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Humeral Hypertrophy in Response to Exercise*

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ABSTRACT: We compared roentgenograms of the humeri of a group of professional tennis players and showed that there was pronounced hypertrophy of bone on the playing side. The cortical thickness on that side was greater by 34.9 per cent in men and 28.4 per cent in women compared with the control side. This represents a highly significant hypertrophy of bone in response to exercise.

In 1972 we had the opportunity to examine the upper extremities of eighty-four active professional tennis players. In this paper we describe the hypertrophy of the humerus of the playing arm that we demonstrated roentgenographically.

Materials and Methods

The players represented eighteen nationalities; nearly all of them had national or international ranking. The mean age of the men was twenty-seven years (range, eighteen to fifty years) and that of the women, twenty-four years (range, fourteen to thirty-four years). The mean length of playing experience of the men was eighteen years and that of the women, fourteen years.

We recorded the data on each player as to participation in sports and injuries received. A limited physical examination was carried out, photographs were taken, and measurements were made of range of motion of the joints of the upper extremity, girth of the arms and forearms, and grip strength [4]. The height and weight of each player were recorded. Satisfactory anteroposterior and lateral roentgenograms of both humeri were obtained from forty-eight men and thirty women, and we tried to correlate the roentgenographic changes in the humerus with the findings and the playing history. We reported on the injuries and clinical data elsewhere [11]. A portable x-ray machine was used to make the roentgenograms. We used non-screen film and an anode-film distance of seventy-one centimeters. The humerus was uniformly held in contact with the film holder while the roentgenogram was made.

The sites selected for measurement (Figs. 1-A and 1-B) were designed to portray the dimensions of each humerus and its medullary cavity as well as the cortical thickness at four standard sites. As other authors pointed out [2], in adults there is a region of the humeral shaft where the opposite cortical walls are nearly parallel on both the anteroposterior and lateral projections. This region is about three centimeters long and is centered about eleven centimeters proximal to the distal end of the humerus. Thus, the site we actually se-

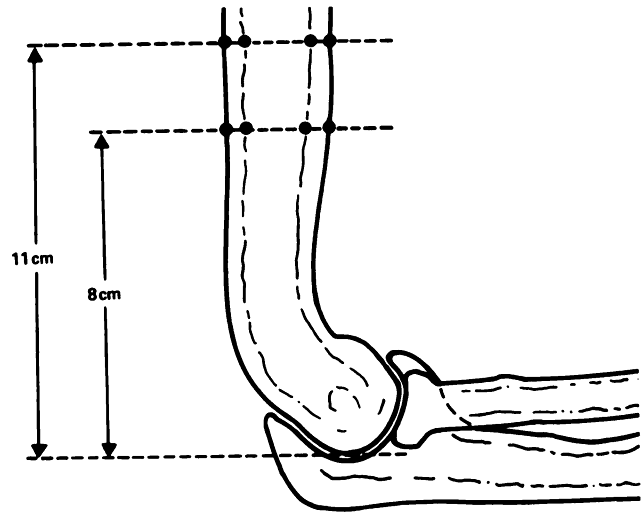

FIG. 1-A

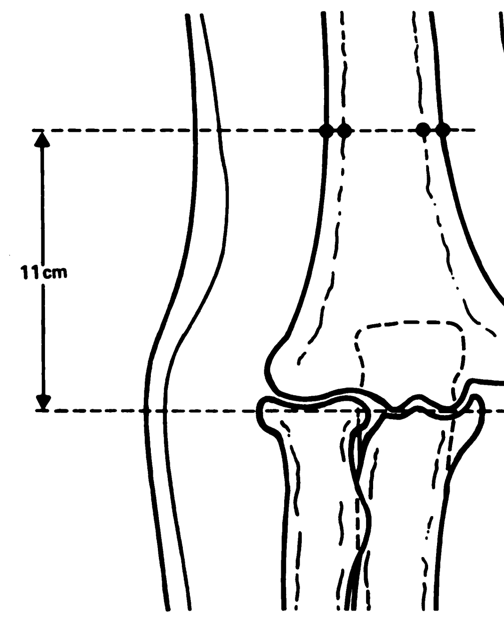

FIG. 1-B

Sites of measurements made from roentgenograms (Fig. 1-A, lateral; Fig. 1-B, anteroposterior).

