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REVIEW ARTICLE

Adjuvant compression therapy in orthopaedic surgery—an evidence-based review

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Abstract
Objectives Orthopaedic trauma surgery is still associated with major complications related to reduced circulation, including thromboembolic events, oedema, deficient healing and infections. Adjuvant therapy by intermittent pneumatic compression (IPC) has recently demonstrated encouraging results and versatility. In this review, we discuss the indications, effects, mechanisms of action and the future potential of IPC. Data sources, study selection, data extraction, data synthesis We conducted a MEDLINE search on intermittent pneumatic compression, identifying 707 articles from 1970 to 2012. The emphasis was placed on recent patient-oriented level 1 literature using the strength-of-recommendation taxonomy (SORT) strength of recommendation grades.
Conclusions IPC prevents deep venous thrombosis (DVT) post-surgery at an equal rate as unfractioned heparin and may be the only prophylaxis available for trauma patients at high risk of bleeding (SORT-A). Combining IPC with pharmacoprophylaxis (PT) significantly reduced the incidence of symptomatic DVT compared with PT alone (SORT-A). In patients with swelling after, e.g. foot, ankle and lower limb fractures, IPC reduces pre- and postoperative oedema leading to shortened hospital stay, improved joint mobility, pain relief and decreased incidence of skin complications (SORT-A). Recent studies on fracture and soft tissue repair concluded that IPC appears to be an effective modality for enhancing fracture and soft-tissue healing and decreasing infection rate, this should, however, be verified by large clinical studies (SORT-B). The mechanisms of action of IPC include: (1) increased venous, arterial and interstitial circulation improving the supply of oxygen, anti-thrombotic substances and growth factors, (2) alterations in cellular gene expression and (3) improved structural tissue properties.
Strength-of-recommendation taxonomy A: Consistent, good-quality patient-oriented evidence B: Inconsistent or limited quality patient-oriented evidence C: Consensus, disease-oriented evidence, usual practice, expert opinion or case series

Keywords Deep vein thrombosis · Intermittent pneumatic compression · Thromboembolism · Oedema · Healing · Mechanisms of action

Introduction

Intermittent pneumatic compression (IPC) therapy is an established method for prophylaxis and treatment of patients with impaired venous [1], arterial [2] and interstitial circulation [3] (Table 1).

IPC treatment aims at passively increasing blood flow by cycling external pressure on lower or upper limbs by means of inflating or deflating a pneumatic cuff (Figs. 1, 2, 3). By applying lower limb compression cuffs in one of five different positions (on the foot, foot and calf, calf, calf and thigh, or whole limb) venous stasis can be reduced, arterial blood flow enhanced and interstitial circulation increased [4]. Contraindications to the treatment with IPC are allergy to the components of the cuff, presence of localized sensitive skin, wound infection or cellulitis [5].

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Table 1 Indications for the use of IPC associated with orthopaedic surgery, including some of the most important references

Indications for the use of IPC	
Venous circulation	• IPC alone prevents the risk of DVT (SORT-A)[20].
	• IPC alone for DVT reduction can be used in patients at high risk of bleeding (SORT-A)[20, 27].
	• IPC *increases the efficacy of* pharmacological thromboprophylaxis in the postoperative period (SORT-A)[17, 69].
	• IPC should be used on both legs during all the immobilized time, at least 6 h daily and with daily monitoring of usage (SORT-B)[63, 20].
Interstitial circulation	• IPC reduces oedema both pre- and postoperatively in, e.g. calcaneus and lower limb fractures (SORT-A)[3, 34, 35].
	• IPC is more effective than ice and elevation and can improve joint mobility and pain relief, and decrease the incidence of skin complications (SORT-A)[3, 34, 35].
Arterial circulation	• IPC improves wound healing and reduces the risk of amputation in patients with critical ischemia (SORT-B)[50, 70].
	• IPC may lead to improved fracture and soft tissue healing; however, more clinical studies are needed to clarify this effect (SORT-C)[40].

