Continuous passive motion in the prevention of deep-vein thrombosis

A RANDOMISED COMPARISON IN TRAUMA PATIENTS

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There is a high risk of venous thromboembolism when patients are immobilised following trauma. The combination of low-molecular-weight heparin (LMWH) with graduated compression stockings is frequently used in orthopaedic surgery to try and prevent this, but a relatively high incidence of thromboembolic events remains. Mechanical devices which perform continuous passive motion imitate contractions and increase the volume and velocity of venous flow.

In this study 227 trauma patients were randomised to receive either treatment with the Arthroflow device and LMWH or only with the latter. The Arthroflow device passively extends and plantarflexes the feet. Patients were assessed initially by venous-occlusion plethysmography, compression ultrasonography and continuous wave Doppler, which were repeated weekly without knowledge of the category of randomisation. Those who showed evidence of deep-vein thrombosis underwent venography for confirmation. The incidence of deep-vein thrombosis was 25% in the LMWH group compared with 3.6% in those who had additional treatment with the Arthroflow device ($p < 0.001$). There were no substantial complications or problems of non-compliance with the Arthroflow device. Logistic regression analysis of the risk factors of deep-vein thrombosis showed high odds ratios for operation (4.1), immobilisation (4.3), older than 40 years of age (2.8) and obesity (2.2).

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Deep-vein thrombosis (DVT) may lead to acute fatal pulmonary embolism and the development of chronic venous insufficiency. A combination of low-molecular-weight heparin (LMWH) with graduated compression stockings is commonly used as prophylaxis in orthopaedic surgery. In the absence of protective measures the incidence of DVT is estimated to be up to 56% in high-risk patients.[1] LMWH is regarded as at least as efficient as unfractionated heparin and tends to cause less haemorrhage.[2,3] In a meta-analysis, Wells, Lensing and Hirsch[4] showed that the use of graduated compression stockings for prophylaxis resulted in a significant reduction in the risk of DVT. However, there remains a relatively high risk of DVT whichever treatment is used suggesting that a combination of the two may be worthwhile.[5] Early mobilisation and mechanical methods are of clinical interest, since LMWH carries a risk of post-operative bleeding of 1.5%.[6]

Venous stasis due to the absence of muscular contraction in immobilised patients is an essential risk factor as indicated by Virchow.[7] The use of mechanical devices which imitate muscular contractions is an attractive proposition and stimulation of the crural muscles and intermittent pneumatic compression of the legs is used in an attempt to accelerate venous blood flow. This may lead to a better dispersal of activated blood components and dissolution of small thrombi attached to the venous wall.[8] Gardner and Fox[9] showed that venous foot pumps may help prevent DVT by reducing venous stasis. This resulted in the development of the AV-Impulse-System (Novamedix, Andover, UK). Fleming et al[10] showed that its effectiveness is influenced by the position of the foot with an increase in the velocity and volume of venous blood flow when the foot lay in 25° of plantar flexion, the reverse-Trendelenburg position.

Continuous passive motion (CPM) is used in orthopaedic surgery to prevent joint stiffness and reduce the formation of haematomas and oedema, which may lead to fibrosis.[11] Bonnaire et al[12] showed that a CPM device applied to the ankle joint could increase the volume of flow in the femoral vein to 123% of the initial values within five minutes and to 143% after 15 minutes. These positive effects were still evi-

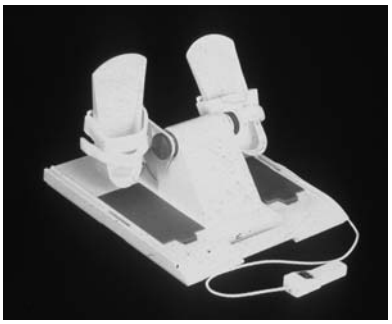

Fig. 1a

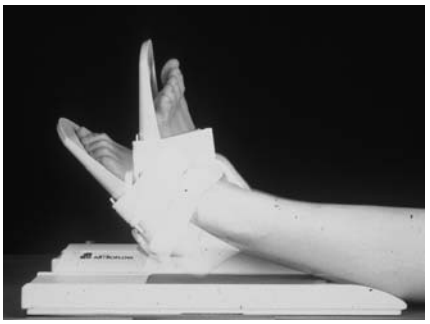

Fig. 1b

Figure 1a – Photograph of the Arthroflow device, a means of mechanical thromboprophylaxis. Figure 1b – Photograph showing the Arthroflow device in action.

