INTERMITTENT CLAUDICATION OF THE FOOT IN VIEW OF FOOT MUSCLE BLOOD FLOW MEASURED BY $^{133}$Xe CLEARANCE TECHNIQUE AND ARTERIOGRAPHIC FINDINGS

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In 20 limbs of 10 healthy subjects and 55 limbs of 41 patients with occlusive arterial diseases of the legs, muscle blood flow was measured in the flexor hallucis brevis muscle by $^{133}$Xe clearance technique. The clearance curves after the ischemic exercise differentiated limbs with intermittent claudication of the foot from normals and limbs without claudication. An attempt was also made with arteriographic findings in 102 limbs of 84 patients with occlusions of the leg and/or foot arteries only. From results obtained, it is concluded that $^{133}$Xe clearance technique applied in the flexor hallucis brevis muscle can be used for diagnosis of foot pain during walking of uncertain origin and intermittent claudication of the foot is caused by severe circulatory insufficiencies of the plantar muscles during walking in the patients with involvements of the posterior tibial and/or plantar arteries.

INTERMITTENT claudication is well recognized as exertional pain in the legs evoked by walking and relieved by a brief period of rest. Intermittent claudication of the calf is seen in the most common and reacts to the inadequate flow of blood due to occlusions of the femoro-popliteal segments. Involvements of the tibial and peroneal arteries only may be manifested as pain in the foot during walking but the exact mechanism responsible for this symptom is still obscure and a little understood, because of a lack of proper studying method.

The clearance of $^{133}$Xe from muscle following its local injection is a measure of blood flow at capillary level, and this technique has been widely employed in the anterior tibial or gastrocnemius muscle for diagnosis and clinical investigation of intermittent claudication of the calf.

In this paper, $^{133}$Xe clearance technique was applied in the flexor hallucis brevis muscle and its diagnostic value for intermittent claudication of the foot was evaluated by comparing clearance curves among normal subjects and different groups of patients with occlusive arterial diseases of the legs. Furthermore, pathogenesis of intermittent claudication of the foot was discussed in view of foot muscle blood flow and arteriographic findings.

MATERIALS AND METHODS
Blood flow in the flexor hallucis brevis muscle Twenty limbs of 10 healthy subjects and 55 limbs of 41 patients with radiologically verified occlusive arterial diseases of the legs were studied. The normal group consisted of hospital personal and young student volunteers. Their age ranged between 20 and 45 years.

The patients were aged from 23 to 65 years. All the patients were in a clinically steady state and no gangrenous or pre-gangrenous changes

Key Words:
$^{133}$Xe clearance technique
The flexor hallucis brevis
Muscle blood flow
Occlusive arterial diseases of the leg

(Received on October 23, 1975; Accepted on January 20, 1976)
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Fig. 1. $^{133}$Xe clearance curve from the flexor hallucis brevis of a patient with intermittent claudication of the foot. The curve shows moderate blood flow after the ischemic exercise ($MBF_H = 17.7 \text{ml/100g/min}$). The time from the release of the cuff to the commencement of $MBF_H$ ($T_H$) on this curve is 3.0 min and the total duration of reactive hyperemia ($T$) is 8.0 min. The remaining hyperemia (PIE-index) is 82%. PIE-index is that percentage of the total fall of the clearance curve which occurs 2 minutes after the release of the cuff.

Longitudinal axis means $\log_{10}$ (CPS/N). N is Initial CPS/10 and ranges from 200 to 500.

were seen. Although most patients had slight cyanosis in the foot or toes, they did not complain of rest pain. Nobody suffered from diabetes mellitus. All limbs were divided into three groups according to both the site of arterial occlusion and intermittent claudication. The first group named "no claudication group" included 25 limbs whose occlusions were located in the leg and/or foot arteries only without claudication. The second group termed "foot claudication group" included 17 limbs which had occlusions in the leg and/or foot arteries only with intermittent claudication of the foot. In both groups, vessels proximal to the popliteal bifurcation were smooth and regular. The last group named "calf claudication group" included 13 limbs whose occlusions were in the arteries proximal to the popliteal bifurcation with intermittent claudication of the calf.

Foot muscle blood flow was measured by $^{133}$Xe solution, containing approximately 30 to 50 microcuries of $^{133}$Xe, was injected into the flexor hallucis brevis muscle, 7–8 mm medial to the tendon of the flexor hallucis longus muscle and inferior edge of the ball of the foot. The injection was made with a fine needle (outer diameter 0.4 mm) at a depth of 1 cm. The disappearance rate of the isotope was measured using a sodium iodide (TI) crystal connected to a ratemeter.

The resting clearance rate was measured during the first five minutes in the prone position. Thereafter, the subjects were asked to stand on the bed. Then a cuff placed just around the ankle was rapidly inflated to a pressure of about 250 mmHg. During the induced ischemia they were instructed to exercise by rising as high as possible on their toes 50 times per min for two minutes. After the ischemic exercise, the subjects were instructed to lie in the prone position again. The scintillation probe was placed and the cuff was suddenly released, and during the subsequent stage of reactive hyperemia $^{133}$Xe clearance curve was recorded.