Although there exist several IPC providers producing devices with different settings, such as variations in inflation rate, maximum pressure, pressure duration, compression frequency and mode of compression (i.e. uniform/graded/sequential), there are little evidence at this moment about differences in between them when it concerns venous thromboembolism (VTE) prevention. Nevertheless, it is known that compression is less haemodynamically effective in the foot than in other segments of the lower limb when it comes to peak speed flow in the femoral vein [6].

This review will discuss IPC collectively since, to date, there are no good quality studies demonstrating major differences in outcome between the various devices.

Fig. 1 An example of IPC applied to both calves, indicated for the prevention of deep venous thromboses

DVT prophylaxis

Deep vein thrombosis (DVT) is one of the most common complications of hospitalization [7, 8]. DVT can lead to pulmonary embolism; in fact, both are considered as complementary manifestations of the same pathophysiologic process, termed venous thromboembolism [9]. VTE affects an estimated 300,000 to 600,000 individuals in the USA each year, causing considerable morbidity and mortality [10]. In the UK, 25,000 people die from VTE every year, comprising more deaths than are attributable to breast cancer, AIDS and road traffic accidents all together [9].

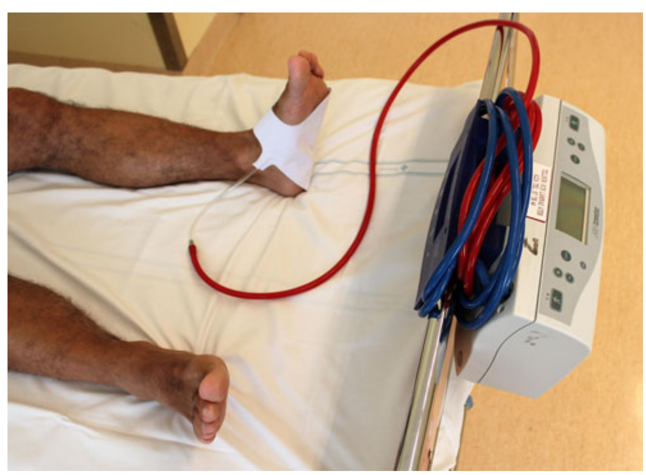

Fig. 2 An example of IPC applied to one foot, indicated for the treatment or prevention of oedema. A foot compression pad can be applied under an external fixator or a plaster cast in the case of, e.g. an ankle fracture in need of oedema reduction. Should the patient also be treated for the prevention of deep venous thromboses then the contralateral limb should also receive compression therapy.

Fig. 3 An example of IPC applied to the upper limb for the treatment or prevention of oedema

All surgical procedures are associated with an increased risk of VTE, mainly because of the postoperative immobility, surgical trauma and the state of hypercoagulability induced by surgery [9] (Table 1). In orthopaedic procedures on the lower extremity, the incidence of DVT in the absence of thromboprophylaxis is estimated to be as high as 40–70 % [9]. Symptomatic pulmonary embolism occurs in up to 25 % of these patients and fatal pulmonary embolism in as many as 6 % of patients with symptomatic pulmonary embolism [9].

Approximately 25 % of cases of VTE are complicated by long-term venous insufficiency, which causes disabling symptoms of swelling, chronic pain and skin ulceration grouped under the name of post-thrombotic syndrome [11]. Prevention of VTE is the only effective approach for preventing post-thrombotic syndrome [12].

Prevention of VTE and post-thrombotic syndrome in orthopaedic patients is, currently, predominantly based on pharmaceutical thromboprophylaxis (PT) [13–15]. The knowledge on mechanical thromboprophylaxis and its evidence-based advantages, however, has been less widespread. The European Society for Medical Oncology recommends the use of mechanical methods such as IPC in addition to PT in cancer patients undergoing major surgery, but not as monotherapy unless PT is contraindicated (SORT-A) [16].

IPC in combination with pharmaceutical thromboprophylaxis

IPC therapy increases the effect of PT in limiting VTE. A Cochrane review based on a meta-analysis of 11 studies including 7,431 patients, concluded that combining compression treatment with PT significantly reduced the incidence of symptomatic DVT by more than 75 % compared with PT alone [1] (SORT-A).