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lected for measurement could have been slightly above or below that level without affecting the results, and there was no need to adjust for differences in length of the humerus between individuals of different heights.

FIG. 2-A

Anteroposterior roentgenograms of the elbows of a twenty-three-year-old right-handed tennis player who started playing tennis at the age of nine years. The non-playing side is on the left and the playing side, on the right. To facilitate comparison, reproductions of the roentgenograms of one elbow were reversed.

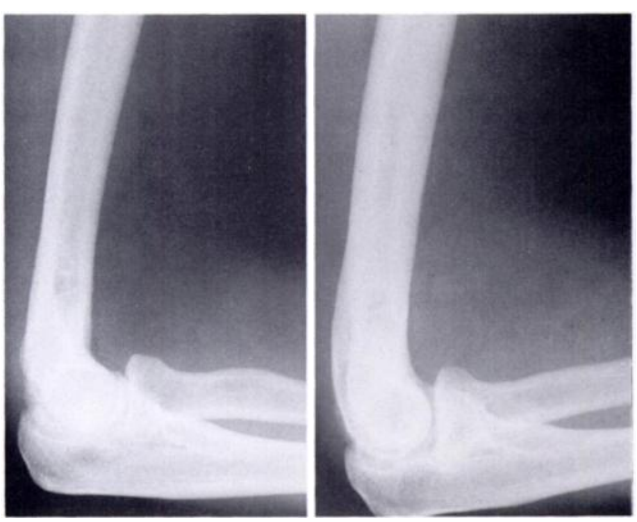

Fig. 2-B

Lateral roentgenograms of the non-playing and playing sides.

For measuring purposes the roentgenogram was placed directly on the viewing surface of a motion analyzer (Vanguard model M35Cs), and the coordinate cross hairs were lined up with the points to be measured. The instrument reproducibly registers the positions of the cross hairs in inches to the third decimal place. Parallax was avoided by observing the image of the cross hairs through a cylinder four centimeters long with a hole 0.6 centimeter in diameter oriented perpendicular to the viewing surface. Calibration showed that accuracy was better than ± 0.12 inch (0.3 centimeter) on either axis.

Some measurement points, such as the outer cortical margins of the humerus, were easily identified on all roentgenograms and were measurable to within the limits of accuracy of the apparatus. On some roentgenograms, however, other points were more difficult to see either because the roentgenogram was low in contrast or because the inner wall of the humerus had irregular margins. All measurements used in calculating our results were made by one of us (J. D. P.). The only comparisons we made were between the playing side and the non-playing side of the same subject — that is, matched-pair analysis (Figs. 2-A through 3-B). If a point could not be identified on a particular roentgenogram, no measurement was made and the corresponding measurement on the player's other extremity was discarded from the calculations.

The magnification of the roentgenographic image was calculated by geometry, using anode-film distance (seventy-one centimeters) and distance between the humerus and the film as measured on the lateral roentgenogram. The magnification ranged from 4 to 8 per cent. The difference in magnification was calculated for each subject's playing side versus the non-playing side. It usually was less than 0.2 per cent and never exceeded 0.5 per cent. Only a very small correction would be required if it were necessary to determine non-magnified dimensions and the corrections would have been insignificant relative to the differences we observed. Accordingly, the measurements have not been corrected for error due to magnification.

To evaluate the effect of different degrees of rotation from the true anteroposterior or lateral projection, we made roentgenograms of a cadaver arm in different measured degrees of rotation about the long axis. The results indicated that there was not enough rotation in our roentgenograms from true anteroposterior or lateral projections to have a significant effect on the measurements we made.

The data on each player was punched into IBM cards and entered into a computer. Statistical analysis was carried out using conventional computations. The standard error was calculated by matched-pair analysis, and probability was calculated using the Fisher two-tailed t test. Tables I and II provide data on the players tested.

