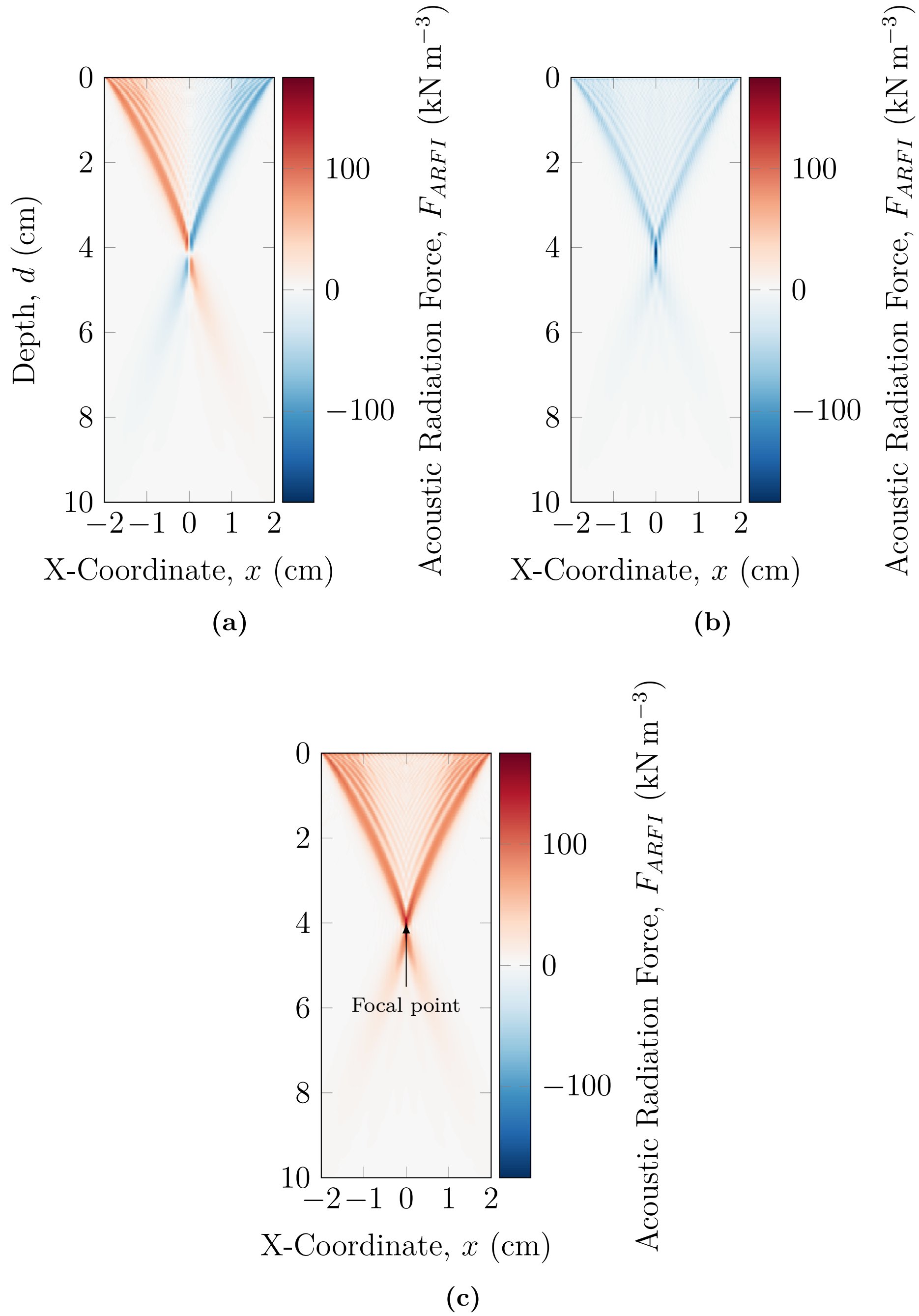

Fig. 4.3: Sample acoustic radiation force distribution in the (a) lateral and (b) axial directions, and (c) the resultant L^2-norm generated by a 2 MHz transducer operating with an aperture of 4 cm focusing an acoustic beam at a depth of 4 cm continuously for 150 µs applying a pressure of 3.35 MPa.