Compared with PT alone, the use of combined modalities significantly reduced the incidence of DVT from 4.21 % to 0.65 % and reduced the incidence of both symptomatic pulmonary embolism (from about 3 % to 1 %) and DVT (from about 4 % to 1 %) [17]. Hence, the data indicate that pharmacological or compression treatments used separately each produce similar DVT reduction, and that the effect of combined treatment is highly superior to single therapy.

Thus, the guidelines developed by the National Institute for Clinical Excellence (NICE) in the UK, advise the orthopaedic surgeon to combine thromboprophylaxis with compression devices on all patients undergoing orthopaedic surgery, if they are considered at high thromboembolic risk [9]. Moreover, the use of IPC for the prevention of VTE in the orthopaedic patient was proven to be cost effective [18, 19].

Mechanical thromboprophylaxis

Many orthopaedic patients at high risk of developing DVT are poor candidates for PT, mainly due to their risk of bleeding. In the American College of Chest Physicians guidelines, it is stated that mechanical thromboprophylaxis may be the only VTE-preventing strategy available in patients with increased risk of bleeding [20] (SORT-A).

In fact, IPC per se, or in combination with compression stockings, was shown to be a safe means of preventing VTE in patients undergoing lower extremity joint replacement, such as in hip and knee replacement, even in the absence of PT [9, 21–23]. In the latest CHEST guidelines, IPC is stated as an alternative to PT to reduce DVT in low-risk patients undergoing hip and knee replacement [20]. However, this does not apply to orthopaedic patients who undergo hip replacement due to oncologic indications [24] and in high-risk patients [13]. For these patients, it is recommended to use the combination of IPC with PT.

These reports, confirmed by a meta-analysis of 16 studies including 3,887 postoperative and post-trauma patients, suggest that the use of IPC yields results similar to heparin administration, but with the advantage of eliminating bleeding risks [25, 26]. Thus, IPC is currently recommended instead of PT in patients at high risk for bleeding [27]. The most used type of IPC in these studies is calf compression.

There are some recent studies demonstrating better DVT prophylaxis and less side effects with IPC compared to compression stockings [28, 29]. A combined analysis of ten trials demonstrated a DVT rate of 5.9 % for graduated compression stockings and 2.8 % for IPC. The authors concluded that there is weak evidence for a difference in performance between these prophylaxis methods [30] (SORT-B). Some authors even recommend the use of both IPC and compression stockings although this has to be demonstrated in a clinical study. As a systematic review from 2010 did not identify any significant differences between IPC and compression stockings [29], the NICE guidelines recommend both modalities [9].

Oedema reduction

Post-traumatic oedema is a major complication in orthopaedic surgery, leading to prolonged hospital stays because of postponed operations and delayed discharge [31, 32]. Moreover, increased post-traumatic oedema is also associated with delayed fracture healing [33].

Thus, IPC (Figs. 1 and 2) has been used preoperatively in patients pending surgery. In patients with ankle fractures, foot IPC was proven to reduce oedema more effectively than treatment with ice and elevation [34, 35]. Similarly, foot IPC reduced preoperative swelling in patients with calcaneus fractures [36] and lower limb fractures [3, 37], leading to improved joint mobility and pain relief and decreased incidence of skin complications [3] (SORT-A).

Lymphatic vascular insufficiency is a common problem in orthopaedics following cancer surgery and immobility. The incorporation of IPC devices into a multidisciplinary therapeutic approach in these patients has been advocated to reduce oedema [38, 39] (SORT-A).

Oedema reduction, and assessment of swelling, may, however, also encounter methodological problems due to, e.g. that the degree of oedema may differ at the thigh, calf, ankle and foot, according to various factors, such as the pathological conditions of diseases, daily activity, occupation, etc. Thus, different patients may need different length of cuffs to adequately reduce the limb oedema (e.g. foot, foot and calf, or whole limb).

