Bone marrow perfusion in healthy subjects assessed by scintigraphy after application of a tourniquet

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ABSTRACT **By means of a gamma camera technique involving a bolus injection of autologous ^{99m}Tc-labeled erythrocytes, we found that despite a tourniquet on the limb, the erythrocytes entered the bone marrow, and caused oozing in both lower (10 subjects) and upper limbs (14 subjects). The 24 healthy volunteers, 18 men, had a mean age of 50 (range 20–86) years. The activity reached the distal femur in a median of 365 (quartile 278–560) seconds and the distal humerus in a median of 280 (quartile 208–370) seconds. The median velocity for movement of erythrocytes in the femur was 3.7 (quartile 2.7–4.4) cm/min and in the humerus, it was 4.0 (quartile 3.1–5.3) cm/min. In 21 subjects, this activity reached the periarticular soft tissue. After 15 min with the tourniquet inflated, the activity in the distal femur of the tourniquet limb was 9 (quartile 5–18)% of that in the limb without a tourniquet. This study shows that although a tourniquet effectively occludes the extra-osseous blood supply, some intra-osseous blood supply is retained, which makes it difficult to obtain a bloodless field in some patients, despite the use of a tourniquet.**

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Only a few authors have studied the blood supply of bones distal to a tourniquet (Spira et al. 1965, Furlow 1971, Klenerman and Crawley 1977, Santavirta et al. 1978). In the examination of bone perfusion in living humans, both angiography (Atsumi and Yamano 1997) and venography (Wegner et al. 1969, Arnoldi et al. 1980, Heiden et al. 1991) have proved useful, but today more indirect methods, such as MRI and ^{99m}Tc-MDP bone scan, are used more widely. Positron emission tomography (PET) has also been of value in assessing bone marrow blood volumes in healthy volunteers (Iida et al. 1999). To visualize the intra-osseous blood flow in both upper and lower limbs and the ooze beneath a tourniquet, we developed a scintigraphic method based on the combined use of ^{99m}Tc-labeled erythrocytes and a limb tourniquet. We used this method to obtain new information about the vascularization of human extremities.

Patients and methods

18 healthy men and 6 healthy women having a mean age of 50 (20–86) years were given an autologous injection of ^{99m}Tc-radiolabeled erythrocytes. The mean radioactivity was 792 MBq. The radiolabeling of the erythrocytes was done using Pavel et al.'s method (1977). All subjects had palpable peripheral pulses. Demographic data concerning height, weight, blood pressure, and age were recorded. Total fat mass was measured with dual-energy X-ray absorptiometry (DXA-scan) (XR-36, Norland Medical Systems Inc, Fort Atkinson, WI, USA). A 14-cm wide pneumatic tourniquet was mounted on the proximal third of the thigh or upper arm. The cuff was inflated to a pressure of 150 mmHg above the systolic arm pressure on the thigh and of 100 mmHg on the arm. A bolus injection of labeled erythrocytes was given in a peripheral arm vein on the contralateral side and dynamic imaging was done in 1-sec frames for 15 min with a gamma camera. To mark the joint lines, a 57Co source was placed

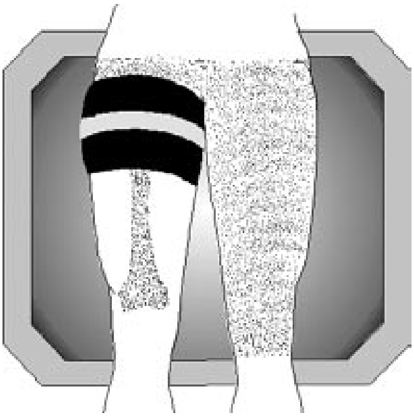

Figure 1. The lower limbs were aligned on the gamma camera with a tourniquet mounted proximally on the right thigh.

Figure 2. Scintigram of the lower limbs taken 500 sec after inflation of a tourniquet. Activity can be seen in the marrow of the femur's diaphysis distal to the cuff.

