Osteoporosis in Hemiplegia

BY NICHOLAS PANIN, M.D., F.A.C.P.,* W. J. GORDAY, M.D.,† AND B. J. PAUL, M.D.‡

Abstract:
Localized osteoporosis in 25 long-term stroke patients was evaluated by means of measuring the combined cortical thickness in the humerus, radius and third metacarpal bones of both involved and noninvolved upper extremities. The combined cortical thickness was found to be consistently smaller on the involved side. Since the factors of weight bearing and calcium homeostasis were eliminated or controlled in this study, the authors were able to focus on the role of muscle pull as manifested by voluntary muscle function and spasticity in relation to the degree of cortical thinning. A smaller degree of cortical thinning was associated with better voluntary muscle function, but the relationship of spasticity to preservation of cortical thickness was not clear cut. The applicability of these techniques to the study of factors affecting localized osteoporosis is discussed.

ADDITIONAL KEY WORDS
combining cortical thickness hemiparesis
cerebral infarction physical therapy

Difficulty in dealing with this problem prophylactically or therapeutically arises because (1) the etiological factors and their interrelationship are not clearly understood, and (2) simple, readily accessible and universally applicable techniques of assessment are not available or widely known. Osteoporosis has been described as a decrease in a total mass of bone levels needed for mechanical support. It is not a single disease entity but is, rather, a syndrome which may result from many disease processes, the expression of which is limited as far as the skeleton is concerned. Among the contributing factors, endocrine, nutritional, vascular and neuromuscular disorders as well as immobilization have been mentioned, and the role of some of these factors has been studied. One author conceives of osteoporosis as consisting of two broad categories: homeostatic and nonhomeostatic. The homeostatic group would include the truly generalized osteoporosis, such as postmenopausal and senile osteoporosis, endocrine and probably nutritional osteoporosis, in which calcium homeostasis is the central issue. The nonhomeostatic variety includes all mechanisms reducing bone mass independently of the calcium needs of the organism, and is best exemplified by the local osteoporeses such as disuse osteoporosis, recognizing that locally active factors, such as mechanical stress, altered blood flow and inflammation, may, in certain regions or bones, disrupt the homeostatic linkage of bone formation and resorption.

It occurred to the authors that the stroke patient with unilateral involvement represented...
an excellent opportunity for a clinical study of the localized type of this disorder, concentrating on such factors as immobilization, muscle pull (as manifested by residual motor function and spasticity), and duration of the neurological impairment resulting in such immobilization and the changes consequent to it. In such a study, the uninvolved extremities could serve as a control, equalizing such factors as age, sex, endocrine function and nutrition, factors which contribute to the homeostatic type of osteoporosis which might possibly be operating in some of these patients.

The question of methodology by which osteoporosis is evaluated deserves comment. A number of clinical methods have been described in the literature, but these can be divided into techniques of measuring bone density, combinations of densitometry and cortical thickness measurements, biopsy techniques utilizing ash studies, and quantitative microradiography. The method of combined cortical thickness measurements (hereafter referred to as CCT) commended itself to us by its simplicity and ready availability as compared with the more time-consuming and costly densitometry techniques which require relatively sophisticated apparatus and personnel. This method is apparently of sufficient reliability when applied to the study of long-term patients.

Methods

Twenty-five patients were included in this study. The criteria for inclusion were as follows:

1. The patient must have suffered a cerebral vascular accident with unilateral involvement at least six months prior to the collection of the data for this study.
2. All the patients studied must have been known to the investigators as hemiplegic at the onset but could present various degrees of functional recovery at the time of recording the data presented in the study.

In order to eliminate the factor of weight bearing and to concentrate on the possible protective effect of muscle pull as produced by voluntary muscle contraction and/or spasticity, we limited our investigation to upper extremities only.

Data collected (table 1) included age, sex, side involved and duration of stroke. Handedness was also recorded, but was excluded from table 1 since all our patients were originally righthanded.

The motor function in each major segment and spasticity of the involved upper extremity were graded and recorded according to the scale presented in table 1.

CCT measurements were obtained for the humerus, radius and third metacarpal bones of both upper extremities by means of the following technique:

Two standard projections of the skeleton were selected:

1. A lateral view of the distal half of the humerus and proximal half of the forearm with the forearm in pronation was taken on one film inside an intensifying cassette. The anode-film distance was 40 inches. The right and left elbow regions were taken on a single film.
2. Posterior-anterior views of both hands were taken on a single film inside a cardboard holder. The anode-film distance was 40 inches.