From the clearance curves, following parameters were calculated. 1. the resting muscle blood flow 2. the maximal blood flow after the ischemic exercise ($MBF_H$). Blood flow can be calculated using the formula of Lassen which states that $Flow = D \times 161 \text{ ml/100 g/min}$ where D
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with occlusive arterial diseases of the legs were selected in this study. In all limbs serial femoral arteriograms revealed occlusions in the leg and/or foot arteries only without occlusion or stenosis proximal to the popliteal bifurcation. All limbs were divided into three groups according to arteriographic appearances (Fig. 2).

Group 1: 24 limbs with occlusions of the anterior tibial, dorsalis pedis and/or peroneal arteries. They had no involvements of the posterior tibial or plantar arteries.

Group 2: 30 limbs with occlusion of the posterior tibial artery. Plantar arteries were visualized well through collateral vessels.

Group 3: 48 limbs with occlusions of the plantar arteries with or without occlusion of the posterior tibial artery.

In both Group 2 and 3, conditions of the anterior tibial, dorsalis pedis and/or peroneal arteries were ignored. An attempt was made to correlate the rate of occurrence of intermittent claudication of the foot with arteriographic findings.

RESULTS
Blood flow in the flexor hallucis brevis muscle
In “normal group,” the mean of resting muscle blood flow was 2.8 ml/100 g/min (SD=1.3). It was 2.9 (SD=1.6) in “no claudication group,” 2.3 (SD=1.1) in “foot claudication group” and 2.8 (SD=1.5) in “calf claudication group.” The differences among four groups were not statistically significant.

Figure 3 gives the means and values of each individual of four parameters during reactive hyperemia. In the values of TH and PIE-index there were significant differences between “normal group” and “no claudication group,” although considerable overlapping was shown. Between “no claudication group” and “foot claudication group” there were highly significant differences in all parameters, especially in the values of TH and PIE-index the less overlapping was shown. No significant differences were seen between “foot claudication group” and “calf claudication group.” These results indicate that predominant muscle circulatory insufficiency exists in the flexor hallucis brevis muscle in both “foot claudication group” and “calf claudication group.”

Arteriographic findings
One hundred and two limbs of 84 patients

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is the decrease in one minute of a tangent drawn to the logarithmic plot of the clearance curve. 3. the duration of reactive hyperemia (T) 4. the time taken from the release of the cuff to recording of MBFH (TH) 5. an index for the part of the hyperemic reaction to the ischemic exercise still remaining two minutes after the release of the cuff (Post-Ischemic Exercise index, PIE-index). This remaining hyperemia is calculated from the equation: PIE-index=B/A X 100(%). A is the total decrease of the clearance curve during reactive hyperemia. B is the cumulative fall of the clearance curve between two and T minutes after the release of the cuff (Fig. 1). PIE-index is modification of R-index which is commonly used in 133Xe clearance curve of the leg muscles3,4.
Thirty-four of 102 limbs, 33%, had intermittent claudication of the foot. In the Group 1, no limbs had claudication. In the Group 2, 13 of 30 limbs, 43%, complained of pain in the foot during walking and in the Group 3, 21 or 48 limbs, 44%, complained of it. These data were obtained from a detailed case history. The site of pain during walking was located in the sole of the foot in all cases.

**DISCUSSION**

A number of nonvascular conditions are associated with symptoms in the foot which superficially resemble intermittent claudication, such as tendinitis, arthritis or neuritis. In these diseases there should be no associated signs of impairment of arterial circulation. At the same time, the abnormality in the bony joint or tendinous structure is readily demonstrable. Such
findings therefore help to differentiate the symptoms due to nonvascular conditions from intermittent claudication located in the small muscles of the foot. However, it is necessary to point out that it is quite possible to have both diseases. Under these circumstances, \(^{133}\text{Xe}\) clearance technique applied in the flexor hallucis brevis muscle can be used for diagnosis of foot pain during walking of uncertain origin. Striking differences of flow pattern after the ischemic exercise were found between cases with and without intermittent claudication of the foot. The clearance curves of cases with intermittent claudication of the foot showed the reduction in maximal blood flow, with predominant delay in onset and markedly prolonged duration of hyperemia. These curves agreed very well with those obtained from the anterior tibial muscle of the patients with intermittent claudication of the calf reported by other workers.\(^{2,5,6}\) This observation means severe muscle ischemia during exercise.

From results obtained, patients with occlusions of the anterior tibial, dorsalis pedis and/or peroneal arteries without involvement of the posterior tibial or plantar arteries did not complain of intermittent claudication in the foot. In development of this symptom, it is an indispensable condition that the posterior tibial and/or plantar arteries are involved. This fact corresponds that in our all cases pain during walking was located in the sole of the foot. Therefore, the word “instep claudication,” which is used in the most common, is unsuitable. “Foot claudication” is better. The anterior tibial, dorsalis pedis or peroneal artery may be useful as collateral vessels in cases whose posterior tibial artery is occluded. Whether foot claudication develops or not in cases whose posterior tibial and/or plantar arteries are occluded might depend on the degree of these collateral circulations and/or damages of the nutrient arteries of plantar muscles.

For determining of circulation of the plantar muscles the flexor hallucis brevis muscle was selected in this study. The reason is that erroneous injection of the isotope into non-muscular tissue is rare. This muscle is adjacent to the tendon of the flexor hallucis longus muscle which can be confirmed easily by dorsal flexion of the big toe. The another reason is that the regions of claudication include the ball and/or the arch of the foot in almost of cases. However, there may be foot claudication caused by circulatory insufficiencies of the other plantar muscles except of the flexor hallucis brevis muscle.

REFERENCES