Coll. Antropol. **34** (2010) Suppl. 1: 77–81
Original scientific paper

Vasculometry of Upper and Lower Extremities in Correlation with Development of Pathologic Conditions like the Diabetic Foot

Vasilije Nikolić[1], Radivoje Radić[1], Robert Selthofer[1], Tonči Mišević[2], Branko Dmitrović[3], Darija Šnajder[1], Vladimir Šišljagić[4], Tatjana Belovari[5] and Zvonimir Sučić[6]

[1] Department of Anatomy and Neurosciences, School of Medicine, University »J. J. Strossmayer«, Osijek, Croatia
[2] Department of Radiology, University Hospital Center Osijek, Osijek, Croatia
[3] Department of Pathology, School of Medicine, University »J. J. Strossmayer«, Osijek, Croatia
[4] Department of Surgery, School of Medicine, University »J. J. Strossmayer«, Osijek, Croatia
[5] Department of Histology and Embriology, School of Medicine, University »J. J. Strossmayer«, Osijek, Croatia
[6] Department of Radiology, University Hospital »Sv. Duh«, Zagreb, Croatia

A B S T R A C T

We assume that the vascular apparatus of the lower limb did not evolutionary adapt to leg mass and volume. The lower limb is grater in length and volume that the upper limb, and therefore the arteries should have a bigger diameter and cross-sectional area. During pathoanatomic autopsies at the Department of Pathology of University Hospital Center Osijek we have taken segments of 1 cm of length from the subclavian, femoral, radial and tibial artery. Our sample contained segments from 51 bodies, 24 female and 27 male. We have measured leg and arm length and circumference. From these data the idealized limbs volume was calculated by geometric approximations to a cone fragment. The relation between idealized leg and arm volume and arterial cross-sectional area were calculated. For statistical analysis, Student's t-test was used. At the Department of Radiology of the University Hospital Center Osijek we measured the diameter of subclavian and femoral artery in systole and diastole in 41 patients (21 female and 20 male) by Color Doppler ultrasound, and the circumference and length of upper and lower limb was measured. There is a slightly difference between the diameter and cross-sectional area of subclavian and femoral artery. Leg length was for 48.5% bigger than arm length and the difference in volume between upper and lower limb is significantly different. The foot has four to five times greater volume than the arm, and is vascularised by an arterial tree of similar diameter. This fact proves our hypothesis that the blood supply to the lower limbs compared to the mass of tissue is smaller.

Key words: *biomechanics, vascularization, diabetic foot*

Introduction

Through the human evolution and the process of bipedal locomotion, the lower limbs undertake essentially changed biomechanical conditions resulting by an evolutionary adaptation of the human body to erect position[1]. Lower limbs undertake entire loading force from the body and different biomechanic and kinematic role as well a different process of functional adaptation than the upper limbs[2–4]. Therefore, the evolutionary adaptation of the locomotor apparatus (muscles, bones and connective tissue) of the lower limb went the other way than the upper limb, which resulted in different pathology, for instance in diabetic foot[5,6].

Diabetic foot is a complex syndrome characterized by tissue damage, ulceration or gangrene associated with diabetes, but very complex due to a combination of many factors: neurological, vascular, biomechanical, metabolic, etc.[7]. The proportion of individual factors in the emergence of diabetic foot varies from case to case[8].

Received for publication January 15, 2010

Ulceration occurs by damaging of the skin barrier and affects the deep tissues. Such ulcera heal difficultly, primarily due to repeated mechanical tissue damage due to insufficient blood flow because of damaged vascular perfusion, damaged innervation and accompanying infection[9].

Local mechanical factors, such as compressive and shear exertions are for normal tissues within the physiological limits of tolerance[10]. In patiens with diabetes physiological mechanical stress can lead to stronger damage of vascular tissue perfusion, which repeatedly reduces the vital and mechanical quality of tissue, which closes the circle that leads to irreversible damage and foot gangrene[11,12].