To obtain so-called normal values with which to compare our findings we extracted data from the articles by Meema and Meema and by Bloom and Laws. The lateral projection of the elbow as shown by the reproduction in the former article is quite comparable to the projection we used. These authors did not mention the anode-film

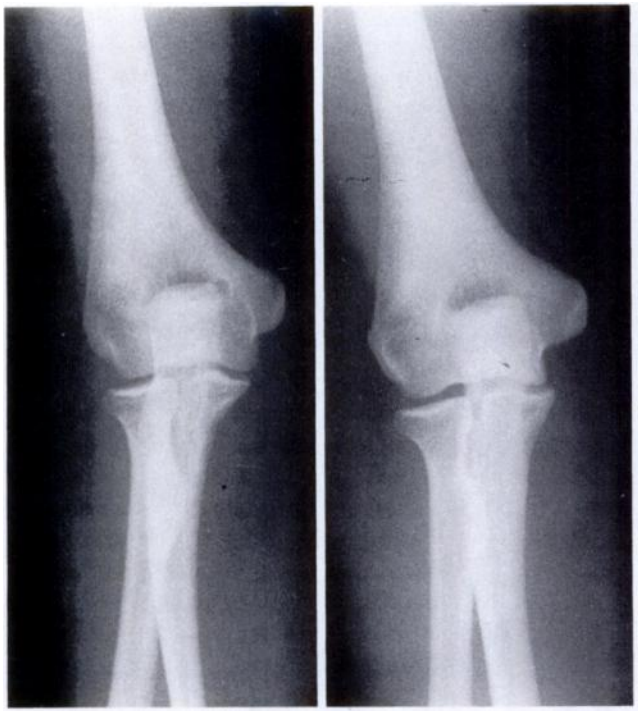

Fig. 3-A

Anteroposterior roentgenograms of the elbows of a twenty-three-year-old right-handed professional tennis player who began playing tennis when she was eleven years old. The non-playing side is on the left and the playing side, on the right.

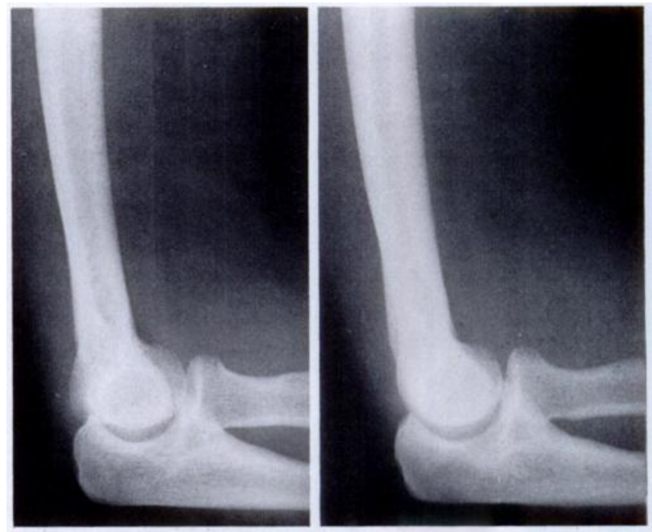

Fig. 3-B

Lateral roentgenograms of the non-playing and playing sides.

distance used; we assume that it was 100 centimeters, the distance commonly employed. Bloom and Laws did not reproduce their roentgenograms. They stated that an anteroposterior roentgenogram of the shaft and distal end of the left humerus was made and gave the anode-film distance as 107 centimeters. This projection was very similar to ours except for possible differences in the centering of the roentgen beam. In their work it may have been centered proximal to, rather than over, the elbow joint, which would result in some difference in elongation distortion but would not affect cortical thickness or humeral diameter. Our use of an anode-film distance of seventy-one centimeters produces a magnification of the image 2 per cent greater than that produced by Bloom and Laws but this difference is insignificant.

To facilitate visualization of the hypertrophy we obtained a computer print-out of the points measured at the eleven-centimeter level plotted to scale at a magnification of four. By connecting the points and superimposing the images of the playing and non-playing sides of the same player, the degree and manner of hypertrophy are more readily appreciated.

