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Graduated compression stockings in the prevention of venous thromboembolism

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Background: Surveys still show a wide variation in routine use of deep vein thrombosis (DVT) prophylaxis despite its established place in current patient management. This article reviews the mechanism of action, efficacy and complications of stockings in preventing DVT.

Methods: Relevant publications indexed in Medline (1966–1998) and the Cochrane database were identified. Appropriate articles identified from the reference lists of the above searches were also selected and reviewed.

Results and conclusion: Graduated compression stockings reduce the overall cross-sectional area of the limb, increase the linear velocity of venous flow, reduce venous wall distension and improve valvular function. Fifteen randomized controlled trials of graduated compression stockings alone were reviewed. Stockings reduced the relative risk of DVT by 64 per cent in general surgical patients and 57 per cent following total hip replacement. The effect of stockings was enhanced by combination with pharmacological agents such as heparin; the combination is recommended in patients at moderate or high risk of DVT. Knee-length stockings are as effective and should replace above-knee stockings. Complications are rare and avoidable.

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Prevention of deep vein thrombosis (DVT) in hospitalized patients has received considerable attention because of the risk of potentially fatal pulmonary thromboembolism and the long-term morbidity associated with chronic venous valvular insufficiency. The result has been a continuing drop in the incidence and complications of DVT[1–5]. Without prophylaxis, the risk of DVT ranges from 25 to 30 per cent in general surgical patients to 70 per cent following some orthopaedic procedures[6–9]. Prophylaxis, often consisting of a combination of pharmacological and mechanical agents, reduces the risk of DVT by 60–80 per cent in general surgical and 50–64 per cent in orthopaedic patients[10–13].

Despite the established place of prophylaxis in current patient management, more episodes of venous thromboembolism are reported in clinical practice than would be expected. Surveys show a wide variation in routine use of DVT prophylaxis[14–17]. This variation may represent a lag between intended and actual implemented prophylaxis. There appears to be a shortfall in awareness of the mechanism of action and efficacy, especially of mechanical agents. Violation of established protocols, which may involve up to 30 per cent of patients, has also been reported[18].

Graduated compression stockings are the most widely used mechanical antithrombotic agents. They are of proven efficacy in general surgical patients[11]. However, the case for stockings may not be as convincing in some other surgical specialties, especially orthopaedics, where patients are at much greater risk[19–21]. The value of stockings for obstetric, long-stay general medical and geriatric patients is also unclear. Evidence supporting current stocking pressure profiles, which have been in use for over 25 years, needs reappraisal especially in patient groups in which stockings are not proving as effective. Evidence comparing the efficacy of thigh- *versus* knee-length stockings needs clarification. Although stockings are generally regarded as safe, complications occasionally occur.

This review considers the current evidence on the mechanism of action, design, efficacy and complications associated with graduated compression stockings in the prevention of venous thromboembolism.