Table I. Localisation of trauma according to treatment group, by number and *percentage*

	Arthroflow group (n = 111)	Control group (n = 116)	Total (n = 227)
Acetabulum	15 (*13.5*)	13 (*11.2*)	28 (*12.3*)
Pelvis	12 (*10.8*)	7 (*6.0*)	19 (*8.4*)
Knee	3 (*2.7*)	3 (*2.6*)	6 (*2.6*)
Multiple lower limb fractures	2 (*1.8*)	3 (*2.6*)	5 (*2.2*)
Femur	20 (*18.0*)	28 (*24.1*)	48 (*21.1*)
Ankle	0	8 (*6.9*)	8 (*3.5*)
THR*	19 (*17.1*)	20 (*17.2*)	39 (*17.2*)
Lower leg	0	4 (*3.4*)	4 (*1.8*)
Spine	40 (*36.0*)	30 (*25.9*)	70 (*30.8*)

* THR, total hip replacement

dent 15 minutes after the device had been turned off.

The Arthroflow device (Ormed, Freiburg, Germany) (Fig. 1) allows continuous passive motion of the ankle joint with maximal extension and plantar flexion at a frequency of 30 excursions per minute, giving compression of the crural compartments. The close relationship of the talocrural joint and the venous network around the ankle is such that movement of the joint causes a measurable increase in the venous blood flow producing the function of a physiological pump.[13,14]

Information concerning the Arthroflow device is limited. Two available studies have had either small patient numbers or were restricted to those undergoing total knee replacement (TKR).[10,11]

Patients and Methods

Methods of thromboprophylaxis. This study was undertaken between February 1993 and March 1995 on 227 patients who had suffered trauma. One group of 111 had passive exercises with the Arthroflow device and the other 116 formed the control group and were not subject to its use. All patients received 5000 U of unfractionated Heparin (B. Braun, Melsungen, Germany) subcutaneously three times daily, which was administered at 7 am, 1 pm and 7 pm without consideration of the patient's weight. Treatment was started on the evening before surgery or, in some cases which required an emergency operation, immediately following this. All patients had intense physiotherapy including breathing exercises, isometric muscle contraction, kinetotherapy (to increase strength and range of movement) and early mobilisation.

The patients in the Arthroflow group were treated using the Arthroflow three times daily (at 9 am, 2 pm and 7 pm) for 30 minutes. This electrically-driven device mobilises both talocrural joints passively within a range of 20° of dorsiflexion and 40° of plantar flexion 30 times per minute. Elastic compression stockings were not used in either group.

Inclusion criteria. The patients included were between 18 and 80 years of age, and had suffered bony or ligamentous trauma to the spine, the pelvis including the acetabulum or the femur, tibia, or ankle. Those who had a total hip replacement following a fracture of the femoral neck were also included (Table I).

Patients were excluded who had suffered multiple trauma, had evidence of decompensated coronary heart disease, advanced peripheral arterial occlusion, severe liver failure, haemorrhagic diathesis, stroke, pregnancy, malignant neoplasia, arthritis and arthrodesis of the lower limb, manifest acute thrombosis or thrombophlebitis, pulmonary embolism, paraplegia, chronic muscular dystrophy and lack of compliance. These criteria excluded 79 patients. A further 26 patients refused their consent and in six there was no time available to perform venography. Due to mechanical reasons, patients with trauma to the ankle or tibia had to be excluded from the Arthroflow group.

Initial diagnostics. In taking the initial history, risk factors such as obesity (Broca index ≥ 1.2), varicosities, contraception, paralysis of the lower limb and previous venous thromboembolism (VTE) were recorded (Table II). Pre-existing thrombosis was then ruled out by venous-occlusion plethysmography, compression ultrasonography and continuous wave Doppler. The patients were randomly assigned by computer before operation to either the Arthroflow group (n = 111) or the control group (n = 116) without stratification. The outcome of this randomisation was then screened for differences between both groups as regards the personal details of the patients (Table II), the pattern of risk factors for DVT and the site of the trauma (Table I), with

Table II. Details of 227 patients randomised and prevalence of risk factors in the test and control group, by number and *percentage*