Results

Every player showed hypertrophy of bone on the playing side in all the parameters assessed. The medullary cavity commonly was narrowed owing to encroachment by the thickened cortex. The combined cortical thickness, defined as the sum of all four determinations at one level, showed an increase on the playing side of 34.9 per cent for the men and 28.4 per cent for the women.

The sum of the anterior and posterior cortical thicknesses given as normal by Meema and Meema for men does not differ from the values we obtained for the non-playing side of our male players. Their value for women is slightly lower than our value but the difference is not statistically significant. The sum of the lateral and medial cortical thicknesses reported by Bloom and Laws for the left humerus of women only is lower than that which we obtained but is within one standard deviation of our value for women.

Comparison of the sagittal and coronal diameters of the humerus at the eleven-centimeter level showed that the cross section of the humerus at this site is usually oval rather than circular. The sagittal diameter on the non-playing side exceeded the coronal in thirty-two of forty-nine players we could analyze. The coronal diameter was greater in eight players and in nine the diameters were

TABLE I*

Cortical Thickness	No. of Subjects	Sex	Playing Extremity (*cm*)	Non-Playing Extremity (*cm*)	Per Cent of Change
Anterior	44	M	0.76 (0.09)	0.55 (0.06)	36.4†
	23	F	0.61 (0.07)	0.49 (0.07)	24.8‡
Posterior	43	M	0.71 (0.10)	0.51 (0.07)	38.8‡
	22	F	0.58 (0.08)	0.46 (0.06)	27.7†
Medial	39	M	0.75 (0.09)	0.54 (0.06)	37.0†
	14	F	0.63 (0.07)	0.49 (0.06)	30.5‡
Lateral	39	M	0.75 (0.12)	0.59 (0.10)	27.3†
	14	F	0.58 (0.06)	0.45 (0.04)	29.9†

* Record of the measurements made eleven centimeters proximal to the distal end of the humerus (Figs. 1-A and 1-B). Changes measured from the lateral view at the eight-centimeter level were similar to those at the eleven-centimeter level.

Probability, calculated using the Fisher two-tailed t test, was $p < 0.001$. The standard error was calculated by matched-pair analysis: † = ±0.01 and ‡ = ±0.02.

TABLE II*

Other Measurements	No. of Subjects	Sex	Playing Extremity (cm)	Non-Playing Extremity (cm)	Per Cent of Change
Anteropost. diam.,	43	M	2.47 (0.18)	2.24 (0.16)	9.9‡
humerus	23	F	2.11 (0.13)	1.97 (0.14)	7.0†
Anteropost. diam.,	43	M	1.00 (0.19)	1.18 (0.21)	−14.8‡
medullary cavity	23	F	0.92 (0.16)	1.04 (0.15)	−11.2‡
Mediolat. diam.,	39	M	2.44 (0.19)	2.15 (0.20)	13.4‡
humerus	14	F	2.03 (0.13)	1.82 (0.11)	11.7§
Mediolat. diam.,	39	M	0.95 (0.18)	1.02 (0.20)	−7.0‡
medullary cavity	14	F	0.82 (0.16)	0.88 (0.13)	−7.8§, $p < 0.02$

* Record of the measurements made eleven centimeters proximal to the distal end of the humerus (Figs. 1-A and 1-B). Changes measured from the lateral view at the eight-centimeter level were similar to those at the eleven-centimeter level.

Probability, calculated using the Fisher two-tailed t test, was $p < 0.001$, except for the single instance noted. The standard error was calculated by matched-pair analysis: † = ±0.01; ‡ = ±0.02; and § = ±0.03.

equal. On the playing side, the sagittal diameter was greater in twenty-three players, the coronal was greater in thirteen, and in thirteen the diameters were equal.

The players also differed in the pattern of humeral hypertrophy. For example, Player A in Figure 4 had an increase in all cortical measurements as well as in the circumference of the bone, but the diameter of the medullary cavity was smaller. Player B had predominantly thickened the lateral cortex, enlarged the circumference of the bone, and widened the medullary cavity.