Diabetic foot is a common disorder in patiens with diabetes, as opposed to »diabetic hand«, a rare phenomenon, which suggests that the evolutionary role of lower limbs leads to a situation that lower limbs cumulate negative factors suitable for development of diabetic foot syndrome. Our hypothesis is that this happens because the evolutionary adaptation did not affect all structures and tissues equally. This means that in the course of evolution some systems did not sufficiently follow locomotor apparatus and connective tissue adaptation to changed and increased mechanical load. An example of sufficient adaptation are the evolutionary changes in the human spine, which in the process of righting adapted to vertical load forces assuming a mechanical form of »rod of equal strength«, i.e., every lower segment of the spine became more massive, for enduring a greater load. Spinal cord, however, is not affected by mechanical force and did not follow the changes in the osteoarticular part of the spine.

Lower limbs evolutionary became significantly more massive than the upper limbs; they have a more developed osteoarticular and muscular segment. The question is whether the vascular apparatus adequately followed this evolutionary change? It is clear that the blood and lymph drainage through veins and lymph vessels is going in the opposite direction of gravity which acts on hydrostatic pressure. Venous and lymphatic valves, communicating veins between the superficial and deep veins, and the position of deep veins near pulsing arteries and between muscles help the blood flow, but balance is labile and disorders are very common (varicose veins, ulcera cruris)[13].

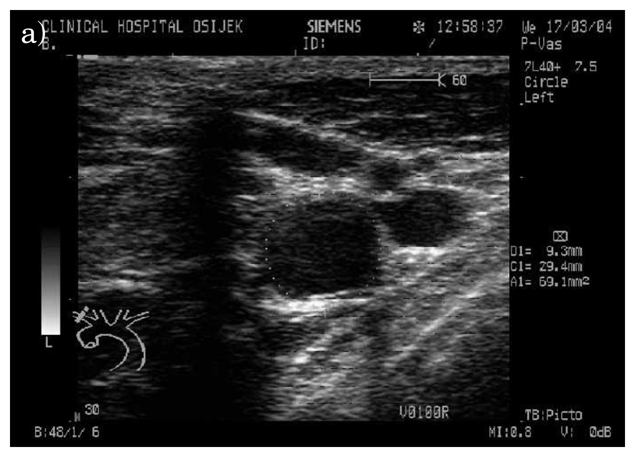
We think that the arterial vascular system of lower limb did not evolutionary adjust to leg mass and volume. Lower limb has a significantly greater mass that the upper limb, and therefore the arteries in the lower extremities should have a larger diameter and cross-sectional area. If the arteries did not follow these changes, the difference between artery diameter and limb volume would be unfavourable for lower limb, which would result in poor circulation in the legs even in physiological conditions, and therefore pathologic processes would early and easily lead to irreversible damage, like the diabetic foot syndrome in diabetes.

Materials and Methods

During pathoanatomic autopsies at the Department of Pathology of the University Hospital Center Osijek we analyzed the relation between diameter of the subclavian artery (*arteria subclavia*) and length and volume of upper limb, and the relation between diameter of femoral artery (*a. femoralis*) and length and volume of lower limb. The sample contained 51 bodies of different age, 27 male and 24 female.

The segment of subclavian artery measuring 1 cm was taken below the clavicle and the segment of femoral artery was taken below the inguinal ligament, i.e., on the junction between external iliac and femoral artery. Segments were also taken from the distal part of radial and tibial artery near the medial malleol. The samples were embedded in formalin, diameter was measured under magnification with precision of 0.1 mm, and cross-sectional area of the arteries was calculated.

The length of upper arm was measured from acromion to styloid processus of radial bone, and the length of the hand was measured from styloid processus to the top of the middle finger. Arm circumference was mea-



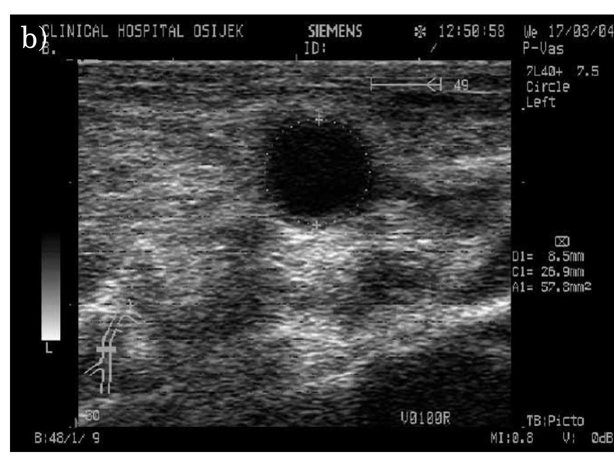


Fig. 1. a) Measurement of diameter of subclavian artery by Color Doppler ultrasound; b) Measurement of diameter of iliac (femoral) artery by Color Doppler ultrasound.