	Arthroflow group (n = 111)	Control group (n = 116)	Mann-Whitney U test
Gender (men:women)	57:54	74:42	0.058
Mean age in yrs (SD)	47.1 (19.7)	51.9 (19.5)	0.070
Median number of operations (range)	1 (0 to 4)	1 (0 to 7)	0.008
Median days of immobilisation (range)	14 (7 to 60)	14 (7 to 98)	0.473
Trauma	92 (*82.9*)	104 (*89.7*)	0.138
Operation	80 (*72.1*)	90 (*77.6*)	0.339
Age > 40 yrs	60 (*54.1*)	80 (*69.0*)	0.021
Immobilisation	99 (*89.2*)	106 (*91.4*)	0.578
Plaster cast	16 (*14.4*)	29 (*25.0*)	0.046
Obesity	39 (*35.1*)	40 (*34.5*)	0.918
Varicosities	29 (*26.1*)	24 (*20.7*)	0.334
Contraception	6 (*5.4*)	3 (*2.6*)	0.278
Paralysis of lower limb	2 (*1.8*)	4 (*3.4*)	0.441
History of venous thromboembolism	7 (*15.3*)	13 (*11.2*)	0.362
Median number of risk factors per patient (range)	4 (2 to 7)	4 (2 to 8)	0.078

Table III. Comparison of risk factors in patients with and without deep-vein thrombosis (DVT)

Risk factors for DVT	DVT patients (n = 33)	No DVT (n = 194)	p value*	Odds ratio
Gender (men:women)	19:14	112:82	1.000	0.977
Trauma	28	168	0.785	1.723
Operation	30	140	0.028	4.138
Age > 40 yrs	26	114	0.033	2.810
Immobilisation	32	173	0.214	4.323
Plaster cast	10	35	0.153	1.453
Obesity	17	62	0.047	2.221
Varicosities	7	46	0.828	0.406
Contraception	0	9	0.364	0.000
Paralysis of lower limb	0	6	0.596	0.000
History of venous thromboembolism	6	24	0.403	1.520
Median number of risk factors per patient (range)	5 (2 to 8)*	4 (2 to 7)*	0.004†	

* Fisher's exact test
† Mann-Whitney U test

the Mann-Whitney U test applied for analysis of independent variables.

Screenings. We monitored the development of DVT in both legs weekly. Clinical examination looked for signs of venous thromboembolism such as oedema, tenderness, cyanosis, chest pain, tachycardia, the respiratory rate, cough and signs of pneumonia. The leucocyte count and the erythrocyte sedimentation rate were recorded. Compression ultrasonography, with 5 MHz and 7.5 MHz transducers, was applied accompanied by continuous wave Doppler. Venous-occlusion plethysmography was then carried out on both legs. Thrombosis, if present, was treated. The observations were reviewed by a consultant radiologist with a particular interest in DVT who was blinded as to which group the patient had been assigned. If plethysmography or sonography suggested the presence of a DVT venography was undertaken.

If a DVT occurred the patient was removed from the study, Arthroflow treatment was stopped and DVT therapy initiated. Otherwise, the patients received prophylactic treatment and were observed until they had mobilised completely, were capable of getting up independently at least three times daily and could partially weight-bear on the injured leg. They were finally reviewed three months after surgery either in the outpatient clinic or by telephone. Approval of the local Medical Research and Ethics Committee was obtained.

Statistical analysis. As noted above, the non-parametric Mann-Whitney U test was used for assessment of independent values (Tables I and II). Continuous variables were analysed by the unpaired Student's *t*-test after confirmation of a reasonable fit to a Gaussian distribution. Categorical variables were analysed by the chi-squared and Fisher's exact tests. Since there were multiple secondary outcomes, a Bonferroni correction was used to avoid an alpha error producing false-positive results. A p value < 0.005 was considered as significant for risk factors (Table III), representing a Bonferroni correction of 0.05 divided by 11 secondary outcomes. All risk factors were included as dummy explanatory variables in a logistic regression analysis using the presence or absence of DVT as the outcome. The exponential values of the logistic regression coefficients are odds ratios. Odds ratios were also used to give an indication for the quantitative effect of treatment.

Table IV. Overall incidence of thrombosis shows a highly significant difference between both groups (chi-squared test; $p < 0.001$)

	Test group (n = 111)	Control group (n = 116)	Total (n = 227)
Thrombosis (%)	4 (*3.6*)	29 (*25.0*)	33 (*14.5*)
No thrombosis (%)	107 (*96.4*)	87 (*75.0*)	194 (*85.5*)

The required sample size was calculated and it was estimated that a sample size of 120 patients in each group would give an 80% power of detecting a difference of 15%. A mean incidence of DVT of 30% was presumed at the 5% significance level of a two-sided test and 24 months was defined as the observation period. All results were examined for statistical significance using the SigmaStat computer statistics package (SPSS Inc., Chicago, Illinois) and SPSS (SPSS Inc.).

