

Regional hemodynamics in patients with femoral shaft nonunions treated with combined external fixation and intramedullary nail**T.I. Dolganova¹, T.I. Menschikova¹, S.N. Kolchin¹, D.Yu. Borzunov^{1,2}, D.S. Mokhovikov¹**¹Russian Ilizarov Scientific Center for Restorative Traumatology and Orthopaedics, Kurgan, Russian Federation;²Tyumen State Medical University, Tyumen, Russian Federation

Objective The purpose of the study was to explore peripheral hemodynamics in patients with femoral shaft nonunions treated with combined external fixation and intramedullary nail. **Material and methods** Two groups of patients were identified. Group I included 11 patients with a deformity at the apex of nonunion treated with consecutive combined osteosynthesis. Group II consisted of 15 patients with nonunions and femoral shortening treated with synchronous combined distraction-compression osteosynthesis. Methods of examination comprised duplex ultrasound of veins and parasosseous vessels at the regeneration site (HITACHI HI Vision Avius), USDG (ANGIO-PLUS, Moscow) and tetrapolar rheovasography (RVG) of lower limbs (Rheograph RGPA-6/12, Taganrog). **Results and discussion** Volumetric blood flow of the femur and tibia measured postoperatively with RVG showed no differences in the intact and operated limb whatever technique was applied. In all patients, major blood flow was recorded at stages of combined fixation and Ilizarov fixation, linear systolic velocity and pulsatility index were not significantly different from normal and intact limb values, hemodynamic criteria of vasoconstriction of major vessels were not identified. The steal syndrome of distal segments due to functional bypass was observed in patients with unstable metal constructs and did not aggravate after surgical treatment in Group I. Duplex ultrasound scan of the femoral shaft cortical bone showed expressed arterial and venous color map in all patients with high peripheral indices reflecting vascular tone and measuring $PI = 12 \pm 3.5$; $RI = 0.9 \pm 0.1$. **Conclusion** No significant hemodynamic changes were detected in major arteries during treatment of patients with femoral nonunions using combined techniques of external fixation and intramedullary nail. Vasodilatation of veins recorded during treatment of patients with femoral nonunions using combined techniques of external fixation and intramedullary nail was determined as a risk factor for venous thromboembolism. A local increase in the arterial and venous parasosseous blood flow was recorded at the cortical site of nonunion with combined intramedullary osteosynthesis.

Keywords: regional hemodynamics, nonunion, osteosynthesis, Ilizarov external fixation

INTRODUCTION

Combined techniques of transosseous and intramedullary osteosynthesis are currently used to rehabilitate patients with femoral shaft nonunions [1, 2, 3]. Reaming of intramedullary canal is required for nail implantation. Some authors report that reaming of intramedullary canal causes no harm to intraosseous blood flow [4], is accompanied by increased cortical circulation and osteogenic potential [5] and leads to a circulated blood content in the surrounding soft tissues [6] maintaining for the period of up to 12 weeks [7]. A combination of a traumatic injury to the bone and soft tissues at a fracture fixed with intramedullary nail exhibited enhanced blood flow in the muscles and decreased circulation in the bone [8]. Intramedullary nail is reported to result in a two-fold decrease blood flow in a. nutricia [9] and decreased cortical circulation within 4 weeks [10]. A combination of a low cortical circulation and locally increased blood flow at the fracture site was also reported [11].

Increased blood flow in intraosseous and periosteal vessels was favourable employed for treatment of patients with nonunions due to the primary role of periosteum in secondary healing of long bones followed by remodeling of endosteum vessels [12, 13]. Peripheral hemodynamics and partial pressure of oxygen studied in the tissues with transcutaneous polarography show no statistically significant differences and essentially reflect mechanism of limb fracture with no effect of intramedullary nail on regional hemodynamics [14].