sured by tape meter at the upper and lower part of the upper arm and the upper and lower part of the forearm – below the elbow and wrist. Leg length was measured from middle of the inguinal ligament to the top of the medial malleol, and the foot length was measured from heel to the top of the thumb. Leg circumference was recorded on the upper part of the thigh and above the knee, and the circumference of the lower leg below the knee on the widest part and above the malleoli.

From these data the idealized limbs volume was calculated by geometric approximations to a cone fragment. The quotient of the cross-sectional area of proximal and distal segments of the arteries, arterial cross-sectional area and arm and leg length, and relation between idealized leg and arm volume and arterial cross-sectional area were calculated. For statistical analysis, Student's t-test was used.

At the Department of Radiology of the University Hospital Center Osijek diameter of subclavian and femoral arteries during systole and diastole were measured in 41 patients (21 female, 20 male) by Color Doppler ultrasound (Figure 1a and b). Limb length was measured and idealized limb volume was calculated in the same way as described above.

Results

Subclavian artery diameter varied in the range from 1.005 to 0.38 cm, and the diameter of femoral artery from 0.82 to 0.32, but with very large individual variations (standard deviation of subclavian artery diameter was 0.19 cm, and 0.12 cm for femoral artery) (Table 1). The average diameter measure for tibial artery was 0.11, and for radial artery 0.175 (Table 1). Our measurements of artery diameter are slightly smaller than anatomic data mentioned in the literature (for approximately 10 mm for both arteries according to Paturet). The formalin-preserved arteries were in a state without internal pressure, and additionally shrivelled by formalin what could have

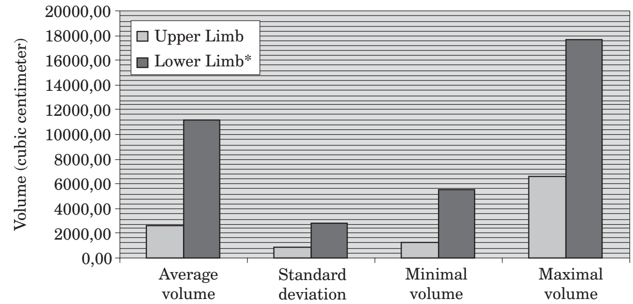


*Fig. 2. Volume of extremities in cadaveric material calculated by approximation to a cone fragment. *p<0.0001, Student's t-test.*

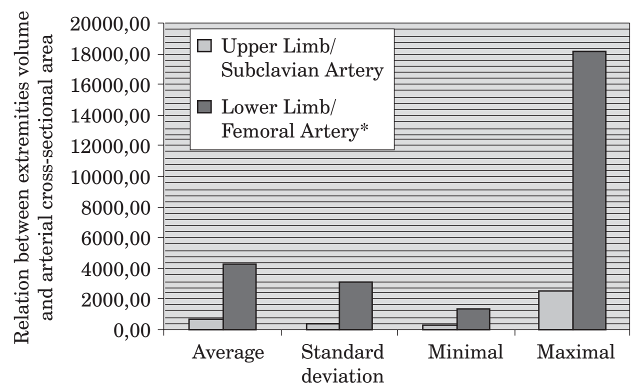


*Fig. 3. Relation between upper limb volume and subclavian artery cross-sectional area and lower limb volume and femoral artery cross-sectional area in cadaveric material. *p<0.0001, Student's t-test.*

TABLE 1
DIAMETER OF MEASURED ARTERIES (CADAVERIC MATERIAL)

Artery	Subclavian artery	Radial artery	Femoral artery	Tibial artery
Average diameter (cm)	0.716765	0.175	0.6328	0.110098039
Standard deviation (cm)	0.15507	0.039256	0.123434	0.050373507
Minimal diameter (cm)	0.38	0.08	0.315	0
Maximal diameter (cm)	1.005	0.26	0.875	0.205

TABLE 2
CALCULATED CROSS-SECTIONAL AREA OF MEASURED ARTERIES (CADAVERIC MATERIAL)