Promotion of fracture and wound healing

Fractures and soft tissue injuries

A recent review examined nine clinical studies on IPC therapy in fracture and soft tissue repair and concluded that IPC appears to be an effective modality for enhancing fracture and soft-tissue healing [40]. A common feature in these clinical studies was that IPC seemed to accelerate functional recovery following both fracture and soft tissue injuries, whereas its role in actual fracture healing yet has to be assessed [3, 36, 37, 41]. Most musculoskeletal injuries are treated with a period of joint immobilization, which leads to functional impairments, sub-optimal tissue repair and decreased tissue biomechanical strength [39, 42–44]. Hence, a Cochrane review on the rehabilitation of distal radius fractures concluded that there is evidence of the short-term benefit of hand IPC [45] (Fig. 3). Experimental studies on animals [44, 46, 47] show accelerated fracture and soft tissue repair and suggest that IPC should be studied in the clinical setting. One prospective clinical study indicated that IPC might have a role in osteoporosis prevention, particularly in sedentary women [48] (SORT-C).

Diabetic foot ulcers

Patients with diabetes mellitus are often seen by the orthopaedic surgeon and checked on a regular basis because of problems from foot ulcers and oedema. A randomized, double-blinded, placebo-controlled trial on these patients demonstrated better and more rapid wound healing in the foot IPC group as compared to the placebo-controlled pump group, and in the compression pump group, healing was achieved in more of the therapy–compliant patients than in those who were non-compliant [49]. The Mayo Clinic experience demonstrates similarly good results when using intermittent foot compression treatment in wound healing in patients with diabetes and limb ischemia [50].

Mechanisms of action

Compression therapy is considered to exert three distinctive mechanisms of action: mechanical, chemical and cell-mediated/molecular (Fig. 4). Mechanical stimuli on the underlying tissues achieve circulatory effects [51], stretch deformation of tissues and cells producing the release of, e.g. anti-thrombotic and proliferative substances. These more immediate effects are followed by alterations in cellular gene expression and structural tissue changes [4].

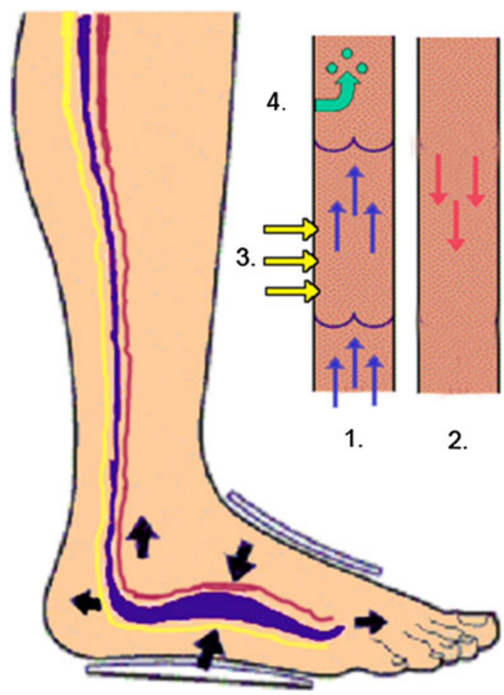

Fig. 4 Mechanisms of action of IPC applied to the lower limb. (*1*) Increased venous flow. (*2*) Increased arterial flow. (*3*) Increased return of interstitial fluids from the third space to the veins. (*4*) Increased venous flow produces shear stress on the endothelial cells, which in response increase production of anti-thrombotic, pro-fibrinolytic, vasodilatory and repair promoting substances

IPC increases the venous peak flow velocity [52] by more than 200 %[53], leading to a higher arteriovenous pressure gradient and subsequent stimulation of arterial blood flow 98.8–274 % [54]. The improved blood flow can thus supply oxygen, stem cells, growth factors and other vascular mediators, e.g. peptides, vital for tissue repair. Compression also increases the subcutaneous interstitial pressure, which forces the third space fluids back into circulation. This action reduces oedema, leading to improved transcutaneous oxygenation and clearance of metabolic toxins [4].

