The heart provides the driving force which propels the blood to the lungs and rest of the body. Each time it contracts, blood is pumped in the aorta, the first and largest artery. The maximum pressure reached in the aorta is called *systolic* blood pressure. After each contraction the heart relaxes, and while it is taking in more blood for the next contraction, the pressure in the aortic artery drops to its lowest, or resting state, the so-called *diastolic* pressure. It is this pressure that decreases in response to ultrasound.

Work started off on small strips of muscle removed from rat hearts and irradiated with ultrasound kept at constant frequency (1 MHz) while varying the intensity. "During the first trials," explains Alan Mortimer, "it was apparent that ultrasonic radiation caused heating in the vicinity of the muscle, making it necessary for us to distinguish between purely thermal effects and those due to ultrasound. So a control experiment was set up where the temperature of the bath containing the muscle was increased after irradiation so that the muscle reached the same temperature which occurred during irradiation. Then, we were able to compare the equivalent thermal component with the non-thermal component which affects only the diastolic force, lowering it significantly. This was our important finding." With these encouraging results, work progressed to whole isolated hearts from rats and rabbits. Here again the same phenomenon was observed: a decrease in the diastolic tension during ultrasonic radiation.

The clinical significance of the finding appears very promising. While most skeletal muscle can sustain some degree of what is called "oxygen debt", cardiac muscle can tolerate very little. (During vigorous exercise the skeletal muscles "live beyond their means" — they incur a debt in oxygen. For this reason, increased oxygen consumption continues after the exercise is terminated). The heart muscle however, does not have an oxygen credit card. When there is insufficient supply of oxygen to the heart, pressure increases and the heart becomes stiffer. A chest pain (as in angina) or a mild heart attack, can result. Ultrasound, in decreasing the diastolic pressure, could help the muscle relax and allow more blood to flow in, thereby increasing the oxygen supply to a depleted heart. Such a change could have therapeutic value to people who experience heart problems.

The next step for the research team will be to try to obtain these same results in a living animal. However, at this stage the system becomes more complex as tighter controls operate in the body to compensate for any alterations, especially mechanical, which might be imposed by ultrasound.

Mr. Mortimer suggests an explanation of ultrasound's effects on normal and diseased hearts. "Our experimental work showed that, in a healthy heart, ultrasound leads to a decrease in diastolic or resting pressure. Two explanations can account for this: first, an increased availability of oxygen to the heart, and second, a localized heating of the supporting structure of the muscle, made more pliant and thus exerting less pressure on the blood. At present, testing this heat hypothesis would require temperature monitoring of single cells, and to date, the smallest thermocouple is still 'large scale' when compared to the size of muscle cells.

"In the diseased heart, along with a decrease in resting pressure there is also an increase in systolic or contraction pressure. This could be due to heating by the ultrasound treatment causing a speed-up in the 120 or so different stages or reactions that make up muscle contraction. This could result in a stronger contraction, an effect not observed in a healthy heart because presumably, it is already operating at maximum efficiency.

"In turn this heating effect provides an explanation of the decrease in pressure during the resting phase of the heart. Stronger contractions could provide an increased oxygen supply during the resting stage, with a consequent decrease in muscle 'stiffness'. This, in conjunction with the increased pliancy of the support tissue that would result from heat, could explain the lowering of diastolic pressure."

Another explanation according to Mortimer, involves the effects of ultrasound on the availability of calcium to the muscle; without this ion, muscle contraction does not take place. In conditions like kidney failure or a heart blockage where the hydrogen ions (or acidity) increase in the muscle medium, these ions compete with calcium, making it less available for muscle contraction. "At certain ultrasound intensities," continues Mortimer, "the contractile state of the muscle increases, a phenomenon not seen when the level of hydrogen ions is normal or when sufficient extra calcium is provided. This seems to indicate that ultrasound may somehow alter the competition between calcium and hydrogen ions, increasing calcium's availability to the cell."

It is not yet possible to determine which of these two mechanisms is in operation when ultrasound acts on cardiac muscle. Though they are the most likely explanations to date, the door is left open for others as the experimental work progresses. "Nonetheless," concludes Alan Mortimer, "we do see this decrease in resting tension of the muscle which doesn't seem to affect the way the muscle contracts, and this is new. It doesn't comply with current belief that the heart's resting tension is due to the fact that the muscle hasn't completely relaxed. So in addition to possible clinical applications, these studies may introduce a new way of looking at, or defining, diastolic tension."☐

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