The anterior and posterior cortices of the humerus were measured at the site where the endosteal and periosteal outlines became parallel, namely, in the supracondylar area of the humerus.

The anterior and posterior cortices of the radius were measured when they became parallel, which was usually just distal to the tuberosity of the radius.

The median and lateral cortices of the shaft of the third metacarpal, i.e., middle metacarpal of each hand, were measured when they became parallel.

Although our basic technique was similar to that of Meema it was not identical inasmuch as the anode-film distance used by us was 40 inches, a commonly used "standard" in most x-ray departments for x-ray views of the skeleton. Meema's technique involved 60-inch anode-film distance. Thus, we obtained about a 3% greater magnification, a fact which should be taken into account when comparing some of our final results with those of Meema.

Results

Table 1 is a presentation of all the data collected. As previously mentioned, all patients in the study turned out to be originally righthanded and, therefore, these data are not included in table 1. Of the 25 patients, 12 were males and 13 were females. Sixteen patients had leftsided involvement and in nine patients the right side was affected. The duration of the stroke varied from seven to 204 months.

Inspection of these data revealed a consistent tendency toward cortical bone thinning in the affected upper extremity as measured by the CCT. In the humerus, the
### TABLE 1

**Clinical and Radiological Data**

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age &amp; Sex</th>
<th>Duration of Stroke (in mos.)</th>
<th>Side Involved</th>
<th>Degree of Spasticity</th>
<th>Motor Function</th>
<th>Combined Cortical Thickness in mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Shoulder</td>
<td>Elbow</td>
</tr>
<tr>
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</tr>
<tr>
<td>2.</td>
<td>69M</td>
<td>76</td>
<td>Left</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>3.</td>
<td>52F</td>
<td>25</td>
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<td>1</td>
</tr>
<tr>
<td>4.</td>
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<td>13</td>
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</tr>
<tr>
<td>5.</td>
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<td>Rt.</td>
<td>2</td>
<td>3</td>
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</tr>
<tr>
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<td>Left</td>
<td>4</td>
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<td>1</td>
</tr>
<tr>
<td>7.</td>
<td>85F</td>
<td>23</td>
<td>Rt.</td>
<td>2</td>
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<td>4</td>
</tr>
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<td>8.</td>
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<td>2</td>
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<tr>
<td>9.</td>
<td>68M</td>
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<td>2</td>
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<td>61M</td>
<td>132</td>
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<td>2</td>
<td>3</td>
</tr>
<tr>
<td>11.</td>
<td>64M</td>
<td>13</td>
<td>Left</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>12.</td>
<td>58F</td>
<td>23</td>
<td>Rt.</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>13.</td>
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<tr>
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<td>3</td>
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<tr>
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<td>46F</td>
<td>8</td>
<td>Left</td>
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<td>1</td>
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<tr>
<td>17.</td>
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<td>204</td>
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<td>18.</td>
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<tr>
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<td>Left</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>20.</td>
<td>58M</td>
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<td>Left</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
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<td>32</td>
<td>Rt.</td>
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<td>3</td>
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<td>31</td>
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<td>1</td>
</tr>
<tr>
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<td>23</td>
<td>Rt.</td>
<td>1</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>24.</td>
<td>58F</td>
<td>60</td>
<td>Left</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>25.</td>
<td>44F</td>
<td>31</td>
<td>Left</td>
<td>3</td>
<td>2</td>
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</tbody>
</table>

**Grading System for Spasticity**

- Grade 1. Hoffman reflex is present with normal or hypoactive deep tendon reflexes in upper extremity.
- Grade 2. Deep tendon reflexes hyperactive.
- Grade 3. Same as 2 plus non-sustained clonus.
- Grade 4. Same as 2 plus sustained clonus.

**Grading System of Motor Function**

- Grade 1. No significant voluntary motion of the joint.
- Grade 2. Some voluntary motion present but markedly impaired.
- Grade 3. Sufficient voluntary motion to perform major function but some impairment present.
- Grade 4. Practically normal voluntary function.
FIGURE 1
Roentgenogram of the hands demonstrating cortical thinning on the involved side, case 13.

CCT was smaller on the involved side in 23 of the 25 cases, with one patient showing equal measurements in the humerus of both upper extremities and one case (#20) showing a measurement slightly larger on the hemiparetic side. The findings were similar in the radius and metacarpal, with 22 of 25 cases for the radius and 21 of 25 cases for the metacarpal showing more cortical thinning on the involved side as illustrated in figure 1.