Traumatic injuries of long bones of lower limbs are often associated with deep vein thrombosis of lower limbs in 7.4 % of the cases [15]. Deep vein thrombosis rate ranges from 33 to 53% in patients who undergo surgical repair of lower limb fractures [16]. No motion in the knee joint turns off the small saphenous vein causing considerable disorders of venous hemodynamics [17]. Disorders of venous hemodynamics caused

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by dysfunction of muscular venous pump play the leading role in clinically meaningful thrombosis after transosseous osteosynthesis. Patients can maintain weight-bearing on the operated limb and motions in the joints with intramedullary osteosynthesis. Application of transosseous osteosynthesis involves the possibility of axial loading with the range of motion being limited in the adjacent joints [18].

MATERIALS AND METHODS

The review includes 26 patients with femoral shaft nonunions and defects treated with combined techniques of transosseous and interlocking intramedullary osteosynthesis between 2008 and 2016. All patients had posttraumatic nonunions aged from 1 year to 13 years of primary injury. Patients were subdivided into two groups with regard to clinical and radiological manifestations and method of osteosynthesis used.

Combined consecutive osteosynthesis was applied for 11 patients of Group I with deformities at the apex of nonunion. The technique was applied in two surgical sessions. The first surgical procedure included Ilizarov external fixation followed by gradual correction of the femoral deformity. Antegrade interlocking nailing was applied with the limb axis realigned.

Synchronous combined distraction-compression osteosynthesis was employed for 15 patients of Group II who had nonunions associated with femoral shortening. The technique involved two surgical sessions. The first surgical procedure included external frame application, nailing and femoral lengthening osteotomy. Distraction started after 5-to-7-day latency period with the rate of 1.0 to 1.5 mm per day to eliminate femoral length discrepancy. With the femoral discrepancy eliminated interlocking nailing was produced according to static scheme and the Ilizarov frame was dismantled.

Deep vein thrombosis of lower limbs was not observed in any clinical observation during inpatient treatment. Prophylaxis of thrombosis was conducted according to protocol developed to prevent pulmonary embolism in surgical patients – an adapted version of GOST Guidelines (91500.11.0007-2003) approved by Order MZ RF № 233 of 09.06.2003.

Instrumental examination of peripheral hemodynamics was performed for:

- patients of Group I after the first surgical session during fixation phase with the Ilizarov frame and after

There were no publications found in the available literature that would discuss changes in the arterial and venous blood flow with combined usage of transosseous and intramedullary osteosynthesis.

The purpose of the study was to explore peripheral hemodynamics in patients with femoral shaft nonunions treated with combined external fixation and intramedullary nail.

the second surgical session of the nail implantation;

- patients of Group II after the first surgical session at the stage of combined osteosynthesis at the end of distraction and after the second surgical session of removal of the Ilizarov external fixator and placement of locking screws.

Methods of examination used

1. Duplex ultrasound of veins and ultrasonography of vessels in the soft tissues and periosteum at the site of regenerate bone was produced with HITACHI HI Vision Avius ultrasound system. Multi-frequency linear 5-12 MHz probe was applied with established practice using colour Doppler energy imaging and spectral analysis to identify hemodynamic phenomena.

2. Ultrasound Dopplerography (ANGIO-PLUS, Moscow). Echography was conducted with standard points in patients in supine position using ultrasound 4 MHz and 8 MHz probes. Maximum (peak) blood flow velocity (Vmax) and pulsatility index (PI) were measured on post-processing signal.

3. Tetrapolar rheovasography (RVG) of lower limbs was performed with computer-assisted Rheograph RGPA-6/12 polyanalyzer (Taganrog) using circular electrodes. RVG data included:

- rheographic index measuring blood content in tissues on the basis of the baseline impedance;
- elasticity modulus (EM, %) measuring elastic and tone of major arterial vessels;
- diastolic index (DI, %) and peripheral vascular resistance index (PVRI, %) measuring mainly vascular resistance determined by the tone of small vessels in the study area (arterioles, capillaries);
- diastolic index (DSI, %) primarily showing condition of venules and veins. Increased DI indicates to hypotonic veins and obstructed venous outflow.