Results

Among general details and risk factors (Table II) there were significant differences with regard to the number of operations, age > 40 years and use of a plaster cast, with a higher prevalence within the control group. Localisation of the trauma showed a large degree of correspondence between both groups (Table I). The Arthroflow device was not administered in injuries to the ankle and lower leg. This also explains the difference in the use of a plaster cast as a risk factor (Table II). Plaster casts allocated to the Arthroflow group did not involve the ankle or could be taken off for therapy. Considering the number of risk factors, it is not surprising that randomisation failed to distribute all values equally. However, both groups were similar to a major extent, although some differences might have influenced the final outcome.

Thrombosis. The overall prevalance of thrombosis within the control group was 25% (29 of 116) compared with 3.6% (4 of 111) in the Arthroflow group, a highly significant difference ($p < 0.001$) (Table IV). The odds ratio (OR) equalled 8.92 (95% confidence interval (CI) 3.02 to 26.34) indicating a nine times higher chance of developing a DVT in the control group. None of the patients showed clinically apparent symptoms of pulmonary embolism and none died within the documented period of observation. The details of all 33 patients with DVT are shown in Table V.

All 33 thromboses were diagnosed by sonography, while plethysmography detected only 21, confirming the view that the latter procedure is not an effective means of screening.[14,15] All thromboses were confirmed by contrast venog-

Table V. Characteristics of deep-vein thrombosis (DVT) patients

Case number/group	Age (yrs)	Gender	Localisation of trauma or surgery	Localisation DVT*
6, Control	67	M	Pelvis	I, F
8, Control	85	F	Total hip	I, F, P, C
11, Control	73	M	Spine	F
23, Control	43	M	Pelvis	I, F
31, Arthroflow	42	M	Acetabulum	I, F
42, Control	40	M	Spine	I, F, P, C
76, Control	58	F	Ankle	P, C
84, Control	63	M	Pelvis	I, F
87, Control	70	F	Total hip	I, F
88, Control	59	F	Ankle	I, F
92, Control	62	F	Total hip	I, F, P
94, Control	51	F	Femur	F, P
118, Arthroflow	73	F	Total hip	I, F, P, C
134, Arthroflow	46	F	Total hip	F
164, Control	80	M	Total hip	C
168, Control	75	F	Total hip	C
170, Control	55	M	Pelvis	F
174, Control	44	M	Acetabulum	I, F, P, C
175, Control	43	M	Acetabulum	I
178, Control	29	F	Acetabulum	I
180, Control	36	M	Pelvis	F, P, C
182, Control	73	M	Calf	I, F, P, C
185, Control	37	M	Femur	F, P, C
189, Control	73	F	Total hip	I, F
192, Control	21	M	Femur	I, F
193, Control	35	M	Femur	I, F
194, Control	56	F	Spine	I, F
195, Control	43	M	Acetabulum	I, F, P, C
196, Control	66	M	Knee	C
201, Control	70	M	Acetabulum	I, F
214, Control	68	F	Femur	C
216, Control	84	F	Femur	C
223, Arthroflow	45	M	Femur	C

* I, iliac; F, femoral; P, popliteal; C, crural

Table VI. Incidence, location and extent of deep-vein thrombosis (DVT) in both Arthroflow and control groups, by number and *percentage*. Thrombi are regarded as small and long as they limit their extension to one of the categories iliac, femoral, popliteal, crural.

	Arthroflow group (n = 111)	Control group (n = 116)	p value*
DVT total	4 (*3.6*)	29 (*25.0*)	< 0.001
DVT calf	1 (*0.9*)	5 (*4.3*)	0.109
DVT proximal	3 (*2.7*)	25 (*20.7*)	< 0.001
Large thrombi	2 (*1.8*)	19 (*16.4*)	< 0.001
Small thrombi	2 (*1.8*)	9 (*7.8*)	0.037

* chi-squared test

raphy. Of these, 17 were located on the same and two on the opposite side to the surgery. The injuries/operations were to the spine or pelvis, and this in the midline, in 14 patients. The thrombi were categorised in groups according to their localisation and size (Table VI). The Arthroflow group showed less proximal and extended thrombi ($p < 0.001$) while more small thrombi ($p < 0.05$) appeared to be sited in the distal calf, although this was not statistically significant. DVT was discovered a median of 14 days after operation.