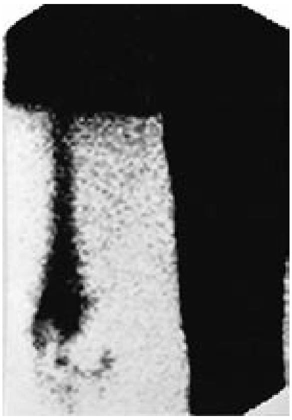

Figure 3. Scintigram of the lower limbs taken 900 sec after inflation of a tourniquet. Activity can be seen in the marrow of the femur condyles and periarticular soft tissue.

beside the distal demarcation of the femur or the humerus. The distance between the distal edge of the tourniquet and the distal part of the femur or humerus was measured on the images with the gamma camera computer software, and the median velocity of the movement of erythrocytes was calculated.

Procedure in lower limbs. 7 men and 3 women participated. Each subject was placed supine with the leg aligned with the knee on a gamma camera (Maxxus, Star 4000i, GE Medical Systems, Ill., WI, USA), equipped with low-energy general purpose collimators and interfaced with a dedicated computer (Figure 1). The limb was raised to 60 degrees for 1 min (Blond et al. 2002) for exsanguination. Then the tourniquet was inflated, the limb realigned, and the bolus injection given. As region of interest (ROI), we used both a rectangle that included the lower part of the femur (bone) and a rectangle that included the lower part of the thigh (bone and soft tissue). We compared the counts obtained in ROIs from the limb with or without tourniquet (Figures 2 and 3).

Procedure in upper limb. 11 men and 3 women participated. Each subject was placed supine with the right arm on a gamma camera (StarCam XR/7, Star 4000i, GE Medical Systems, Ill., WI, USA) (Figure 4). This arm was raised to vertically for 30 sec for exsanguination (Blond and Madsen 2002). Then the tourniquet was inflated, the limb realigned, and the bolus injection given (Figures 5 and 6).

The local Committee on Ethics in Copenhagen approved this study, which was done in accordance with the recommendations of the Declaration of Helsinki. All volunteers were given an injection of autologous ^{99m}Tc-labeled erythrocytes as part of another scientific study.

Statistics

We used linear regression analysis to compare the time taken for the activity to reach the joint line level and the length of the bone distal to the edge of the tourniquet. Multiple linear regression analysis was done to determinate the presence of a relationship between the velocity of movement of erythrocytes and gender, age, total fat mass, or systolic blood pressure.

Results (Table)

Lower limbs. Examples of the movement of labeled erythrocytes are shown in Figures 2 and 3. After 15 minutes of a bloodless field, the median percentage of counts in the tourniquet limb was for the femur 9% (quartile 5–18) and in the femur 5 (3–14)% in the distal part of the thigh, as compared to the contralateral limb.

The activity reached the distal femur in a median of 6 (4.6–9.3) min and the silhouette of the femur's

Figure 4. The arm was aligned on the gamma camera with a tourniquet mounted proximally.

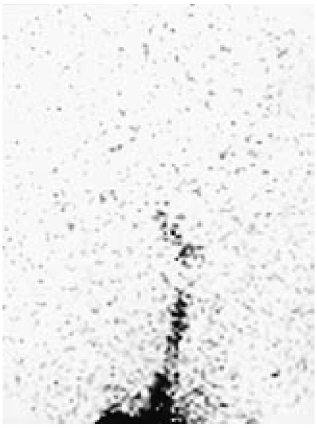

Figure 5. Scintigram of the upper limb taken 500 sec after inflation of the tourniquet. This activity can be seen in the marrow of the humerus diaphysis distally to the cuff.

Figure 6. Scintigram of the upper limbs taken 900 sec after inflation of the tourniquet. This activity can be seen in the marrow of the humerus epicondyles and the periarticular soft tissue.

Clinical findings in the lower limbs of subjects nos. 1–14 and in the upper limbs of subjects nos. 15–24

