP-43). After 2 weeks of treatment, fibroblast density increased by 53% ($P = 0.0004$), vessel density by 64% ($P = 0.022$) and the occurrence of SP by 110% ($P = 0.047$) and CGRP by 47% ($P = 0.0163$) compared with untreated controls. Following 4 weeks of treatment, both the occurrence of sensory neuropeptides and the vessel density remained significantly higher, whereas fibroblast density returned to normal. However, at 4 weeks, the treated tendons displayed a higher degree of organised parallel collagen fibres, a sign of increased maturation. They concluded that daily IPC treatment improves neurovascular ingrowth and fibroblast proliferation in the healing tendon, and may accelerate the repair process.[9]

## Functional improvement after IPC treatment

Functional impairment follows a period of immobilization of joints. In 16 adults treated with cast immobilization for distal radius fractures,[29] there was significant post-casting impairments in forearm rotation (40% deficit in pronation and supination); wrist flexion, extension and radial and ulnar deviation (50% reduction in all motions); grip strength (reduced to approximately 24% of the strength of the unaffected side); and forearm circumference ($-1.1$ cm) and wrist circumference ($+1.5$ cm). These functional impairments prolong the overall recovery from injury. IPC expedites functional recovery following both fracture and soft tissue injuries.

Challis *et al.*[4] randomized 21 patients with distal radius fractures managed conservatively into two groups, one treated with cyclic pneumatic soft-tissue compression and the other as control. The experimental group received IPC during the 6-week immobilization period, whereas the control group received the usual care. By Week 6, as a percentage of the intact side, the experimental group had 12% (95% CI 7–17) more power grip strength, 24% (95% CI 17–32) more pinch grip strength, 15% (95% CI 7–23) more key grip strength, 26% (95% CI 15–37) more supination strength, 8% (95% CI 3–13) more flexion/extension range of motion and 14% (95% CI 5–22) more supination/pronation range of motion than the control group. By Week 10, as a percentage of the intact side, the experimental group had 24% (95% CI 16–32) more power grip strength, 26% (95% CI 19–34) more pinch grip strength, 28% (95% CI 18–37) more key grip strength, 29% (95% CI 16–42) more supination strength, 15% (95% CI 8–21) more flexion/extension range of motion and 10% (95% CI 2–18) more supination/pronation range of motion than the control group.

In a similar study on ankle sprain patients, Airaksinen *et al.*[30] compared the efficacy of elastic bandage alone and with IPC treatments in the rehabilitation of 44 acute ankle sprains. The dysfunction of the lower leg was assessed by measurements of oedema, degree of ankle motion, pain and limb dysfunction when the patient was first included in the study, after treatment for 1 week and at 4 week follow-up. For all the variables studied, elastic bandage with IPC treatment resulted in significantly ($P < 0.001$) faster rehabilitation at the 4-week follow-up than elastic bandage treatment alone. Limb dysfunction improved significantly ($P < 0.01$) during the follow-up period in the group receiving IPC with elastic bandage compared with elastic bandage alone. IPC treatment was effective in acute post-traumatic therapy.

Another study performed by the same authors reviewed the effect of IPC on post-traumatic ankle-joint mobility, pain and oedema in 22 patients with distal lower leg fractures after 6–12 weeks of immobilization in a cast. Each patient was given IPC treatment on five consecutive days for 75 min per day. The control group consisted of 12 patients with lower leg fractures who were not given any treatment. Ankle-joint mobility in the study group increased by 11.9° (SE = 1.5), but by only 1.0° (SE = 0.8) in the control group ($P < 0.001$). The study group also experienced markedly greater pain relief than did the control patients. The reduction of oedema was 170 ml (SE7 = 23) in the study group and 15 ml (SE = 12) in the control group ($P < 0.001$).[31]

## Potential of IPC

Although IPC has been mainly used in orthopaedic practice to decrease the risk of DVT[32–34] and to reduce post-traumatic and post-operative swelling in various clinical situations,[35–38] its use in fracture care has been limited. The potential reasons could be lack of availability of devices to provide IPC in humans, the difficulty of application of external devices, or the cost of such devices. However, with evidence that IPC can enhance both fracture and soft-tissue healing with good functional recovery, the use of such modality in musculoskeletal trauma should be considered. It can be used to treat difficult fractures and soft-tissue injuries including scaphoid fractures, talus fractures, tendo Achilles rupture, etc. Also, as it has been shown to increase the bone mineral density of the proximal femur,[24] IPC can potentially be used to reduce the risk of hip fractures especially in osteoporotic individuals.

## Economical aspect

Every fracture or soft-tissue injury is accompanied by direct and indirect implication on the economy of an individual, an establishment and the nation as a whole. Several studies have focused on the cost implication of fracture management,[39–42] and they all stress on the need for rapid recovery to reduce costs to individual and hospital. With IPC proving useful in accelerating functional recovery, it may have major economical impact in lowering fracture management costs.

## Limitation of the studies

Although IPC has been used in several human and animal studies, the reliability of evidence is poor. There are two main reasons for this: first, only about one-third of animal research eventually translates at the level of humans;[43] secondly, the number of subjects in human studies is small (Table 1). Hence, adequately powered randomized controlled trials in humans are required to produce stronger clinically relevant evidence.

## Conclusion

Among the modalities available to enhance fracture and soft-tissue healing, IPC seems to be safe and effective. Although IPC has been used in several human and animal studies, more human trials are needed to improve the strength of evidence. With the concept of 'time

is money' being evident into every aspect of human life, a race towards 'enhanced' fracture management is inevitable.

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