Statistical data analysis was performed with Microsoft EXEL-2000 and AtteStat computer

program. Measurements of distributed profiles of asymmetrical estimates of the intact limb (RVG of the femur and tibia, USDG of arteries) in 26 observations using modified criteria of Kolmogorov, Smirnov, asymmetry and excess criteria indicated to the normal hypothesis being declined with the variables challenging normal probability law. Quantitative

characteristics of the samples are presented in Table 1 as median of 25 % ÷ 75 % percentiles and number of observations (n) that underwent examinations. Variation statistics was used for the small population sample with the significance threshold set at $p \leq 0.05$. Wilcoxon rank-sum tests were used to identify statistical significance of the variables.

RESULTS

Rheovasographic measurements of the femur and tibia are presented in Table 1 and USDG measurements of lower limbs in patients with femoral

shaft nonunions treated with combined techniques of external fixation and intramedullary nailing are presented in Table 2.

Table 1

Rheovasographic measurements of the femur and tibia in patients with femoral shaft nonunions at stages of treatment using combined external fixation and intramedullary nailing (median; 0.25 ÷ 0.75 percentile)

	BI	RI	EM	DI	DSI	PES	PVRI
Intact limb (n = 52)							
femur	113 (86 ÷ 175)	0.16 (0.12 ÷ 0.20)	15.0 (13.0 ÷ 16.5)	45.0 (31.5 ÷ 55.5)	48.0 (37.5 ÷ 66.5)	125.0 (109.5 ÷ 138.0)	89.0 (79.5 ÷ 97.0)
tibia	279 (212 ÷ 343)	0.44 (0.38 ÷ 0.52)	18.0 (15.0 ÷ 19.0)	26.0 (18.0 ÷ 33.0)	33.0 (26.5 ÷ 37.0)	127.0 (115.0 ÷ 147.5)	65.0 (56.0 ÷ 72.5)
Preoperative involved limb No foreign bodies (n = 10)							
femur	107.7 (83.7 ÷ 132.6)	0.14 (0.13 ÷ 0.19)	14.5 (11.5 ÷ 16.5)	42.5 (35.5 ÷ 49.0)	49.5 (38.5 ÷ 61.5)	121.5 (106 ÷ 146)	83 (72.5 ÷ 90)
tibia	275 (220 ÷ 289)	0.44 (0.32 ÷ 0.59)	16.5 (15.0 ÷ 19.0)	25.5 (17.0 ÷ 32.5)	28.5 (21.5 ÷ 34.5)	126.0 (111.5 ÷ 140)	56.0 (47.0 ÷ 68.5)
Unstable metal osteosynthesis (n = 16)							
femur	115.3 (99.8 ÷ 166.1)	0.13 (0.10 ÷ 0.15)	13.0 (10.0 ÷ 16.0)	42.0 (39.0 ÷ 45.0)	47.0 (44.0 ÷ 65.0)	113.0 (104 ÷ 116)	87 (59.0 ÷ 94.0)
tibia	338 (305.2 ÷ 463.1)	0.44 (0.38 ÷ 0.47)	14.0 (11.0 ÷ 16.0)	21.0 (12.0 ÷ 28.0)	31.0 (26.0 ÷ 44.0)	119.0 (92.0 ÷ 120.0)	52.0 (47.0 ÷ 59.0)