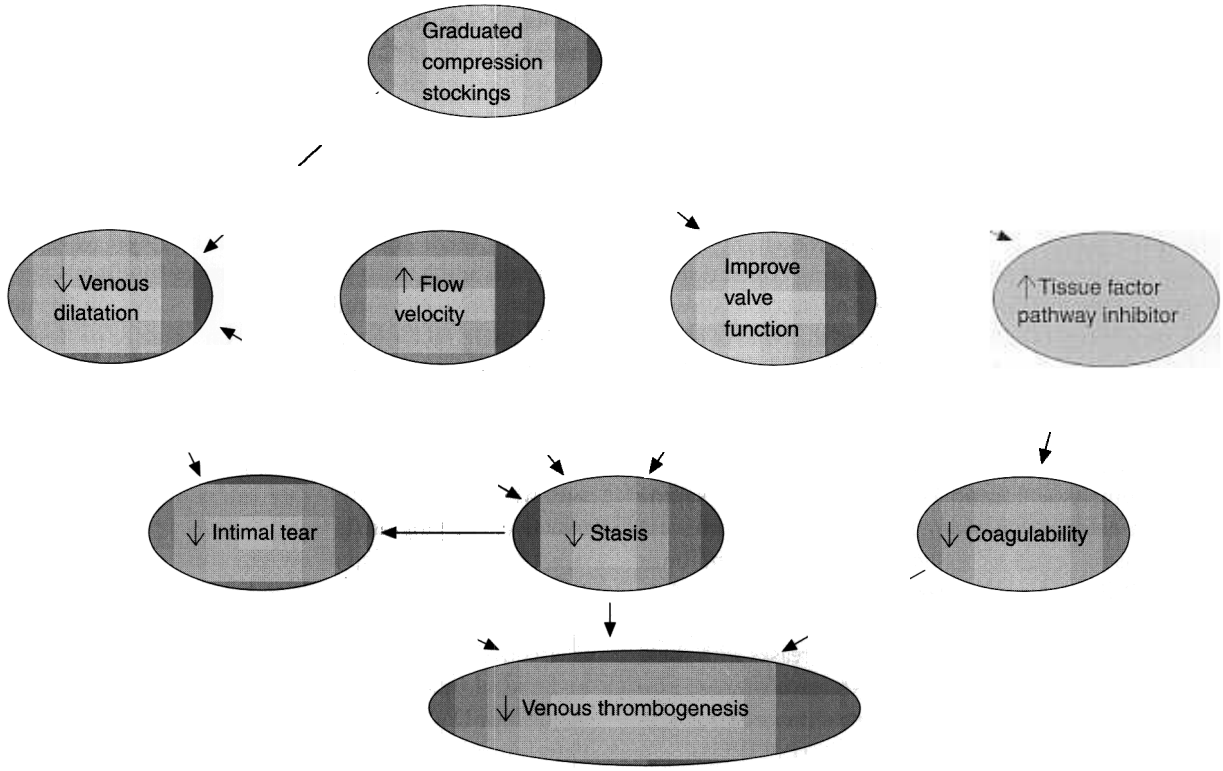

Fig. 1 Possible mechanism of action of graduated compression stocking in preventing deep vein thrombosis

Methods

Relevant publications indexed in Medline (1966–1998) were identified using the medical subject headings 'stockings', 'clothing', 'bandages', 'thrombophlebitis', 'venous thrombosis', 'postoperative complications' and 'thrombosis/prevention'. The Cochrane database was also searched and relevant studies identified. Further articles identified from the reference lists of the above searches were also selected and reviewed. Odds ratios of studies reviewed were combined using the Mantel–Haenszel χ^2 procedure. Number needed to treat was calculated based on a 25 per cent risk of DVT in untreated general surgical patients and a 40 per cent risk following total hip replacement.

Mechanism

The mechanism of action of compression stockings in preventing venous thrombosis remains unclear and is probably multifactorial (*Fig. 1*). Compression stockings achieve their effect by affecting the three classical aetiological factors described by Virchow (1856), namely stasis, endothelial damage and hypercoagulability. A decrease in the luminal diameter of the vein appears to play the key role.

Effect of external compression on venous function

External compression reduces the overall cross-sectional area of the lower limb and increases the linear velocity of blood flow within the veins[22–27]. An external pressure of 15 mmHg results in a 20 per cent reduction in the venous cross-sectional area and a significant increase in the velocity of flow in both superficial and deep venous systems[28]. Increased velocity of flow reduces venous stasis and decreases the risk of thrombus formation by reducing venous wall distension, local contact time and the concentration of coagulation reactants. Compression stockings also improve evacuation of incompetent and incompletely emptied valvular cusps[29]. Stasis within these cusps is associated with the initiation of venous thrombosis[30]. Stockings have also been shown to enhance venous function by improving coaptation of valvular cusps, again reducing reflux-related stasis and the risk of thrombosis, especially in patients with valvular insufficiency[31].

Postoperative DVT is associated with intraoperative systemic venodilatation affecting both lower and upper limbs[32,33]. Passive venodilatation stretches the endothelium beyond the support of the tunica media. The resulting intimal tears have been demonstrated on electron micro-

scopy in canine models. Intimal tears predispose to DVT by exposing thrombogenic subendothelial collagen, in the presence of venous stasis, to activated platelets, clotting factors and other thrombogenic products of tissue injury[34]. Venodilatation in excess of 20 per cent of resting diameter has been shown to be associated with an increased risk of DVT[32]. Coleridge Smith *et al.*[35] demonstrated a median 48 (interquartile range 26–53) per cent reduction in the diameter of gastrocnemius veins during operation in patients wearing graduated compression stockings. Additionally, in the same study, in contrast to the control group, no venous distension occurred during operation in patients wearing stockings.