Subject no.	Gender	Age	Height (cm)	Weight (kg)	Total fat mass (%)	Systolic arm pressure (mmHg)	Time to joint line (sec)	Time to periarticular soft tissue (sec)	Distance from tourniquet to joint line (cm)	Blood flow cm/min
1	M	20	181	78	19.2	125	310	460	12	2.3
2	M	26	202	101	21.7	130	260	420	20	4.7
3	M	31	181	77	20.9	125	230	300	21	5.4
4	M	24	189	94	10.8	115	410	670	21	3.1
5	M	23	174	68	17.9	135	280	460	20	4.2
6	M	27	180	74	25.4	110	300	660	19	3.7
7	M	27	185	104	30.8	115	300	370	17	3.4
8	M	34	193	91	20	130	390	420	22	3.4
9	M	27	181	83	25.7	150	70	160	18	15.3
10	M	24	198	95	18.9	130	200	430	16	4.8
11	F	84	159	67	48.0	135	400	600	16	2.4
12	F	83	160	59	32.6	140	900		22	1.5
13	M	75	176	69	28.6	145	50	200	16	19.2
14	F	85	155	74	45.6	195	140	190	17	7.3
15	M	26	176	86	22.1	115	350	500	22	3.8
16	M	31	177	61	13.2	130	260	300	17	3.9
17	M	24	184	95	29.1	150	600	750	25	2.5
18	M	28	185	77	21.4	120	440	660	27	3.7
19	F	79	167	70	41.9	100	900		26	1.7
20	M	81	169	90	33.5	185	380	470	29	4.6
21	F	79	159	69	51.8	155	90	130	22	14.4
22	M	86	188	86	27.1	150	330	500	19	3.4
23	F	82	156	67	38.4	188	880		24	1.7
24	M	83	160	75	35.6	165	140	280	21	8.9

condyles became visible in the following seconds. Then, in 8 subjects, the labeled erythrocytes left the condyles and activity was seen in the periarticular soft tissue after a median of 8 (4.9–9) min. The median velocity of the erythrocytes was 3.7 (2.7–4.4) cm/min.

Upper limbs. Examples of the movement of erythrocytes are shown in Figures 5 and 6. The activity reached the distal humerus in a median of 4.7 (3.5–6.2) min and in the following seconds the silhouette of the epicondyles of the humerus became visible. Then, in 13 subjects, the labeled erythrocytes left the condyles and activity was seen in the periarticular soft tissue after a median of 7 (5–7.7) min. The median velocity of the erythrocytes was 4 (3.1–5.3) cm/min.

Lower and upper limbs. A correlation ($r = 0.52$, $p = 0.01$) was found between the length of the bone and the time taken for the blood to reach the joint line level. No significant correlation was found between the velocity of movement and gender, age, total fat mass, or systolic blood pressure.

Discussion

Our findings confirm the results of Spira et al. (1965), who used a scintigraphic technique to study ooze beneath a tourniquet in 3 patients undergoing surgery. This ooze may be due to failure to clamp the nutrient artery, since it may be located proximally to the tourniquet. However, the metaphyseal artery is found even more proximally, and it communicates with the diaphyseal bone marrow, maintains some blood supply (Brookes 1971) and is an even more probable cause.

We found that the erythrocytes reached the condyles and, in all but 3 subjects, they passed via periarticular vessels to reach soft tissue distally to the joint. This accords with a previous report by Furlow (1971), who observed ooze beneath a tourniquet in the amputated upper limbs of dogs.

Moreover, we found a significant correlation between the length of the bone and the time taken for the blood to reach the joint line level, which means that the blood passed distally at a relatively constant speed. Our findings show that although a tourniquet can effectively occlude the extra-osseous blood supply, some intra-osseous blood supply persists, which makes it difficult to obtain an entirely bloodless field in some patients. An increase in tourniquet pressure to reduce the ooze is usually not helpful and may cause tourniquet nerve palsy (Aho et al. 1983, Gersoff et al. 1989, Nitz et al. 1989). We therefore emphasize the importance of the recommendations regarding the guidelines for use of a pneumatic tourniquet (McEwen 2001, AORN Recommended Practices Committee 2002).

The use of a tourniquet in knee arthroplasty has recently been discussed by Abdel-Salam and Eyres (1995) and Tetro and Rudan (2001). It is not known whether bleeding from the cut surfaces of the condyles, when a tourniquet is avoided, compromises cementation. We found that, after 15 min with the tourniquet inflated, the scintigraphic activity in the femur condyles was 9%, as compared to the contralateral limb. The low velocity of movement of erythrocytes can be explained both by the theory of Furlow (1971), that the blood distal to the tourniquet is solely under venous pressure, and by the observation of Kiær et al. (1994), that the blood flow in the bone marrow is reduced when the venous outflow is impaired. We found no correlation between the velocity of movement of erythrocytes and the arterial blood pressure.

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No competing interests declared.

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