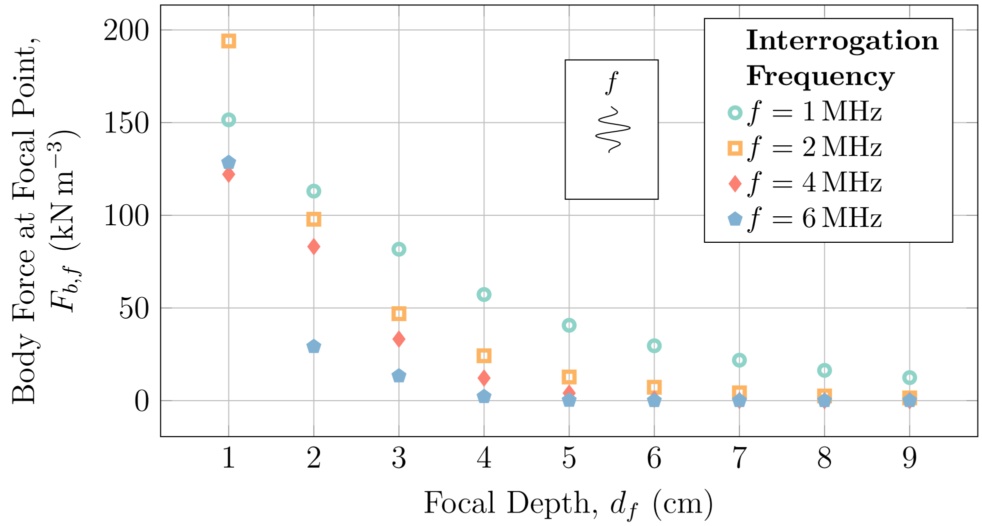

Fig. 4.4: Effect of depth and interrogation frequency on the magnitude of acoustic body forces developed in tissue. Increasing the interrogation frequency or the focal depth results in lesser body loads experienced by the tissue at the focal point, with the greatest loss of magnitude resulting from focal depth.

As Fig. 4.4 shows, increasing focal depth and probing frequency drastically decreases the magnitude of the force at the focal point of the tissue. In general, forces that are greater in magnitude are ideal as the deflection in the tissue that they cause must be detectable by the same transducer that is applying the forces—if the resulting deflections are too low, the tracking waves sent by the transducer will not be able to distinguish the motion. For the Siemens ACUSON S2000™ machine used in the validation of these studies, this lower limit is quoted as being 1/100 of the applied wavelength, or approximately 1.7 µm for a 9 MHz probing frequency [114].

Since the forces developed in the tissue represent a transfer of energy, theoretically increasing the amount of energy input into the system should increase, or at least assist in greater amount of energy being transferred to the tissue. One way of increasing the amount of energy applied to the tissue by the transducer is to increase the size, or the "aperture" of the transducer—an aperture of 8 cm will use twice as many physical pulsing elements than an aperture of 4 cm. To study this, the magnitude of the body force at the focal point was studied in simulation as the aperture changed. The results of this study are shown in Fig. 4.5.