Discussion

Although many consider that hypertrophy of bone will be a natural response to exercise, a search of the literature did not provide much data on the subject. King and coworkers called attention to hypertrophy of the humerus of the pitching arm in professional baseball players but provided no measurements. Lewis described clinical and roentgenographic evaluation of the upper extremities of four professional tennis players. By coincidence, his four subjects are included in our study. He called attention to an increase in bone diameter and cortical thickness on the playing side but provided no measurements. Buskirk and associates reported muscle hypertrophy but no significant bone widening in seven nationally ranked tennis players. Review of their paper suggests that their failure to detect bone widening relates directly to their method of taking measurements. They used a simple ruler on roentgenograms which did not include the shaft of the humerus. The study of Saville and Whyte demonstrated hypertrophy of bone in rats resulting from running. Bassett reported that bone production is stimulated by intermittent stress in patients whose bones are undermineralized. Garn studied gain and loss in bone substance and concluded that great activity versus moderate activity did not increase the skeletal mass. Nilsson and Westlin demonstrated a measurable increase in bone density in the distal part of the femora of athletes compared with those of non-athletes. In the athletes, they also found an increase in density in the femur of the preferred extremity compared with the other side. Dalén and Olsson found a 20 per cent increase in the trabecular bone in the extremities of a group of cross-country runners compared with a sedentary control group. The dramatic hypertrophy demonstrated on the roentgenograms of the professional tennis players in our

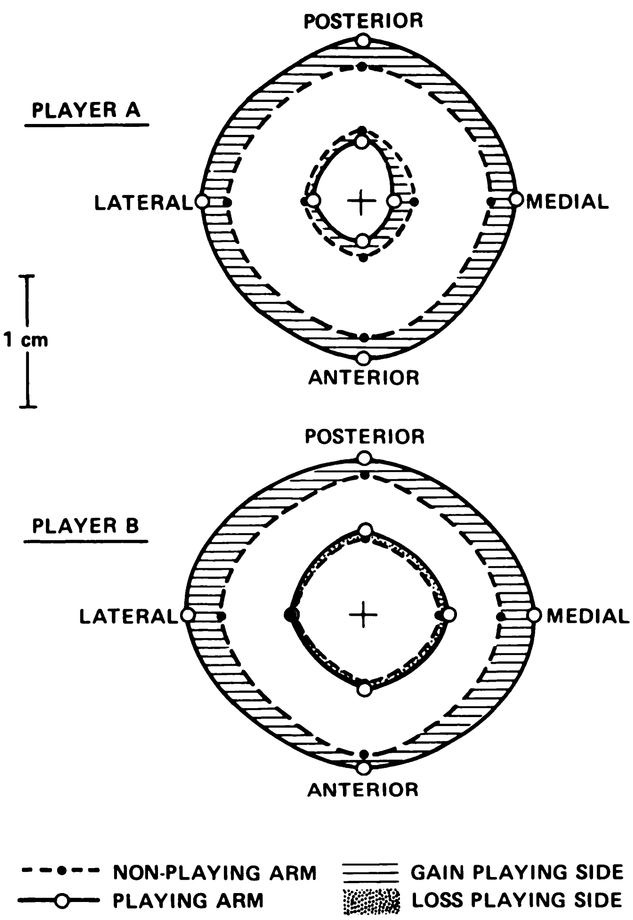

FIG. 4

These cross sections were derived by plotting the cortices of the humerus eleven centimeters proximal to the distal end as measured from the roentgenograms. The lines joining the points are fictitious. The center of each cross section was arbitrarily chosen as the mid-point of the anteroposterior (mid-coronal) and lateral (mid-sagittal) outside diameters. Player A was a twenty-four-year-old left-handed international tennis player who had been playing since he was six years old. Player B was a twenty-five-year-old right-handed international player with eighteen years of playing experience.

study strongly supports the conclusion that exercise can promote bone hypertrophy.

Is there a difference in humeral diameters and cortical thickness between left and right arms of an unselected adult population? We found no measurements pertinent to this question in the literature. Since starting this study we have paid particular attention to the roentgenograms of patients who have had roentgen examinations of both left and right humeri, usually for acute trauma, but have not detected any important differences. The close agreement of the values for combined cortical thickness reported by Meema and Meema and by Bloom and Laws with those found on the non-playing side of our subjects indicates that our players constitute a representative population sample.

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