Cyclic tissue and cell loading may initiate cell proliferation and enhanced tissue repair [44]. Thus, IPC stimulates proliferation of fibroblasts and endothelial cells, which results in enhanced rat soft tissue healing [11]. In fracture repair, compression presumably leads to cyclic mechanical loading over the fracture gap, which stimulates bone healing. Furthermore, shear stress on, e.g. the endothelial cells, induce production of chemical substances: vasodilative nitric oxide (NO), anti-thrombotic (tissue factor pathway inhibitor) and pro-fibrinolytic substances (tissue plasminogen activator) [4, 55]. Chemical substances increased by compression treatment, which directly can enhance tissue repair, include NO [56], sensory neuropeptide substance P (SP) and calcitonin gene-related peptide (CGRP) [46]. SP and CGRP can exert inflammatory effects [57], and in vivo studies show promoted healing partly by enhancing the mobilization of stromal-like stem cells [57, 58].

Long-term effects of compression are achieved by increased cellular gene expression and changes in tissue structure. In vivo animal studies show upregulated mRNA expression of important regulators of, e.g. vasodilatation (NO) [4] and angiogenesis (e.g. vascular endothelial growth factor) [59]. This has been verified by subsequent improvements in tissue structure, e.g. neurovascular ingrowth, callus production, increased bone mineral density and bone mineral content following IPC treatment of experimental fractures [47, 60, 61].

Discussion

Venous stasis, oedema and delayed healing are common problems in orthopaedic surgery.

Provided that the orthopaedic elective or trauma patients require VTE prevention, it has been demonstrated that IPC in combination with pharmacological thromboprophylaxis is superior to monotherapy [1, 16, 17] (SORT-A). Thus, recent NICE guidelines recommend the use of IPC in at-risk patients undergoing orthopaedic procedure [9]. Moreover, IPC per se is recommended as a valid means of VTE prevention in patients who cannot receive pharmacological thromboprophylaxis due to the risk of bleeding [25–27] (SORT-A).

In patients with impaired microcirculation, IPC has been shown as well to reduce post-traumatic oedema more effectively than treatment with ice and elevation [3, 40] (SORT-B). After IPC treatment, both pre- and postoperative swelling have been reduced, leading to a lower incidence of skin complications in patients with ankle fractures and faster rehabilitation resulting in enhanced joint mobility and shortened hospital stay [3, 42] (SORT-B).

Bilateral IPC treatment of extremities demonstrates better VTE prevention than unilateral treatment, not only because of preventing a DVT in the non-operated leg, but presumably due to the systemic effects of compression therapy. A release of antithrombotic substances (NO, tissue plasminogen activator) because of improved blood flow in an extremity treated with IPC can reduce the risk of venous thromboembolism even in the contralateral extremity.

IPC has been used to promote healing in patients with venous leg ulcers [62] (SORT-A), diabetic foot ulcers [49, 50] (SORT-B), fractures and soft tissue injuries [40, 42] (SORT-C). Although current clinical evidence is limited with respect to the treatment of fractures, future research could help in identifying the class of patients who would benefit most from IPC therapy.

One advantage of IPC is that there are very limited contraindications to its use (Table 2). The NICE guidelines regarding the use of IPC in patients at risk of venous thromboembolism list allergy to the components of the device as the only contraindication to its use [9]. Moreover, patients with heart failure and oedema need to be under supervision and given extra diuretics when IPC is initiated. In theory, IPC can aggravate heart failure due to increased oedema/venous return. Patients with severe renal and hepatic failure should be under specialist care. If the patient exhibits impairments in cutaneous sensitivity, the compressed skin should be inspected daily. Comfort moreover does not seem to be a major problem. One study demonstrated that the majority of patients found the cuffs comfortable. The mean comfort score was 7.6 (range, 1 to 10) [63].

On the other hand, several studies have, however, pointed out limitations in the use of IPC:

– Patient compliance to IPC use may be less pronounced than to other pharmacological or mechanical measures. IPC devices can be cumbersome, and research continues to assess the efficacy of portable, more practical devices [64]. The importance of compliance was shown in a study where patients using IPC 6 h daily had reduced DVT incidence compared to patients using IPC less than 6 h daily [63]. CHEST 2012 recommends 18 h of daily compliance with the use of portable, battery-powered IPC devices, which record and report proper wear time on a daily basis.