Elastic compression may achieve some of its effects by altering the balance of coagulation reactants in patients at risk of thrombosis. Elastic compression in the supine reverse Trendelenburg position has been shown to increase systemic plasma levels of tissue factor pathway inhibitor (TFPI)[36]. TFPI is a recently described factor Xa-dependent inhibitor of the tissue factor (extrinsic) coagulation pathway. TFPI is endothelium derived, and increases with shear stress in the upright posture, after extensive exercise and following administration of both unfractionated heparin and low molecular weight heparins (LMWHs)[37–41]. Increased TFPI in the upright tilt may be an endothelial response to venous stasis and luminal distension to prevent local thrombosis. Enhancing this TFPI effect by elastic compression may represent another mechanism of local and systemic venous thromboprophylaxis.

Design of compression stockings

Compression stockings may be designed to apply graduated or uniform compression. Graduated compression refers to the application of varying degrees of constant compression to different segments of the leg, with pressure being greatest at the ankle and gradually decreasing proximally. Uniform compression aims to deliver a similar degree of pressure to the whole leg. Graduated compression has been the favoured option since Sigel *et al.*[42] demonstrated small but consistent increases in velocity of flow in the common femoral vein compared with that obtained with uniform compression. This conclusion was based on the effect of a uniform compression of 11 mmHg in four subjects in a supine position at 15° foot-down tilt. The hydrostatic gradient introduced by this position (about 14 mmHg) is scarcely representative of the patient lying in hospital and is large enough to affect the validity of their results. While graduated compression is of proven efficacy in preventing DVT, evidence to support its superiority over uniform compression appears inconclusive and needs revalidation. Discrediting uniform compression on the basis of trials of Tubigrip (Seton Health Group, Oldham, UK) is probably inappropriate, as the latter is unlikely to deliver uniform compression with increasing proximal lower limb circumference. Instead, a reverse compression gradient or tourniquet effect is to be expected.

The design of the majority of stockings in current use is based on a pressure profile of 18, 14, 8, 10, 8 mmHg from ankle to thigh as recommended by Sigel *et al.*[42] and Lawrence and Kakkar[43], and confirmed by clinical trials in comparison to untreated controls[44,45]. Although 30 mmHg at the ankle had a greater effect on velocity of flow than 18 mmHg, the latter was deemed safer, being less likely to compromise subcutaneous oxygenation[43,46]. Sparrow *et al.*[47] showed that the efficiency of stockings correlated closely with changes in calf compression if ankle compression was held constant; higher calf compression was more effective. Varying ankle compression and ankle–calf gradient were not as important. A profile of 16·8, 14·5 and 6·4 mmHg at the ankle, calf and thigh respectively proved most effective. Although the 18 to 8 mmHg pressure profile is effective, it may not necessarily represent the best profile or be ideal in all clinical situations in which stockings are needed for DVT prophylaxis. Further studies are needed to determine the optimal profile in different clinical situations. These studies would require a large number of subjects, a wide variety of pressure profiles and postures, and should be based on the effect of stockings on both venodilatation and velocity of venous outflow.

Efficacy

Results of initial trials on the value of compression for venous thromboprophylaxis were equivocal. Wilkins *et al.*[48] reported, in a post-mortem study, one non-fatal pulmonary embolism (PE) in 100 deaths in 2346 patients with stockings compared with six PEs (two fatal) in 89 deaths in 2395 untreated non-randomized controls. Makin[49] reported a reduced incidence of clinically diagnosed DVT with Tubigrip. Rosengarten *et al.*[50] and Browse *et al.*[51] were unable to demonstrate any difference between stockings and control using the fibrinogen uptake test. These discrepancies probably resulted from the use of Tubigrip for compression, which exerts non-uniform and potentially reverse gradient compression. In addition, the studies used clinical diagnosis, which is undoubtedly unreliable in predicting the incidence of DVT and PE. Subsequent studies using better stocking design and more reliable diagnostic tools provide a clearer picture.

General surgery

The majority of studies of stockings for the prevention of venous thrombosis have been on general surgical patients.