Artery	Subclavian artery	Radial artery	Iliac artery	Tibial artery
Average cross-sectional area (cm^2)	0.42*	0.03**	0.33	0.01
Standard deviation (cm^2)	0.17	0.01	0.12	0.01
Minimal cross-sectional area (cm^2)	0.11	0.01	0.08	0.00
Maximal cross-sectional area (cm^2)	0.79	0.05	0.60	0.03

*p<0.0001, Student's t-test, comparison between subclavian and iliac artery
**p<0.0001, Student's t-test, comparison between radial and tibial artery

TABLE 3
SYSTOLIC AND DIASTOLIC CROSS-SECTIONAL AREA OF ARTERIES MEASURED BY COLOR DOPPLER ULTRASOUND IN LIVING PATIENTS

Artery	Subclavian artery		Iliac artery	
	Systole	Diastole	Systole	Diastole
Average cross-sectional area (cm^2)	0.67	0.58	0.79	0.69
Standard deviation (cm^2)	0.18	0.17	0.23	0.2
Minimal cross-sectional area (cm^2)	0.351	0.312	0.398	0.333
Maximal cross-sectional area (cm^2)	1.4	1.2	1.5	1.3

had an effect to the results of diameter and cross-sectional area of cadaveric material. Because all arteries were treated in the same way, their interrelation has remained the same. Accordingly, the cross-sectional areas of the arteries can be observed in the same way (Table 2).

In measurements done by Color Doppler ultrasound subclavian artery cross-sectional area varied from 0.351 to 1.4 cm^2 in systole and from 0.312 to 1.2 cm^2 in diastole, and the cross-sectional area of femoral artery varied from 0.398 to 1.5 cm^2 in systole and from 0.333 to 1.3 cm^2 in diastole (Table 3).

The volume of lower limb varied from 5554.84 to 17602.31 cm^3, and the volume of upper limb was from 1257.21 to 6608.76 cm^3 in cadaveric material (Figure 2).

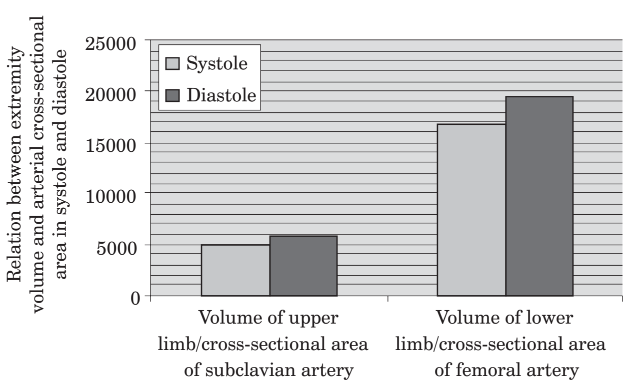


Fig. 4. Relation between upper limb volume and subclavian artery cross-sectional area and lower limb volume and femoral artery cross-sectional area in systole and diastole in living patients.

The results show that the relation between the volume of lower limb and the cross-sectional area of femoral artery is unfavorable in comparison to the relation of the volume of upper limb and the cross-sectional area of subclavian artery in measurements done in cadaveric material (Figure 3). The same conclusion can be drawn in living patients and measurements done by Color Doppler ultrasound, but there is no relevant difference between systole and diastole (Figure 4).

Conclusion

According to these results, there was a slightly difference between the diameter and cross-sectional area of subclavian and femoral artery. In several cases, subclavian artery was wider than the femoral, while the length and, particularly, the volume of the lower limb were much larger. Leg length was for 48.5% bigger than arm length, which means that the vascular network of arterial tree with approximately equal diameter and cross-sectional area is longer in the lower limb. However, the difference in volume between upper and lower limb is significantly different. The foot has four to five times greater volume than the arm, and is vascularised by an arterial tree of similar diameter. This fact proves our hypothesis that the blood supply to the lower limbs compared to the mass of tissue is smaller, what emphasises other etiological factors with which cumulation the diabetic foot occurs. Each of the pathological factors resulting in diabetes can very easily disarrange the balance in the supply of blood in the lower limb and disrupt the very small adjustment manoeuvre between blood flow and the need for blood.