Risk factors. The comparison between patients who had a DVT and those who did not, showed no significant difference in risk factors as assessed by Fisher's exact test after adjusting levels of significance for multiple testing to $p < 0.005$ (Table III). Logistic regression analysis showed several risk factors. Operation itself (OR 4.1; 95% CI 1.1 to 15.1) and immobilisation (OR 4.3; 95% CI 0.5 to 35.2) had the highest impact on the incidence of DVT. Age > 40 years (OR 2.8; 95% CI 1.0 to 7.8), obesity (OR 2.2; 95% CI 1.0 to 5.1), trauma (OR 1.7; 95% CI 0.5 to 5.4) and a positive history of previous thromboembolism (OR 1.5; 95% CI 0.5 to 4.8) carried a higher risk of DVT. The total number of risk factors turned out to be significantly higher in patients who sustained a DVT (Mann-Whitney U test; $p = 0.004$). Special risk factors which predicted the occurrence of proximal or distal and small or large thrombi could not be identified.

Discussion

The overall incidence of thrombosis was significantly lower in the Arthroflow group ($p < 0.001$). There was a nine times greater chance of a DVT within the control group. Risk factors such as older than 40 years of age, use of a plaster cast and surgery were more frequent in the control group. There appeared to be a significant protective effect with the Arthroflow device, as had been noted in earlier trials.[10,16]

Logistic regression analysis indicated the influence of the suspected risk factors in the development of venous thromboembolism. The performance of surgery itself (OR 4.1) and immobilisation (OR 4.3) had the highest impact. Other factors such as an age > 40 years (OR 2.8), obesity (Broca index ≥ 1.2) (OR 2.2), the trauma itself (OR 1.7), a positive history of thromboembolism (OR 1.5) and use of a plaster cast (OR 1.4) were seen more frequently in patients with DVT who also had an increased number of such factors.

The presence of both proximal and distal thrombi was recorded although only a proximal thrombosis is regarded as a possible source for pulmonary embolism. Some authors consider distal thrombi as a potential origin for upward-growing thrombi which can develop into an extended proximal clot.[17-20]

The beneficial effects of mechanical prophylaxis are well known. Most authors describe inflatable devices which transmit pressure on the soft tissue of the lower limb. Handoll et al[3] found that foot and calf pumping devices appear to prevent DVT and reduce mortality caused by pulmonary embolism. Lack of compliance using those instruments has been a problem. One type of foot pump is the A-V Impulse System (AVI; Orthofix Ltd, Berkshire, UK) which intermittently inflates a pneumatic pad applied to the sole of the foot in order to empty its venous plexus. Bulitta et al[21] showed that the AVI is able to promote the maximum venous blood flow in plaster casts. Wilson et al[22] showed within a small population that the application of AVI was superior to not using any means of prevention. They failed to show a significant decrease in the total number of thrombi but found a lower incidence of proximal DVT and large thrombi. In a randomised controlled study by Santori et al[23] the AVI was found to be superior to heparin, with significantly less DVT in patients treated with AVI (13.4% *vs* 35.4%). There was also less pain and less local oedema. However, Blanchard et al[6] noted a highly significant disadvantage in patients treated only with the pneumatic device ($p < 0.001$) compared with LMWH, and 25% of the patients decided to stop the trial with the impulse system because of discomfort. Westrich and Sculco[24] found that a combination of aspirin and AVI is more effective than the isolated administration of aspirin with an incidence of thrombosis of 27% compared with 59% in the control group. Warwick et al[18] compared exercises with AVI and the administration of a LMWH and concluded that neither method provided superior prophylaxis but the impulse system seemed to cause fewer side effects. The large majority of lesions found in this study were minor calf thrombi, which might indicate a very sensitive method of examination. Winemiller et al[25] examined the effectiveness of pneumatic compression compared with heparin in patients with injuries to the spinal cord. Heparin was more effective in the first two weeks, although by six weeks the pneumatic device seemed to bring more benefit.