Group I (n = 11) Phase: fixation with frame on							
femur	123.3 (110 ÷ 156)	0.14 (0.07 ÷ 0.25)	17.5 (12.0 ÷ 20.0)	77.5* (58.0 ÷ 84.0)	88.5* (63.0 ÷ 104.0)	105.5 (96.0 ÷ 134.0)	102.0 (79.0 ÷ 116.0)
tibia	216.8 (162.3 ÷ 258)	0.46 (0.25 ÷ 0.53)	18.0 (15.0 ÷ 22.0)	25.5 (15.0 ÷ 33.0)	26.5 (18.0 ÷ 48.0)	128.0 (113.0 ÷ 165.0)	77.0 (62.5 ÷ 78.5)
Phase: intramedullary nailing							
femur	141.5 (84.2 ÷ 143.9)	0.14 (0.06 ÷ 0.20)	15.5 (13.0 ÷ 17.0)	44.0 (33.0 ÷ 48.5)	50.0 (37.0 ÷ 58.0)	111.0 (96.5 ÷ 124.0)	109.0 (75.0 ÷ 113.5)
tibia	298.7 (247 ÷ 322.5)	0.40 (0.23 ÷ 0.44)	18.0 (17.0 ÷ 22.0)	22.0 (19.0 ÷ 33.0)	31.0 (21.0 ÷ 34.5)	123.0 (106.0 ÷ 145.0)	67.0 (58.0 ÷ 75.5)
Group II (n = 15) Phase: fixation with frame on + nail							
femur	121.5 (107 ÷ 152)	0.14 (0.11 ÷ 0.19)	16.3 (12.0 ÷ 18.4)	49.4 (44.0 ÷ 65.0)	53.5 (47.0 ÷ 74.5)	129.5 (112.5 ÷ 140.5)	115.5 (107 ÷ 134.0)
tibia	302.0 (258 ÷ 388)	0.45 (0.28 ÷ 0.55)	18.4 (15.5 ÷ 20.5)	20.0 (17.0 ÷ 38.0)	27.5 (22.5 ÷ 52.0)	133.4 (115 ÷ 144.5)	75.5 (67.9 ÷ 79.0)
Phase: interlocking nail							
femur	138.5 (117 ÷ 168)	0.12 (0.10 ÷ 0.14)	15.5 (14.0 ÷ 16.0)	43.5 (37.0 ÷ 45.0)	50.5 (44.0 ÷ 69.5)	122.5 (110.5 ÷ 144.5)	111.5 (106 ÷ 120.0)
tibia	280.9 (248 ÷ 376)	0.41 (0.23 ÷ 0.49)	19.0 (17.5 ÷ 20.0)	25.0 (20.5 ÷ 38.0)	27.5 (23.5 ÷ 38.0)	124.5 (112 ÷ 156.5)	70.5 (69.5 ÷ 76.0)
3-month follow-up (n = 16)							
femur	92.2 (75.4 ÷ 131.5)	0.17 (0.12 ÷ 0.27)	11.5 (10.0 ÷ 15.5)	48.0 (33.0 ÷ 49.0)	48.5 (37.0 ÷ 50.0)	113.0 (97.0 ÷ 136.0)	108.0 (75.0 ÷ 115.5)
tibia	235.5 (190 ÷ 34.0)	0.47 (0.32 ÷ 0.51)	17.5 (15.5 ÷ 19.9)	22.0 (18.8 ÷ 39.4)	27.0 (24.5 ÷ 44.0)	117.0 (105.0 ÷ 132.5)	69.0 (52.0 ÷ 77.1)

Note: * significant ($p \leq 0.05$) differences shown in relation to preoperative measurements of intact limb. BI (om) – baseline impedance of tissues; RI (rel. units) – rheographic index involving impedance of tissues; EM (%), elasticity module; PVRI (%), peripheral vascular resistance index; DSI (%), diastolic index; DI (%), dicrotic index; n, number of observations.

Table 2

USDG measurements of lower limbs in patients with femoral shaft nonunions at stages of treatment using combined external fixation and intramedullary nailing