Table 1 Results of randomized controlled trials of graduated compression stockings in preventing deep vein thrombosis

Reference	Year	Diagnostic test	Incidence of deep vein thrombosis*		Odds ratio†	Risk reduction (%)	No. needed to treat‡
			Stockings	Control			
General/abdominal surgery							
Holford[44]	1976	FUT	11 of 48 (23)	23 of 47 (49)	0·31 (0·12–0·82)	53	6
Scurr *et al.*[52]	1977	FUT	8 of 70 (11)	26 of 70 (37)	0·22 (0·08–0·57)	69	5
Torngren[53]	1980	FUT	4 of 98 (4)	12 of 98 (12)	0·31 (0·08–1·07)	67	6
Allan *et al.*[45]	1983	FUT/venography	15 of 97 (15)	37 of 103 (36)	0·33 (0·16–0·68)	57	7
Bergqvist and Lindblad[54]	1984	FUT	0 of 80 (0)	8 of 80 (10)	0·00 (0·00–0·55)	100	4
Wille-Jorgensen *et al.*[55]	1985	FUT/venography	2 of 86 (2)	11 of 90 (12)	0·17 (0·03–0·86)	81	5
Mellbring and Palmer[56]	1986	FUT	1 of 54 (2)	2 of 54 (4)	0·49 (0·02–7·22)	50	9
			7 of 54 (13)	6 of 54 (11)	1·19 (0·32–0·39)	−17	−50
Scurr *et al.*[57]	1987	FUT/venography	1 of 78 (1)	7 of 78 (9)	0·13 (0·01–0·11)	86	5
Willie-Jorgensen *et al.*[58]	1991	FUT/venography	2 of 83 (2)	12 of 83 (14)	0·14 (0·02–0·70)	84	5
Total			51 of 748 (7)	144 of 757 (19)	0·31 (0·22–0·44)	64	8
Gynaecology							
Turner *et al.*[59]	1984	FUT	0 of 104 (0)	4 of 92 (4)	0·00 (0·00–1·32)	100	7
Neurosurgery							
Turpie *et al.*[60]	1989	FUT/venography	7 of 80 (9)	16 of 81 (20)	0·38 (0·14–1·09)	56	7

Values in parentheses are *percentages or †95 per cent confidence intervals. ‡Based on PEER (patient expected event rate) = 0·25. FUT, fibrinogen ^{125}I uptake test; venography, contrast venography

Table 1 shows the results of randomized controlled trials comparing the incidence of DVT in general surgical patients. The overall incidence of DVT was 51 (7 per cent) of 748 in the treatment group compared with 144 (19 per cent) of 757 in the control group. The summary odds ratio was 0·31, which translated to a relative risk reduction of 64 (95 per cent confidence interval 53–73) per cent in patients wearing stockings. Treating eight general surgical patients with graduated compression stockings prevented the occurrence of one DVT. Wells *et al.*[61] reported a 68 per cent relative risk reduction of DVT in general surgical patients using stockings. In practice, stockings are often combined with pharmacological agents, especially low-dose heparin or LMWH. This combination leads to improved results (see later).

Direct evidence of the value of graduated compression stockings in preventing fatal PE is inconclusive. Numbers limit most trials, as a large sample size would be required to show a significant reduction because of the low incidence of PE, particularly as the widespread use of heparin has substantially reduced the risk of DVT and PE. The effect of stockings in preventing the long-term post-thrombotic sequelae of DVT is easier to demonstrate. Some 60 per cent of patients treated for DVT will have residual venous valvular insufficiency[62] with symptoms ranging from leg swelling and discomfort to venous ulcers. Graduated compression stockings have been shown to prevent primary and recurrent DVT, and decrease the risk and severity of the post-thrombotic syndrome[61,63,64]. A recent randomized clinical trial of the effect of compression stockings in 194 patients following symptomatic proximal vein thrombosis reported mild to moderate post-thrombotic syndrome in 19 patients (20 per cent) wearing stockings compared with 46 controls (47 per cent) ($P < 0·001$). In addition, only 11 patients (11 per cent) wearing stockings developed a severe post-thrombotic syndrome compared with 23 control patients (23 per cent) ($P < 0·001$)[64].