Table 2 shows the mean values for the CCT measurements and demonstrates that the differences between the means of the involved and noninvolved sides are significant.

Table 2
Comparison of Mean CCT (in mm) on Involved and Noninvolved Sides in Three Bone Sites

<table>
<thead>
<tr>
<th>Bone Site</th>
<th>Mean value CCT (mm) involved side</th>
<th>CCT (mm) noninvolved side</th>
<th>Difference between means</th>
<th>Standard error of difference</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Humerus</td>
<td>6.45</td>
<td>8.6</td>
<td>2.2</td>
<td>.31</td>
<td>.0001</td>
</tr>
<tr>
<td>Radius</td>
<td>4.2</td>
<td>5.2</td>
<td>1.0</td>
<td>.16</td>
<td>.001</td>
</tr>
<tr>
<td>Metacarpal</td>
<td>2.9</td>
<td>3.8</td>
<td>0.9</td>
<td>.16</td>
<td>.001</td>
</tr>
</tbody>
</table>

We sought to determine the relationships between spasticity and the degree of cortical thinning and also between motor function and cortical thinning. The humerus was selected as a representative bone site in studying these relationships because its greater thickness allows for more readily discernible percentage difference.

Tables 3 and 4 show the relationships of degree of spasticity and degree of motor function to the difference in combined cortical thickness between the two limbs (humeral bones).

When we examine the relationship between spasticity and asymmetry or difference in combined cortical thickness of the humerus (see table 3) we find no evidence of any significant correlation.

Table 4 illustrates the relationship between the degree of residual motor function and CCT differences, suggesting that better motor function is related to a lesser degree of cortical thinning in the involved arm. Among the nine patients with relatively good recovery of motor function (grades 3 & 4), seven had differences of combined cortical thickness below the median for the total population, whereas in the case of the 15 patients with relatively poor recovery of motor function (grades 1 & 2), two-thirds or ten patients showed differences of CCT of the humerus above the median.

We considered the possibility that the involvement of the nondominant upper extremity might possibly produce a relatively greater differential cortical atrophy than would occur should the dominant upper extremity be affected. In 16 patients in whom the nondominant side was affected, the mean CCT of the noninvolved bone sites. These correlations were 0.57 for the humerus and radius, 0.54 for the humerus and metacarpal, and 0.43 for the radius and metacarpal.
affected humerus was 6.3 mm as compared with a mean of 9 mm in the unimpaired arm. When the dominant side was involved (nine cases) the mean CCT of the affected humerus was 6.7 mm, compared with 8.3 mm for the nonaffected side. Thus it seems apparent that handedness did not play a role in selective cortical atrophy.

We inspected our data to determine the distribution of humeral measurements showing a combined cortical thickness below 6 mm and above 7 mm since, according to the criteria of Meema and Meema, these are the values which denote the presence or absence of osteoporosis. Figure 2 illustrates that values below 6 mm, indicating frank osteoporosis, occurred in 19 instances, values above 7 mm occurred in 23 instances, and eight humeral bones had a CCT between 6 and 7 mm. The figure indicates that osteoporotic values were much more likely to occur in females and in the humerus of the involved extremity, whereas normal values are more apt to occur in males and in the normally functioning extremity. Indeed the mean value of CCT of the humerus on the involved side in male patients was 7.6 mm while on the noninvolved side it was 10.2 mm. In female patients it was 5.4 mm on the affected side and 7.1 mm on the nonaffected side.

Discussion
Our hypothesis on initiation of this study was that loss of motor function such as occurs in hemiplegia results in localized osteoporosis affecting the involved limb and that the stress of muscle pull on the skeleton by voluntary muscle contraction and/or spasticity plays a protective role in preventing or minimizing this process. This hypothesis is based on the long-accepted concept of laws affecting bone formation and the literature which emphasizes the role of stress in maintaining bone integrity. We were also interested in demonstrating the applicability of the technique of measuring the CCT to the study of this problem.

Asymmetrical osteoporosis in hemiplegics and its complications have been reported with respect to the paretic lower extremity. However, since many hemiplegic patients, with or without significant spasticity or return of voluntary motor function, may be able to ambulate with weight bearing by means of bracing the affected lower extremity, we chose to study the upper extremity in order to eliminate the factor of weight bearing, the role of which, in the prevention of osteoporosis, remains unclear.