CFA		DFA		PA		PTA		ATA		DPA	
Vmax cm/s	PI	Vmax cm/s	PI	Vmax cm/s	PI	Vmax cm/s	PI	Vmax cm/s	PI	Vmax cm/s	PI
Intact limb (n = 26)											
72.6 (55.0 ÷ 84.0)	1.62 (1.01 ÷ 1.95)	68.9 (54.0 ÷ 71.2)	1.51 (1.11 ÷ 1.64)	48.2 (40.1 ÷ 59.6)	1.49 (1.29 ÷ 1.84)	55.9 (42.9 ÷ 79.7)	2.02 (1.44 ÷ 2.22)	44.9 (33.9 ÷ 68.7)	2.12 (1.34 ÷ 2.33)	54.9 (41.8 ÷ 78.7)	2.48 (1.44 ÷ 2.62)
Preoperative involved limb (n = 26)											
Absence of foreign bodies (n = 10)											
70.9 (58.0 ÷ 82.0)	1.69 (1.11 ÷ 1.98)	66.9 (54.0 ÷ 78.2)	1.57 (1.12 ÷ 1.71)	58.2 (42.1 ÷ 69.1)	1.89 (1.21 ÷ 1.96)	56.9 (40.9 ÷ 70.7)	1.88 (1.22 ÷ 2.12)	49.9 (38.9 ÷ 61.7)	2.02 (1.45 ÷ 2.67)	54.7 (45.8 ÷ 76.7)	2.38 (1.30 ÷ 2.52)
Unstable metal osteosynthesis (n = 16)											
71.9 (55.0 ÷ 79.0)	1.69 (1.21 ÷ 1.82)	64.9 (55.0 ÷ 71.8)	1.66 (1.22 ÷ 1.74)	55.2 (43.1 ÷ 62.1)	1.59 (1.31 ÷ 1.76)	53.9 (42.9 ÷ 71.7)	2.88 (1.62 ÷ 3.02)	29.9* (18.9 ÷ 41.7)	2.42 (1.69 ÷ 2.77)	34.7* (25.8 ÷ 46.7)	2.08 (1.80 ÷ 2.53)
Group I (n = 11)											
Phase: fixation with frame on											
73.9 (58.0 ÷ 82.0)	1.49 (1.33 ÷ 1.77)	54.9 (45.0 ÷ 74.8)	1.56 (1.22 ÷ 1.84)	35.2 (23.1 ÷ 52.4)	1.64 (1.31 ÷ 1.88)	52.7 (41.9 ÷ 66.7)	2.44 (1.77 ÷ 2.98)	30.9* (21.1 ÷ 41.9)	2.11 (1.74 ÷ 2.34)	37.8* (29.8 ÷ 49.9)	2.22 (1.81 ÷ 2.64)
Phase: intramedullary nailing											
74.9 (51.0 ÷ 85.0)	1.77 (1.44 ÷ 1.95)	64.9 (47.0 ÷ 79.7)	1.26 (1.02 ÷ 1.88)	55.2 (29.2 ÷ 82.4)	1.94 (1.41 ÷ 2.77)	59.7 (41.7 ÷ 76.9)	2.01 (1.88 ÷ 3.55)	39.9 (28.1 ÷ 61.9)	2.11 (1.74 ÷ 2.34)	37.8 (29.8 ÷ 69.9)	2.22 (1.81 ÷ 2.64)
Group II (n = 15)											
Phase: fixation with frame on + nail											
77.2 (60.0 ÷ 88.0)	1.79 (1.44 ÷ 2.11)	65.1 (44.0 ÷ 75.5)	2.12 (1.49 ÷ 2.29)	55.9 (33.8 ÷ 70.0)	1.75 (1.34 ÷ 1.99)	55.1 (44.2 ÷ 70.0)	2.44 (1.79 ÷ 2.69)	40.2 (30.9 ÷ 62.0)	2.88 (1.99 ÷ 3.09)	45.4 (30.9 ÷ 75.9)	3.81 (2.80 ÷ 4.24)
Phase: interlocking nail											
74.2 (61.0 ÷ 89.0)	1.69 (1.55 ÷ 2.11)	55.1 (40.0 ÷ 72.9)	1.44 (1.29 ÷ 1.67)	53.9 (38.8 ÷ 72.0)	1.59 (1.40 ÷ 1.77)	48.2 (40.2 ÷ 66.0)	2.34 (1.80 ÷ 2.55)	41.2 (35.9 ÷ 66.4)	2.18 (1.86 ÷ 2.44)	43.4 (35.9 ÷ 65.9)	2.33 (2.08 ÷ 2.54)
33-month follow-up (n = 16)											
76.1 (61.9 ÷ 80.1)	1.30 (1.21 ÷ 1.54)	75.1 (50.0 ÷ 83.1)	1.64 (1.41 ÷ 1.81)	50.9 (31.8 ÷ 68.1)	1.79 (1.51 ÷ 1.92)	58.0 (41.3 ÷ 68.3)	2.44 (1.99 ÷ 2.65)	41.4 (36.9 ÷ 56.9)	2.16 (1.94 ÷ 2.39)	53.4 (39.4 ÷ 70.0)	2.50 (2.21 ÷ 2.87)