Orthopaedic surgery

The majority of studies in orthopaedics have included patients undergoing elective total hip replacement. Elderly patients with a fractured hip may constitute a more ideal study population as they are often dehydrated, immobile and have a much greater risk of venous thromboembolism[13]. Orthopaedic surgeons in the UK are more likely to use routine prophylaxis in patients undergoing elective hip replacement than surgery for hip fracture despite a fivefold increased risk of fatal PE in the latter group[65]. The incidence of DVT exceeds 50 per cent in untreated controls (*Table 2*); however, thromboprophylaxis appears to be less effective in orthopaedic than in other forms of surgery[10,70–73]. Although the majority of orthopaedic surgeons use pharmacological prophylaxis, the risk of bleeding leading to wound haematoma, infection and implant failure is perceived as unacceptable by a minority[74]. Physical agents are safer and more acceptable in this regard[75,76]. Examining the results of the randomized trials shows a 57 per cent overall relative risk reduction in incidence of DVT following total hip replacement in patients who used

Table 2 Randomized controlled trials of graduated compression stockings for deep vein thrombosis prophylaxis following total hip replacement

Reference	Year	Diagnostic test	Incidence of deep vein thrombosis*		Odds ratio†	Risk reduction (%)	No. needed to treat‡
			Stockings	Control			
Ishak and Morley[66]	1981	Venography	7 of 35 (20)	22 of 41 (54)	0·22 (0·07–0·67)	63	4
Fredin *et al.*[67]	1989	Venography	13 of 44 (30)	21 of 46 (46)	0·50 (0·19–1·30)	35	7
Kalodiki *et al.*[68]	1996	Venography	12 of 38 (32)	13 of 14 (93)	0·04 (0·00–0·32)	66	3
Barnes *et al.*[69]	1978	Doppler	0 of 8 (0)	5 of 10 (50)	0·00 (0·00–1·08)	100	2
Total			32 of 125 (26)	61 of 111 (55)	0·23 (0·12–0·42)	57	4

Values in parentheses are *percentages or †95 per cent confidence intervals. ‡Based on PEER (patient expected event rate) = 0·4. Venography, contrast venography; Doppler, Doppler ultrasonography

stockings compared with controls (*Table 2*). Treating only four patients with stockings prevented the occurrence of one DVT following total hip replacement. A recent meta-analysis of methods of prophylaxis following total hip replacement suggested that, while all recommended methods except aspirin decreased the risk, LMWH and stockings had the greatest relative value in preventing venous thromboembolism[77]. Although LMWH proved more effective, it was associated with a risk of bleeding and heparin-induced thrombocytopenia[41,78–80]. Reporting a placebo-controlled, randomized clinical trial on 78 patients undergoing total hip replacement, Kalodiki *et al.*[68] demonstrated that the combination of LMWH (enoxaparin 40 mg daily) and stockings was more effective in preventing DVT than LMWH alone, and that stockings alone were better than nothing (13, 28 and 57 per cent incidence of proximal DVT in LMWH and stocking group, LMWH alone and untreated control groups respectively). The combination of LMWH and stockings is recommended in patients undergoing hip replacement.

Venous thromboembolism following total knee replacement is especially resistant to prophylaxis[79,81,82]. This may be due to intraoperative positioning for optimal access, direct vascular injury from intraoperative limb manipulation and the thigh tourniquet which is inflated to 450–500 mmHg to achieve a bloodless field[83,84]. Use of a thigh tourniquet impairs venous drainage, damages the endothelium, confines coagulation reactants from surgical trauma below the tourniquet and may increase the risk of venous thrombosis and large emboli[85–88]. Hui *et al.*[19] reported a significant reduction in proximal and calf venous thrombosis after total knee replacement when patients wore below-knee stockings compared with that in controls (32 *versus* 66 per cent). Above-knee stockings were less effective.

The risk of late-onset venous thrombosis persists for at least 5 weeks after joint replacement[89,90]. Patients may therefore benefit from continued use of stockings after discharge from hospital. The value of graduated compression stockings in patients with a fractured hip is still under evaluation.

Gynaecology, obstetrics and urology

The overall risk of DVT ranges between 4 and 45 per cent in gynaecological and 8–80 per cent in urological patients[91], the highest risk being after operations for malignancy[92]. The risk in pregnancy is five times higher than that in non-pregnant age-matched patients. A randomized controlled trial of the value of stockings in 196 patients undergoing major gynaecological surgery showed a significant reduction in venous thrombosis (zero in treated *versus* 4 per cent in controls; $P < 0·05$)[59]. In addition, by preventing venous pooling, stockings may also reduce catecholamine release with beneficial effects for the circulation in pregnancy[93,94]. Clinical data on the effect of stockings in preventing DVT in pregnancy are, however, insufficient.