Our study demonstrates that the method of measuring CCT in long-standing osteoporosis is practical and, by its simplicity, is quite appealing to anyone interested in this specific problem. Comparison of CCT measurements in the involved and uninvolved upper extremities of stroke patients confirms beyond any ques-

**TABLE 3**

<table>
<thead>
<tr>
<th>Grade of spasticity</th>
<th>Below median in CCT difference</th>
<th>Above median in CCT difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>3-4</td>
<td>5</td>
<td>3</td>
</tr>
</tbody>
</table>

Chi-square = 1.09-nonsignificant.

**TABLE 4**

<table>
<thead>
<tr>
<th>Grade of motor function</th>
<th>Below median in CCT difference</th>
<th>Above median in CCT difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>3-4</td>
<td>7</td>
<td>2</td>
</tr>
</tbody>
</table>

Chi-square = 6.4. P = 0.02.
tion that localized osteoporosis takes place practically in every stroke patient, as illustrated in table 1. This appears to occur without regard to the degree of spasticity and also appears to occur despite return of voluntary motor function, although returning motor function seems to have some effect on the degree of localized osteoporosis. The localized osteoporosis occurs in some instances in addition to the generalized (homeostatic) type of osteoporosis, whatever the cause of the latter might be.

Since in our group of patients about 50% were menopausal or postmenopausal females (case #17 being an exception), it could be expected that frank generalized osteoporosis would occur more frequently in females and this has been confirmed in our study. However, the actual thinning of the cortex on the involved side took place in almost all patients and the absolute CCT differences were greater in male patients than in females with the mean difference of 2.6 mm in the former against 1.7 mm average difference in the latter. This, as well as the tendency toward inverse correlation of the CCT differences with the degree of functional return, would appear to suggest the importance of the forces of stress and strain (which are the integral part of muscle action) on the bone. This latter correlation, as well as the apparent lack of correlation between CCT measurements and the degree of spasticity, would appear to indicate that a certain optimal force constellation (degree of force, angle of pull and torque) may be necessary to prevent or even retard osteoporosis, and our findings would tend to indicate that this necessary constellation is apparently not supplied by the degree of muscle pull produced by spasticity or, in some instances, even by the muscle with a "significant return of motor function."

Other factors which could be generally termed "trophic" due to deprivation of the influence of the central nervous system upon motor, sensory, and autonomic output, although not well documented as yet, could be considered as possible contributory influences upon unilateral thinning of the bones in patients with stroke.16,37

This study was limited to long-term patients and, if the concept of the irreversibility of osteoporosis16-21 is valid, such factors as the period of time between the onset of paralysis and the onset of motor return or the onset of spasticity could be of great importance in determining whether or not asymmetrical cortical atrophy or thinning is observed in the patient with long-standing hemiplegia.

Our methods of grading the degree of motor function and the degree of spasticity are quite crude. Precise methods are needed in studying the response of the skeleton (bone mass and structure) to stress in normal and neurologically abnormal extremities. However, our findings are similar to those of other investigators.3 The implication is that voluntary muscle action is most effective in preventing localized osteoporosis. Perhaps spasticity may play some role in the prevention of localized osteoporosis.

More knowledge about (1) the pathogenesis of osteoporosis, (2) the effect of muscle contraction on long bones, and (3) the permanence or reversibility of osteoporosis may come from further study of hemiplegic patients. Investigation should begin soon after the onset of the neurological deficit and should include: (1) measurement of CCT, (2) measurement of bone density, and (3) accurate evaluation of motor function and spasticity.

At the same time, the effect of therapeutic exercise and electrical stimulation of muscle could be assessed. Geiser and Trueta22 report that electrical muscle stimulation decreases bone rarefaction in laboratory animals.

Summary

The combined cortical thickness was measured in the humerus, radius and third metacarpal bones of both the involved and noninvolved upper extremities of 25 long-term stroke patients. The method of measuring CCT is simple and practical as applied to long-term patients. The following conclusions can be made:

1. Consistent thinning of the cortex was present in the bones of the involved extremities when compared with the noninvolved extremities, regardless of the presence or absence of generalized osteoporosis as found in the bones of the noninvolved extremities.
2. There is an inverse relationship between cortical thinning and the degree of voluntary motor function in these patients.
3. No definite evidence of any significant
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correlation with the degree of spasticity was noted.

4. There is need for a longitudinal study in depth of the evolution of localized osteoporosis and its relationship to forces of muscle pull utilizing CCT as well as densitometry measurements and more precise quantitative measurements of the forces of pull by voluntarily or reflexly contracting muscles.

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