Note: *significant ($p \leq 0.05$) differences shown in relation to preoperative measurements of the intact limb. Vmax (cm/s), maximal linear blood flow velocity; PI, pulsatility index; n, number of observations.

No statistically significant differences were observed in preoperative rheovasographic measurements of lower limbs with unstable osteosynthesis and absence of foreign bodies in the femur (Table 1). Patients of Group I showed mean DI of vascular resistance increased by 80 % and DSI of venules and vein condition by 60%. No off-normal RVG measurements were detected in operated and intact limbs at three-month follow-up.

Preoperative three signal component typical for intact main blood stream was recorded in patients with femoral shaft nonunions to be treated with combined osteosynthesis in aa. femoralis, poplitea, tibialis post., tibialis ant. of involved and intact limbs. Measurements of linear systolic blood flow velocity (Vmax) and pulsatility index of the involved limb were not significantly different from those of the intact limb (Table 2). Mean Vmax was shown to decrease by 30% in anterior tibial artery pool with intact main blood stream in patients with previously placed unstable metal constructs.

Main blood stream was recorded in arteries of

lower limbs of patients Groups I and II at stages of Ilizarov bone fixation alone and combined fixation, and measurements of linear systolic blood flow velocity (Vmax) and pulsatility index were not significantly different from those in the norm and of intact limb.

Vasodilatation of superficial and deep veins was recorded in the operated limb of Groups I and II patients during Ilizarov bone fixation and combined osteosynthesis using duplex ultrasound. External iliac vein, common, superficial and deep femoral arteries were permeable all along the explorable way with walls being not thickened and lumen diameter asymmetry of 20 to 35 %. The veins maintained the compressibility, and respiration related phasic blood flow recorded. The main venous outflow in the operated limb was produced via the great saphenous vein and was shown to increase with asymmetry in velocity measurements by 40 to 55 %. No signs of valve insufficiency in the common femoral artery and great saphenous vein were detected. Ultrasound showed enlarged popliteal, sural, superficial,

perforating and deep veins of tibia. The veins were well compressed by the probe. The walls were not thickened and no additional masses were seen in the lumens. Colour map of the blood flow was identified only with compression of the probe. Venous outflow velocity was decreased in the posterior tibial vein and weak positive probe noted with distal digital compression.

Colour mapping of singular arterioles in the cortical bone and adjacent soft tissues was identified with ultrasound in absence of foreign bodies at the nonunion of the femoral shaft. Pulsatility index (PI) representing vascular tone measured 3.29 ± 0.31 . Enhanced colour mapping with arterial and venous components was recorded in the cortical area of nonunion and adjacent soft

tissues in presence of unstable metal constructs. Pulsatility indices were increased by 50 to 70 % and measured $PI = 5.26 \pm 0.44$ that indicated to higher tone of small vessels.

Colour mapping of enhanced arterial and venous components was recorded at the cortical zone and adjacent soft tissues in patients of Groups I and II after the first surgical session with high peripheral indices: $PI = 12 \pm 3.5$; $RI = 0.9 \pm 0.1$ (**Fig. 1**). Vascular pattern was more expressed in patients with baseline unstable osteosynthesis during treatment with combined techniques.