There are no prospective randomized controlled studies of the effect of stockings in urological patients. Hansberry *et al.*[95] compared use of compression stockings with pneumatic compression alone or heparin–dihydroergotamine alone in 74 patients undergoing neoplastic urological procedures using indium-labelled platelet scans. There was no significant difference in the incidence of DVT in the three groups.

Neurology and neurosurgery

Thromboembolism is a major concern in neurological and neurosurgical patients, especially those with spinal cord injury, brain tumour, head injury, stroke and patients undergoing surgery. The risk of DVT in general neurosurgical patients ranges between 19 and 50 per cent[96]. The main advantage of mechanical methods of thromboprophylaxis in these patients is the avoidance of the small but catastrophic risk of intracranial or spinal bleeding complications associated with pharmacological agents[97]. External

pneumatic compression is effective in these patients[60,98,99], although its use may be limited by patient compliance. The ease of application and management of stockings may be an advantage. In a recent randomized controlled trial comparing stockings alone *versus* stockings combined with intermittent pneumatic compression, the DVT rate was 9 per cent for stockings only and 9 per cent for stockings and pneumatic compression, compared with 20 per cent in untreated controls[60]. Stockings alone appeared sufficient. Another multicentre trial showed that LMWH reduced the rate of DVT from 21 per cent with stockings alone, to 14 per cent with stockings and nadroparin (relative risk reduction 34 per cent; $P = 0{\cdot}018$)[100].

Stockings may suffice as the sole agent, especially where pharmacological agents are contraindicated. Graduated compression stockings combined with LMWH or low-dose heparin should provide adequate DVT prophylaxis in neurological and neurosurgical patients.

Medical

In a study of autopsy-proven PE in 2388 hospital deaths, Sandler and Martin[101] showed that only 24 per cent of the 239 patients who died from PE had undergone recent surgery. Although the emphasis in the literature is on surgical patients, DVT is also important in medical patients[102–104]. The efficacy of pharmacological agents, especially heparin, in preventing DVT in patients with heart failure, myocardial infarction and chest infections has been demonstrated by clinical trials[105,106]. In contrast, clinical evidence of the value of mechanical prophylaxis in medical patients is limited. A recent prospective randomized trial of graduated compression stockings in 80 patients aged 70 years and above with acute myocardial infarction, using the fibrinogen uptake test, showed DVT in eight control legs compared with none in legs with stockings[107]. With the exception of this trial and data on stroke patients, no other studies on the efficacy of graduated compression stockings in general medical patients were found. The available data suggest that there is a place for stockings in DVT prophylaxis in medical patients. This is particularly important when hospitalization is prolonged, in patients aged over 40 years and in the presence of medical conditions known to predispose to DVT.

Recurrent deep vein thrombosis

Previous DVT is a major predisposing factor to DVT recurrence[108]. Belcaro *et al.*[63] studied the efficacy of graduated compression stockings in preventing recurrent DVT in 224 patients following an episode of DVT. Three years later the recurrence rate was 46 per cent in untreated controls compared with 9, 5 and 2 per cent in patients using stockings, ibuprofen or stockings and ibuprofen respectively.

Comparison with other prophylactic agents

Graduated compression stockings reduce the risk of DVT by 64 per cent in general surgical patients. *Tables 3* and *4* show the results of trials that compare the effect of stockings alone or combined with other prophylactic modalities. Graduated compression stockings combined with low-dose heparin performed better than stockings or heparin alone (*Table 3*). LMWH combined with stockings was better than stockings alone (*Table 4*). Compression stockings and pneumatic compression were equally effective (*Table 5*). Stockings are, however, easier to manage. Either stockings or pneumatic compression may be used during operation and postoperative mechanical prophylaxis can be continued with stockings alone. In hip replacement, a meta-analysis

Table 3 Venous thromboprophylaxis using graduated compression stockings with and without low-dose heparin

Reference	Year	Type of surgery	Diagnostic test	Incidence of deep vein thrombosis		
				LDH	Stockings and LDH	Stockings
Torngren[53]	1980	Abdomen	FUT	12 of 98 (12)	4 of 98 (4)	—
Borow and Goldson[109]	1983	Abdomen	FUT	15 of 56 (27)	2 of 63 (3)	—
Wille-Jorgensen *et al.*[55]	1985	Abdomen	FUT	11 of 90 (12)	2 of 86 (2)	—
Wille-Jorgensen *et al.*[58]	1991	Abdomen	FUT	12 of 81 (15)	2 of 79 (3)	—
Fasting *et al.*[110]	1985	Abdomen	Tc-pl	4 of 45 (9)	3 of 52 (6)	—
Moser *et al.*[111]	1976	General	FUT	—	2 of 20 (10)	5 of 20 (25)
Nicolaides *et al.*[112]	1972	General	FUT	—	1 of 122 (1)	29 of 122 (24)
Borow and Goldson[109]	1983	General	FUT	—	2 of 63 (3)	15 of 106 (14)

