Morphological effects of mechanical forces on the human humerus

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Various mechanical forces produce a variable stimulus intensity on bone and have different effects on its growth and development. The aim of this project was to study the effects of a variety of mechanical forces on human humerus morphology. This was investigated by measuring the cortical thickness (cm) and diameter (cm) of the humerus at its proximal, middle and distal thirds from radiographs. The humerus of each of 46 men (five controls, six swimmers, eight gymnasts, seven javelin throwers, nine discus throwers and 11 weightlifters) was radiographed on both right and left sides. The humerus size variation among the participants, in order of increasing size, was found to be as follows: gymnasts, controls, swimmers, javelin throwers, weightlifters and discus throwers respectively. The humeral cortex was largest in the weightlifters, being significantly ($P < 0.05$) thicker at distal, medial and proximal sites. The proximal and distal humeral sites in javelin and discus throwers were significantly thicker than those of the control subjects. From the results, static load would seem to provide a higher stimulus to bone than dynamic loading.

Keywords: Human humerus, mechanical forces, growth response

There are reports from many countries on the effects of mechanical forces on human humerus morphology. These forces provide a variable stimulus intensity on bone, leading to different effects on growth and development. Long-distance running may lead to decreased mineral density in vertebrae¹. Physical training, even at low frequency, can increase bone mass or reduce the bone loss associated with age. Equal distribution of force to all parts of the skeleton is probably not necessary to provide a general exercise effect on bone mass². Following an intensive exercise regimen, significant increases in the density and mass of bone can be obtained in young adults within a short period³. Cortical cross-section area was found to be significantly higher in the swimmers compared with the controls. The shape of the bone in cross-section was found to be more rounded in the

swimmers. These marked changes in bone morphology are attributed to the different forces and moments exerted on the humerus during swimming compared with normal locomotion⁴. The purpose of this project was to investigate such changes.

Materials and methods

The subjects for the study comprised 46 healthy men divided into six groups: six swimmers, eight gymnasts, seven javelin throwers, nine discus throwers, 11 weightlifters and five controls. Following the aims of the project, weightlifting was selected as the static load exercise, javelin and discus throwing provided the dynamic load exercise; and gymnastics was considered to represent a combination load. Weightlifting requires symmetrical force on both hands; javelin and discus throwers bear the forces during the movement on their dominant hand and there is no exercise load on the non-dominant hand. Nevertheless, although there is no non-dominant loading in either discus or javelin throwing, there is an accelerative force in the twisting of the thrower's body. Gymnastics and swimming are generally symmetrical in terms of force and power. Unlike the movement groups, the control group participated in no physical training other than their normal work.

An F-44 model X-ray unit (made in PR China) was used to visualize the humerus with a radiograph area of 11×14 cm. With 45 kV at 30 mA, exposure time was 0.3 s at a distance of 75 cm. In each subject the length of each humerus was measured, a radiograph of the anterior of each humerus was made and the cortical thickness measured, and the diameters of the humerus at the proximal, middle and distal thirds were noted.

Results

Table 1 shows the diameters and cortical thicknesses of the middle third of the humerus in the various groups. It is known that the diameters of both humeri in the discus throwers are the highest of the movement groups ($P < 0.05$). Each cortex of both humeri in the weightlifters is the highest of the movement groups ($P < 0.05$).

Figure 1 illustrates the sequences of the right and left humeral diameters in descending order, i.e. for

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Table 1. The diameter and cortex thickness of the mid-third of the humerus in a variety of athletes

	Control	Swimming	Gymnastics	Javelin throwing	Discus throwing	Weightlifting
Right:						
Diameter of mid-third of humerus	2.43(0.15)	2.50(0.17)	2.33(0.15)	2.53(0.21)	2.83(0.21)	2.57(0.06)
Cortex of medial mid-third of humerus	0.57(0.06)	0.54(0.06)	0.60(0.01)	0.70(0.01)	0.67(0.06)	0.77(0.06)
Cortex of lateral mid-third of humerus	0.50(0.07)	0.52(0.07)	0.54(0.06)	0.66(0.04)	0.71(0.04)	0.79(0.12)
Left:						
Diameter of mid-third of humerus	2.23(0.06)	2.40(0.10)	2.40(0.20)	2.40(0.30)	2.73(0.21)	2.47(0.06)
Cortex of medial mid-third of humerus	0.48(0.02)	0.53(0.03)	0.58(0.04)	0.55(0.06)	0.63(0.06)	0.69(0.06)
Cortex of lateral mid-third of humerus	0.46(0.09)	0.51(0.04)	0.52(0.04)	0.54(0.02)	0.67(0.06)	0.73(0.09)