Colour mapping of reduced arterial and venous components was recorded at the cortical zone and adjacent soft tissues of nonunion site at the second stage of surgical treatment.

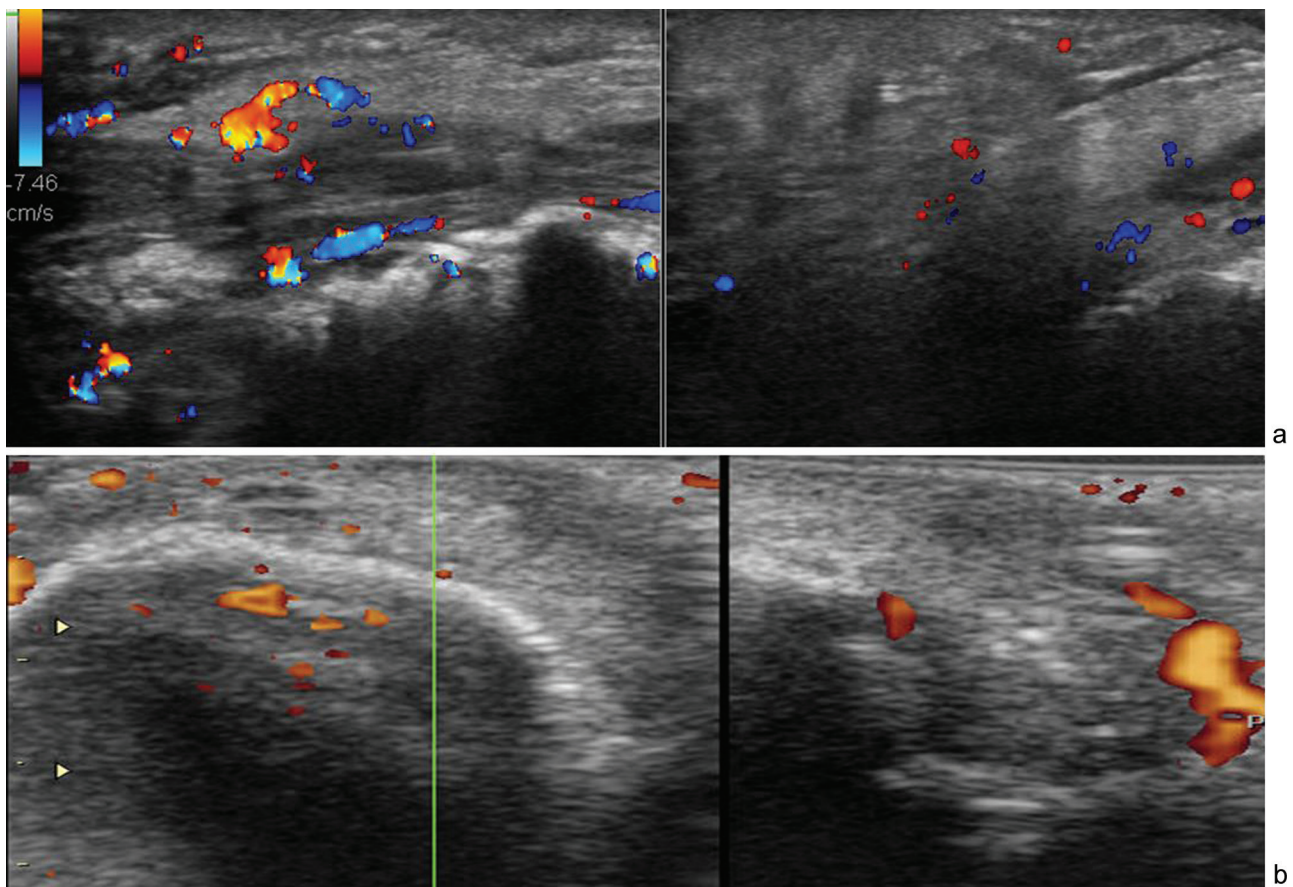


Fig. 1 Colour map of arterial and venous components: a, enhanced vasculature is visualized at the defect site with scanning along the long axis of the segment; b, regeneration fragments and vascular branches of $d = 3-5$ mm are visualized with oblique-diagonal scanning