Values in parentheses are percentages. LDH, low-dose heparin; FUT, fibrinogen ^{125}I uptake test; Tc-pl, Technetium ^{99m} Tc-plasmin scan for deep vein thrombosis

Table 4 Venous thromboprophylaxis using graduated compression stockings with and without low molecular weight heparin

Reference	Year	Type of surgery	Diagnostic test	Incidence of deep vein thrombosis	
				Stockings	Stockings and LMWH
Lassen *et al.*[113]	1991	Hip arthroplasty	Venography	45 of 97 (46)	30 of 97 (31)
Kalodiki *et al.*[68]	1996	Hip arthroplasty	Venography	12 of 32 (38)	8 of 32 (25)
Nurmohamed *et al.*[100]	1996	Neurosurgery	Venography	51 of 244 (21)	33 of 241 (14)
Levine *et al.*[114]	1996	Knee surgery	Venography	60 of 124 (48)	29 of 96 (30)

Values in parentheses are percentages. LMWH, low molecular weight heparin

Table 5 Venous thromboprophylaxis using graduated compression stockings and pneumatic compression

Reference	Year	Type of surgery	Diagnostic test	Incidence of deep vein thrombosis		
				Stockings	Pneumatic compression	Stockings and pneumatic compression
Bucci *et al.* [115]	1989	Neurosurgery	IPG	1 of 38 (3)	1 of 32 (3)	—
Hansberry *et al.*[95]	1991	Urological	Platelet scan*	5 of 25 (20)	3 of 24 (13)	—
Turpie *et al.*[60]	1989	Neurosurgery	FUT	7 of 80 (9)	—	7 of 78 (9)
Goldhaber *et al.*[116]	1995	Cardiac	Ultrasonography	38 of 172 (22)	—	33 of 172 (19)

Values in parentheses are percentages. *^{111}In-labelled platelet scan. IPG, impedance plethysmography; FUT, fibrinogen ^{125}I uptake test

based on 56 trials showed an unadjusted pooled risk of 21 per cent for use of stockings compared with 16 per cent for LMWH and 24 per cent for low-dose heparin[77]. Only LMWH and stockings were shown to reduce the risk of PE in the analysis. Although this agrees with the report by Wilkins *et al.* on the value of stockings in preventing PE, the few trials evaluating this suggestion are limited by small numbers.

Graduated compression stockings alone are effective for the prevention of DVT. Their effect is, however, enhanced by pharmacological agents such as low-dose heparin and LMWH. Stockings alone could provide adequate prophylaxis for patients at low risk of DVT. Patients at moderate or high risk should be managed with stockings combined with LMWH or low-dose heparin[117,118].

Thigh-length *versus* knee-length stockings

The majority of studies on prevention of venous thrombosis have been on thigh- or full-length stockings. Thigh- or full-length stockings are more expensive, more difficult to put on and less tolerated than knee-length stockings[119–121]. Lawrence and Kakkar[43] found no increase in deep venous flow velocity when whole limb compression (18–8 mmHg) was applied compared with below-knee compression (18–14 mmHg). Porteous *et al.*[122] compared thigh- and knee-length stockings in a randomized trial using the fibrinogen uptake test and found no significant difference in their ability to prevent DVT. Sparrow *et al.*[47] observed that the portion of the stocking above the tibial plateau was relatively ineffective in decreasing venous pooling, but appeared to compromise the value of the stocking at lower levels. This prompted concern that the thigh- or full-length stockings may actually be inferior to knee-length stockings. The above-knee segment of a thigh stocking often rolls down, either hanging loosely around the knee or exerting a garter-like tourniquet effect[121,123], thus compromising the effect of the stocking and potentially increasing the risk of thrombosis. A recent survey of patient compliance showed a significantly higher number of improperly applied thigh-length than knee-length stockings[119]. Knee-length stockings should replace thigh-length stockings, being equally effective, cheaper, more likely to fit correctly and better tolerated by patients.