Table 2 Practical recommendations for the use of IPC associated with orthopaedic surgery

Practical recommendations for the use of IPC	
Indications	• DVT prevention (SORT-A)
	• Oedema reduction (SORT-A)
	• Wound (SORT-B) and fracture healing (SORT-C)
Contraindications	• Allergy to the components of the compression cuff, presence of localized sensitive skin, wound infection or cellulitis [5]
Compliance	• Well-educated staff and well-informed patients
	• Daily monitoring of usage [63]
	• Portable devices [20]
Safety	• Daily skin inspections especially in patients with sensitive skin or diabetes
Pain	• A majority of patients find the treatment comfortable [63]
	• In patients with pain, e.g. fractures, administer analgesics and stabilize the fracture before initiation of treatment
Localisation	• Calf-IPC for DVT prevention may be more effective than foot-IPC. Always use bilateral application (Fig. 1)[71].
	• Foot-IPC is generally used for oedema reduction in the lower limb. Unilateral application may work (Fig. 2)[3].
	• Hand-IPC can be used for oedema reduction in the forearm (Fig. 3)[45].
Pressure/frequency	• Calf-IPC is generally pre-set between 30 and 50 mmHg, 1 compression/minute [71].
	• Foot-IPC, between 80 and 200 mmHg, 1–5 compressions/minute. Faster oedema reduction may be achieved by increasing pressure and frequency of the values stated above [71].

Evidenced recommendations are not possible for all statement due to few studies

– IPC devices constitute a heterogeneous class. There is no agreement on what set-up is best for each specific indication, and the optimal frequency and intensity of the compression used may vary from study to study. The orthopaedic surgeon may have difficulties choosing a fitting protocol of use.

There are some data, however, demonstrating that sequential compression exhibits hemodynamic superiority compared to a rapid inflation device [55, 65, 66]. However, data on outcome of DVT are sparse. Another study demonstrated that rapid IPC healed venous ulcers more rapidly and in more patients than slow IPC [67]. Calf pressures used by most devices compress to an average of 40–50 mmHg. However, at the foot, pressures of 130–200 mmHg are needed because of the structure and the small volume of blood stored in the venous foot plexus.

– IPC may have results comparable to other mechanical treatment modalities such as compression stockings but may entail higher costs. However, a recent meta-analysis showed an increased relative risk of DVT 1.75 (95 % CI 0.74, 4.14) in treating with compression stockings compared with IPC [26, 64]. Moreover, the use of IPC for the prevention of VTE in the orthopaedic patient as proven to be cost effective [18, 19].

IPC for oedema reduction can be best applied after the use of an external fixator or after definitive osteosynthesis. In ankle fractures not in the need of external fixation, foot compression under a plaster cast can be used with good results [3] (Fig. 2). The patient should be given analgesics and compression started with low pressure, e.g. foot compression 80 mmHg, successively increased as much as tolerated by the patient (130–200 mmHg), 1–3 s of compression and three compressions per minute, in so far as the device allows pressure adjustment. If the IPC is initiated for VTE prevention only, we recommend calf compression, as experimental studies have shown increased venous return compared to foot compression [68].

Conclusion

In conclusion, growing evidence supports the role of IPC in the prevention and treatment of complications related to impaired venous, arterial and interstitial circulation associated with surgical procedures. However, more research is needed to penetrate the mechanism of action of IPC therapy and to better define its potentials and limits. Experimental studies have shown that IPC can stimulate heeling of both soft tissue and fractures. However, little is known in what way IPC affects the mechanisms of tissue repair, locally and systemically. Can compression be used to initiate early tissue repair or to support and accelerate an ongoing healing process?

If early evaluation of compression therapy was possible by, for example, measuring tissue perfusion, saturation and metabolism, it could be possible to forecast if compression treatment can have prolonged effects. Further research in this field might clarify on which patients and during which part of the healing phase compression treatment is best indicated.

Conflict of interest The authors declare no conflict of interest.

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