DISCUSSION

Patients with limited range of motion in the knee joint can walk and maintain weight-bearing with Ilizarov external fixation of the femur that results in venous stasis due to disturbed function of muscular venous pump [19]. This is confirmed

by rheovasographic findings reflecting vascular resistance and condition of venules and veins that can be interpreted as increased peripheral vascular resistance with hypotonic veins and impaired venous outflow.

Rheovasographic findings showing peripheral vascular tone and venous outflow were not significantly different from normal values and measurements of contralateral limb with the usage of intramedullary and combined fixation of the femur and preserved motion in the knee joint, but ultrasound indicated to venous dilation. Venous stasis accompanied by venous dilation and venous hypertension contributed to delayed thromboembolism. Early functional loading allowed for increase in the range of active motion in the joints of the involved limb treated with intramedullary nailing and provided normalization of venous hemodynamics that prevented thrombosis.

Rheovasographic data of patients with femoral shaft nonunions measured at stages of combined intramedullary nailing and external fixation are in line with those reported in patients treated with different types of tibial fixation [20]. Volumetric blood flow of tibia and femur measured postoperatively with RVG showed no differences in the intact and operated limb regardless fixation technique used.

Doppler ultrasound revealed no hemodynamic criteria of vasoconstriction of main vessels at all stages of combined transosseous and intramedullary osteosynthesis reported in patients with diaphyseal fractures of long bones at acute period and the first 5 to 10 postoperative day [21, 22, 23].

Our findings are on par with those of other series showing that staging and velocity of blood flow recover at the end of two weeks of intramedullary nailing with absent vasodilation of main vessels [20].

Decrease in linear velocity by 30% on average recorded in anterior tibial artery pool of Group I during fixation phase with the Ilizarov frame

could be associated with limited regional blood supply in tibia and foot and low functional activity. Decreased blood supply in distal segments (tibia with pathology located in the femur and the foot with involved site located in the tibia) could be interpreted as a steal syndrome due to a functional bypass effect at trauma level [25, 26]. Similar changes were observed in patients with unstable metal osteosynthesis and were not shown to aggravate with Ilizarov external fixation in patients of Group I. No steal syndrome was noted in Group II with combined bone fixation.

There was no need in defense mechanism of adaptive potential in the body to retain vital functions at stages of Ilizarov external fixation, intramedullary nailing or with the combination of the two techniques [26].

Measurements showing increased blood flow at the cortical zone and surrounding muscles are in line with the data obtained by other researchers [5, 6, 7]. Greater tone of small vessels in the periosteum and adjacent soft tissues was a compensatory reaction of the vascular system to a surgical trauma. Perfusion and swelling of tissues were noted to decrease due to vasoconstriction but there was a risk of haemorheological insufficiency manifesting itself in a low oxygen delivery index [26]. Enhanced vascular pattern in patients with baseline unstable combined osteosynthesis indicated to a high level of osteogenesis with this method of treatment.

No significant hemodynamic changes were detected in major arteries during treatment of patients with femoral nonunions using combined techniques of external fixation and intramedullary nail.

CONCLUSIONS

1. Usage of external bone fixation, interlocking intramedullary nailing and the combination of two techniques is accompanied by increased blood flow at the cortical area and surrounding muscles at the nonunion site.

2. Doppler ultrasound and rheovasography revealed no reaction of major blood flow with application of combined transosseous and intramedullary osteosynthesis.

3. A local increase in the arterial and venous paraosseous blood flow was recorded at the cortical site of nonunion with combined intramedullary osteosynthesis.

4. Vasodilatation of veins recorded during treatment with combined techniques of external fixation and intramedullary nail was determined as a risk factor for delayed thromboembolism that required specific prevention measures.

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