All values are mean(s.d.) cm

the right humeri the order is: discus throwing > weightlifting > javelin throwing > swimming > control > gymnastics; and for the left humeri: discus throwing > weightlifting > swimming > gymnastics and javelin throwing > control group.

Regarding the medial cortex of the right humerus, the sequence is: weightlifting > javelin throwing > discus throwing > gymnastics > control and swimming. The equivalent in the left humerus is weight-

lifting > discus throwing > gymnastics and javelin throwing > swimming > control. The sequence for the lateral cortex of the right humerus is as follows: weightlifting > discus throwing > javelin throwing and gymnastics and swimming > control. Similarly, the lateral cortex of the left humerus follows the sequence: weightlifting > discus throwing > javelin throwing > gymnastics, swimming and the control group.

Figure 1. Sequences of humeral mid-third diameters and medial and lateral cortical thicknesses for participants in five sports and a control group: a, b, c right humerus; d, e, f left humerus

Discussion

At birth, the musculoskeletal system is bilaterally symmetrical but because of different growth patterns, this symmetry disappears. It has been found that swimming stimulates bone growth⁵ and that fracture force is elevated for bone after training⁶. Growth of bone is affected by many mechanical forces which may be divided among three types: (1) static; (2) dynamic; and (3) combination.

Different forces differentially affect bone growth. The results shown in *Figure 1* clearly demonstrate that weightlifters have the thickest humeral cortex. It is suggested that this is because the humerus lies in the longitudinal axis of the stress during the whole process of weightlifting, as it does in the action of the discus thrower. In the javelin throwing technique, the humerus resists a pull stress while in gymnastics it resists the combination stress. The control group had no regular training so the humerus here had no particular directional stress. Physiologically, the greater the stress, the greater the stimulus to humeral growth. Weightlifters bear pressure stress which increases as the load increases. As the loading is progressively increased, so the cortex would show progressive growth. In discus and javelin throwing, i.e. with a dynamic load, the load stimulus is not so progressive, hence weightlifting is associated with the thickest cortical growth. From the results it is seen that the diameters of both humeri are largest in discus throwers, followed by weightlifters. However, the humeral cortex is thickest in weightlifters. This is due to the particular forces being closely related to the particular skills. In the dominant arm, if it is the power hand, e.g. in javelin throwing, the mechanical load stimulates bone as do the muscle contractions, but the non-dominant arm is subjected to virtually no force and so receives little stimulus. In swimming and gymnastics the forces are symmetrical so the non-dominant forces are greater than in javelin throwing.

At the beginning of the javelin throw, there is a stretch-contraction sequence in order to increase the primary length of the shoulder muscle. At this point, the humerus is in a position of adduction and

extension. At the beginning of the throwing action the main muscles involved are pectoralis major, latissimus dorsi, teres major and the anterior deltoid. Their main points of insertion are located on the crista tuberositis deltoidea. The muscular force is applied to the medial aspect of the humerus. Muscle contractions stimulate bone growth with a force vertical to the long axis of the bone wall. During weightlifting and discus and javelin throwing, there is force transmission through the elbow joint, stimulating the humerus in different directions. The greatest force transmission occurs between 0° and 30° of flexion, consistently decreasing with increasing flexion. Force transmission is consistently of higher magnitude when the forearm is in pronation than when in supination⁷.

In different events there are different directions of applied muscle force so a range of stimuli are transmitted to the bone resulting in different speeds of growth, hence the cortex and overall diameters of the humerus differ among the participants of different sports.

From the above results, it can be concluded that static loading provides a greater stimulus to bone than dynamic loading and that pull stress provides a higher stimulus to bone than pressure stress in exercise.

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