A randomised control study comparing foot-pumps and sequential pneumatic compression devices in patients with polytrauma was conducted by Spain et al.[26] These are thigh-high sleeves which are inflated intermittently in order to stimulate venous flow and lymphatic drainage. Both systems turned out to be equally effective with no major complications or problems with compliance. Robertson et al[27] compared sequential pneumatic compression devices with

foot pumps after total joint arthroplasty and found the foot pumps to be more effective. Waldner et al[8] regard intermittent pneumatic compression of the lower limb by inflatable boots or leggings as a useful preventive measure, reducing venous pooling and post-operative bleeding.

Chylarecki et al[13] found an incidence of DVT of 21.6% in trauma patients treated with LMWH but this fell to 2.3% with the addition of the Arthroflow device. Rader et al[17] used the Arthroflow device in a prospective study examining 160 patients following total knee arthroplasty. Again, it was used in conjunction with LMWH, reducing the incidence of DVT from 11.4% to 2.2% ($p < 0.05$). They suggested that the dose of LMWH might be reduced when combined with the Arthroflow.

Methods of screening for DVT are the subject of discussion. Venous ultrasonography is the most accurate noninvasive test for the diagnosis of a first symptomatic proximal DVT and is the initial investigation of choice.[16,28,29] However, if the results of this testing are not clear, venography should be considered.[28,29]

Venography remains the most sensitive method of screening for symptomatic or asymptomatic DVT in the lower limb. However, the technique is invasive and uses ionising contrast material. It may cause discomfort, allergic reactions, nephrotoxicity, iatrogenic DVT and skin necrosis. Therefore, its use as a screening device in unselected patients is undesirable.[16] Venous ultrasonography is not invasive and carries a minimal risk of complications. The sensitivity of ultrasound for subclinical DVT is only moderate, since venous ultrasonography is less accurate for asymptomatic isolated distal DVT than for a proximal clot.[16,28,29] Nevertheless, it is the recommended screening method for subclinical DVT.[16] A symptomatic DVT which is not detected by ultrasound is probably of low risk.

There are strong arguments for the effectiveness of mechanical devices as prophylaxis against DVT. The Arthroflow device in combination with heparin is an effective means of prevention against DVT and is effective in patients with multiple trauma.