Customized stockings

Customized stockings, tailored to the patient's leg dimensions, are usually made from high-modulus yarn with substantial variations in the pressure profile with changing limb circumference. Johnson *et al.*[124] compared these with commercially available non-custom low-modulus circular

knit stockings, but found no advantage. Non-customized stockings actually appeared superior in that their low modulus allowed for flexibility in the calf diameter within the target pressure profile. While commercial non-customized stockings may be preferable to tailored stockings, studies suggest that they do not always conform to the pressures specified by their manufacturers[125,126].

There may be a case for customized stockings in patients with pronounced calf–ankle disproportion, as in severe lipodermatosclerosis[121].

Indications

Patients at risk of DVT may be classified into low-, moderate- and high-risk groups based on the aggregate of predisposing factors[13]. Graduated compression stockings may be used as sole prophylactic agent in patients at low risk of DVT. Stockings may also be used alone in situations where pharmacological prophylaxis is contraindicated and for long-term prevention of recurrence following 3–6 months of anticoagulation for a single episode of DVT[63]. Patients at moderate or high risk should be managed with stockings in combination with LMWH or low-dose heparin. Stockings should be applied at least 2 h before operation, and continued during and after surgery until the patient is fully mobile. Stockings are particularly beneficial in the bedridden[127]. The practice of sitting patients out of bed early after operation can be hazardous. Sitting with the knees flexed to 90° or more for a patient with thigh-length stockings causes a marked increase in popliteal–stocking interface pressure. This compromises the effect of the stockings and may jeopardize thromboprophylaxis[127]. The risk of venous thromboembolism subsists after discharge from hospital[89,128,129]. Stockings may potentially be valuable in reducing this risk. With the increasing trend towards early discharge from hospital, a properly conducted randomized controlled trial of the value of graduated compression stockings following discharge is necessary.

Complications

Although graduated compression stockings are relatively safe, they are not without risk. The main concern is impairment of subcutaneous tissue oxygenation, especially in patients with existing peripheral vascular compromise. A stocking pressure of 10 mmHg produces a 10 per cent reduction in cutaneous blood flow, 30 mmHg a 25 per cent drop and 60 mmHg an 84 per cent drop[130]. An estimate of the hazards of compression treatment of the leg by 154 Scottish surgeons showed that at some stage up to one-third had recognized a patient with damage to the leg as a result of compression therapy[131]. Compression stockings for DVT prophylaxis were associated with 38 of the 147 cases reported. Patients with peripheral arterial disease and diabetics with neuropathy are particularly at risk, and cases resulting in necrosis and amputation have been reported[132,133]. Arterial occlusion, thrombosis and gangrene over the anterior aspect of the ankle secondary to the tourniquet effect of multiple layers of rolled down stocking have also been reported[123,134]. It is therefore essential that significant arterial compromise and peripheral neuropathy are excluded before applying stockings. Manufacturers advise against the use of stockings in patients with an ankle : brachial pressure index less than 0·7. Stockings should also be sized and fitted correctly. Leg measurements should be reviewed regularly especially in swollen or swelling legs, as changes in leg girth significantly change the amount of pressure exerted rendering the stocking ineffective or threatening tissue oxygenation. An increase in leg circumference of 5 cm can double the amount of pressure being applied by a stocking[135].

Conclusions

Graduated compression stockings provide an effective, safe, cheap and convenient means of preventing DVT. Stockings increase the linear velocity of venous outflow, prevent stasis and venous distension, and enhance emptying of valvular cusps. Properly used, stockings can reduce the risk of DVT in hospitalized patients by 55–70 per cent. Evidence on the value of graduated compression stockings in preventing fatal PE is limited and inconclusive. In combination with LMWH or low-dose heparin, stockings provide adequate prophylaxis for the majority of patients at risk. Knee-length stockings are preferable, being effective and potentially superior to thigh- or full-length stockings. Knee-length stockings are cheaper and better tolerated, and should replace thigh- and full-length stockings for DVT prophylaxis. Continued use of stockings to prevent late venous thrombosis following discharge from hospital may be beneficial in patients with poor mobility. The role of stockings in preventing DVT recurrence is noteworthy. Attention to the vascular and neurological status of the leg, proper sizing and regular review of the legs should limit the rare occurrence of ischaemic complications with stockings.

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