REFERENCES

1. AGIĆ A, NIKOLIĆ V, MIJOVIĆ B, Coll Antropol, 30 (2006) 815. — 2. NIKOLIĆ V, HUDEC M, Principi i elementi biomehanike (Školska knjiga, Zagreb, 1988). — 3. NIKOLIĆ V, RADIĆ R, SELTHOFER R, Biomehanika stopala. In: HANČEVIĆ J, COCE F, BOZIKOV V (Eds) Dijabetičko stopalo (Medicinska naklada, Zagreb, 2002). — 4. AGIĆ A, NIKOLIĆ V, MIJOVIĆ B, REISCHL U, Coll Antropol, 32 (2008) 881. — 5. COCE F, Periferna arterijska bolest i šećerna bolest. In: HANČEVIĆ J, COCE F, BOZIKOV V (Eds) Dijabetičko stopalo (Medicinska naklada, Zagreb, 2002). — 6. PRIOLLET P, Arterial disease of the lower limbs in diabetic. In: TURNER R (Ed) Vascular Complications of Diabetes (Editions Pradel, Paris, 1994). — 7. KNOX R, DUTCH W, BLUME P, SUMPIO B, Int J Angiol, 1 (2000) 1. — 8. DYET JF, NICKOLSON AA, ETTLES DFE, Diabet Metab Res Rev, 16 (2000) 16. — 9. EDMONDS ME, Lancet, 354 (1999) 270. — 10. LAING P, Am J Surg, 176 (1998) 11. — 11. BERCELI SA, CHAN A, POMPOSELLI FB JR, GIBBONS GW, CAMPBELL DR, AKBARI CM, BROPHY DT, LOGERFO FW, J Vasc Surg, 30 (1999) 499. — 12. PAMPOSELLI FB, MARCACCIO EJ, GIBBONS GW, CAMPBELL DR, FREEMAN DV, BURGESS AM, MILLER A, LOGERFO FW, J Vasc Surg, 21 (1995) 375. — 13. BRKLJAČIĆ B, MIŠEVIĆ T, HUZJAN R, BRAJČIĆ H, IVANAC G, Coll Antropol, 28 (2004) 761.

R. Radić

Department of Anatomy and Neurosciences, School of Medicine, University »J. J. Strossmayer«, J. Huttlera 4, 31000 Osijek, Croatia
e-mail: rradic@mefos.hr

VASKULOMETRIJA GORNJEG I DONJEG EKSTREMITETA U KORELACIJI S RAZVOJEM PATOLOŠKIH STANJA KAO ŠTO JE DIJABETIČKO STOPALO

S A Ž E T A K

Pretpostavili smo da se krvnožilni aparat donjeg uda nije evolucijski prilagodio masi i volumenu noge. Donji je ud veći po dužini i masi od gornjeg uda pa bi po tome arterije donjeg uda trebale imati veći promjer i površinu. Tijekom patoanatomskih obdukcija na Kliničkom zavodu za patološku anatomiju Kliničkog bolničkog centra Osijek uzeli smo segmente dužine 1 cm iz potključne, bedrene, radijalne i tibijalne arterije. Naš uzorak sastojao se od segmenata uzetih s 51 tijela, od kojih je 24 bilo ženskog spola, a 27 muškog. Mjerili smo dužinu i promjer gornjeg i donjeg uda. Iz tih podataka izračunat je idealizirani volumen udova geometrijskom aproksimacijom s krnjim stošcem. Izračunat je odnos između površine poprečnog presjeka arterija i idealiziranog volumena ruke ili noge. Studentov t-test korišten je za statističku analizu. Na Odjelu za radiologiju Kliničkog bolničkog centra Osijek Color Dopplerom mjereni su promjeri potključne i bedrene arterije u sistoli i dijastoli na 41 pacijentu (21 ženskog spola i 20 muškog) te im je mjeren obujam i dužina gornjeg i donjeg uda. Postoji vrlo mala razlika između promjera i površine poprečnog presjeka potključne i bedrene arterije. Noga je u prosjeku za 48,5% duža od ruke te je ima četiri do pet puta veći volumen od ruke, a vaskularizirana je arterijskim stablom sličnog promjera. To zapravo dokazuje našu hipotezu da je dovod krvi u donje ekstremitete odnosu na masu tkiva manji.