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References

1. **No authors listed.** Prevention of venous thromboembolism: international consensus statement (guidelines according to scientific evidence). *Int Angiol* 1997;16:3-38.
2. **Jorgensen LN, Wille-Jorgensen P, Hauch O.** Prophylaxis of postoperative thromboembolism with low molecular weight heparins. *Br J Surg* 1993;80:689-704.
3. **Handoll HH, Farrar MJ, McBirnie J, et al.** Heparin, low molecular weight heparin and physical methods for preventing deep vein thrombosis and pulmonary embolism following surgery for hip fractures. *Cochrane Database Sys Rev* 2002;4:CD000305.
4. **Wells PS, Lensing AW, Hirsch J.** Graduated compression stockings in the prevention of postoperative venous thromboembolism: a meta-analysis. *Arch Intern Med* 1994;154:67-72.
5. **Amarigi SV, Lees TA.** Elastic compression stockings for prevention of deep vein thrombosis. *Cochrane Database Sys Rev* 2000;2:CD001484.
6. **Blanchard J, Meuwly JY, Leyvraz PF, et al.** Prevention of deep-vein thrombosis after total knee replacement: randomised comparison between a low-molecular-weight heparing (nadroparin) and mechanical prophylaxis with a foot-pump system. *J Bone Joint Surg [Br]* 1999;81-B:654-9.
7. **Brotman DJ, Deitcher SR, Lip GY, Matzdorff AC.** Virchow's trial revisited. *South Med J* 2004;97:213-14.
8. **Waldner H, Schmolder A, Stechmeier B.** Prevention of thrombosis in surgery of the extremities: physical methods in thrombosis prevention. *Orthopade* 1993;22: 106-9 (in German).
9. **Gardner AM, Fox RH.** The venous pump of the human foot: preliminary report. *Bristol Med Chir J* 1983;98:109-12.
10. **Fleming P, Fitzgerald P, Devitt A, Rice J, Murray P.** The effect of the position of the limb on venous impulse foot pumps. *J Bone Joint Surg [Br]* 2000;82-B:433-4.
11. **O'Driscoll SW, Giori NJ.** Continuous passive motion (CPM): theory and principles of clinical application. *J Rehabil Res Dev* 2000;37:179-88.
12. **Bonnaire F, Brandt T, Raedecke J, Bonk A.** Mechanical dynamic ankle passive motion for physical prevention of thrombosis?: changes in hemodynamics in the lower pressure system with new dynamic splints. *Unfallchirurg* 1994;97:366-71 (in German).
13. **Chylarecki C, Hierholzer G, Rudofsky G.** Physical prevention of thrombosis with the ankle joints with the motorized ankle joint movement device: initial results of a clinical study. *Unfallchirurgie* 1995;21:137-47 (in German).
14. **Staubesand J, Heisterkamp T, Stege H.** Use of duplex sonography to investigate the effect of active and passive movement at the ankle joint for promoting venous return. *Clin Anat* 1995;8:96-101.
15. **Heijboer H, Buller HR, Lensing AW, et al.** A comparison of real-time compression ultrasonography with impedance plethysmograpy for the diagnosis of deep-vein thrombosis in symptomatic outpatients. *N Engl J Med* 1993;329:1365-9.
16. **Kelly J, Rudd A, Lewis RR, Hunt BJ.** Screening for subclinical deep-vein thrombosis. *QJM* 2001;94:511-19.
17. **Rader CP, Kramer C, Hendrick C, et al.** Experiences with an ankle joint motion device in prevention of thrombosis in patients after total endoprosthesis knee replacement. *Z Orthop Ihre Grenzgeb* 1998;136:467-70 (in German).
18. **Warwick D, Harrison J, Whitehouse S, Mitchelmore A, Thornton M.** A randomised comparison of a foot pump and low-molecular-weight heparin in the prevention of deep-vein thrombosis after total knee replacement. *J Bone Joint Surg [Br]* 2002;84-B:344-50.
19. **Grady-Benson JC, Oishi CS, Hanson PB, et al.** Postoperative surveillance for deep venous thrombosis with duplex ultrasonography after total knee arthroplasty. *J Bone Joint Surg [Am]* 1994;76-A:1649-57.
20. **Oishi CS, Grady-Benson JC, Otis SM, Colwell CW Jr, Walker RH.** The clinical course of distal deep venous thrombosis after total hip and total knee arthroplasty, as determined with duplex ultrasonography. *J Bone Joint Surg [Am]* 1994;76-A:1658-63.
21. **Bulitta C, Kock HJ, Hanke J, Sievers KW, Schmit-Neuerburg KP.** Promoting venous return in plaster cast by AV impulse system: a preclinical study. *Unfallchirurgie* 1996;22:145-52 (in German).
22. **Wilson NV, Das SK, Kakkar VV, et al.** Thrombo-embolic prophylaxis in total knee replacement: evaluation of the A-V impulse system. *J Bone Joint Surg [Br]* 1992;74-B:50-2.
23. **Santori FS, Vitullo A, Stopponi M, Santori N, Ghera S.** Prophylaxis against deep-vein thrombosis in total hip replacement: comparison of heparin and foot impulse pump. *J Bone Joint Surg [Br]* 1994;76-B:579-83.
24. **Westrich GH, Sculco TP.** Prophylaxis against deep venous thrombosis after total knee arthroplasty: pheumatic plantar compression and aspirin compared with aspirin alone. *J Bone Joint Surg [Am]* 1996;78-A:826-34.
25. **Winemiller MH, Stolp-Smith KA, Silverstein MD, Therneau TM.** Prevention of venous thromboembolism in patients with spinal cord injury: effects of sequential pneumatic compression and heparin. *J Spinal Cord Med* 1999;22:182-91.
26. **Spain DA, Bergamini TM, Hoffmann JF, Carrillo EH, Richardson JD.** Comparison of sequential compression devices and foot pumps for prophylaxis of deep venous thrombosis in high-risk trauma patients. *Am Surg* 1998;64:522-5.
27. **Robertson KA, Bertot AJ, Wolfe MW, Barrack RL.** Patient compliance and satisfaction with mechanical devices for preventing deep venous thrombosis after joint replacement. *J South Orthop Assoc* 2000;9:182-6.
28. **Kearon C, Julian JA, Newman TE, Ginsberg JS.** Noninvasive diagnosis of deep venous thrombosis: McMaster diagnostic imaging practice guidelines initiative. *Ann Intern Med* 1998;128:663-77.
29. **Tapson VF, Carroll BA, Davidson BL, et al.** The diagnostic approach to acute venous thromboembolism: clinical practice guideline. *Am J Respir Crit Care Med* 1999;160:1043-66.