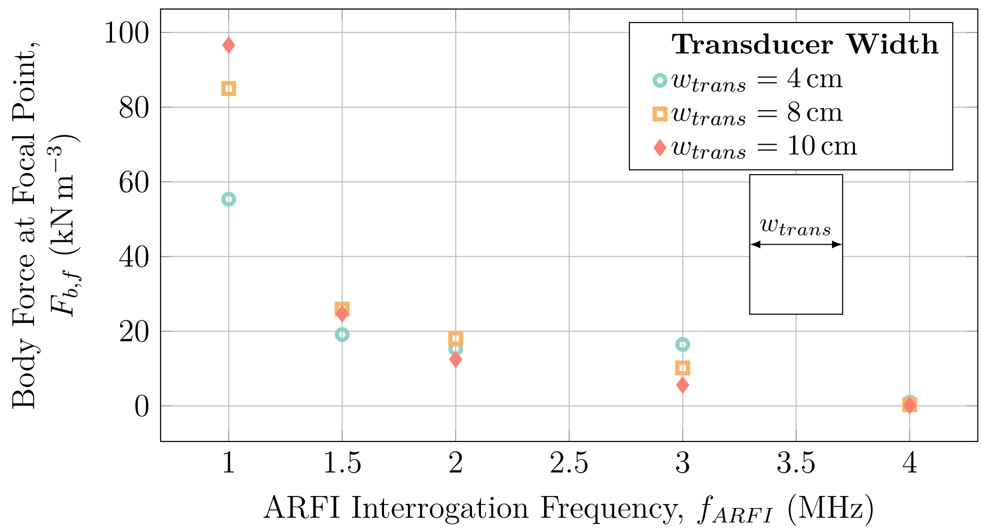

Fig. 4.5: Effect of transducer aperture on the magnitude of developed acoustic radiation force at the focal depth of 6 cm for a range of ultrasound interrogation frequencies.

Surprisingly, there was little consistent effect of the transducer aperture size on the magnitude of the acoustic radiation force that was seen at the focal point. As expected, the greatest and least forces were developed with the lowest and highest frequencies studied, respectively, as per the results found in Fig. 4.4. The greatest effect of the transducer aperture size occurred at a frequency of 1 MHz while the least effect of the transducer aperture size occurred at a frequency of 4 MHz which correlate to the greatest and least amount of energy input into the system respectively.

Another method of increasing the amount of energy transferred into the system is to increase the duration of time that the system is applying pressure to the tissue. In other words, increasing the number of pulse cycles (insonification time) should generate more energy until tissue is under quasi-steady-state insonification. To investigate this, the effect of the number of acoustic pulse cycles—related to the insonification time by equation 4.15—was investigated, with the results shown in Fig. 4.6.

$$t_{inson} = \frac{n_c}{f_{applied}} \tag{4.15}$$

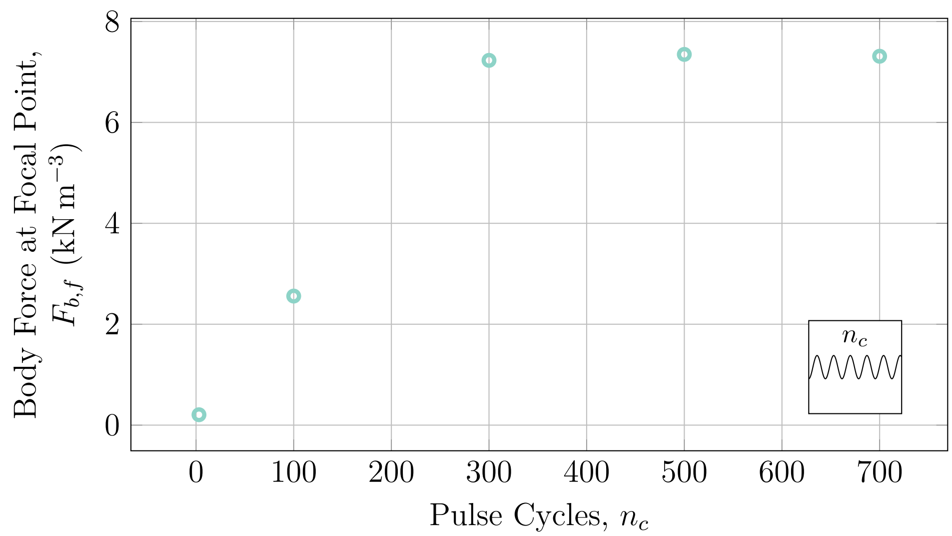

Fig. 4.6: Magnitude of the developed acoustic radiation force in relation to the number of applied pulse cycles in tissue at a focal depth of 6 cm using a transducer aperture of 4 cm and source pressure of 3.35 MPa.

As expected, increasing the number of pulse cycles increased the magnitude of the acoustic radiation force seen at the focal point until the domain reached quasi-steady-state at approximately 300 pulses, or 150 µs of insonification. At this point, since the calculation of the acoustic radiation force given in equation 4.10 relies on the *average* intensity during the insonification time, increasing the number of pulse cycles has little to no effect on the resulting acoustic radiation force.

One further way of increasing the energy in the system and thereby increasing the magnitude of the acoustic radiation force at the focal point is to increase the amount of pressure applied by the individual transducer elements. To investigate this technique, a range of acoustic pulsing element pressures were applied across a range of focal depths and the resulting acoustic radiation force at the focal point was monitored. The results of this study are shown in Fig. 4.7.

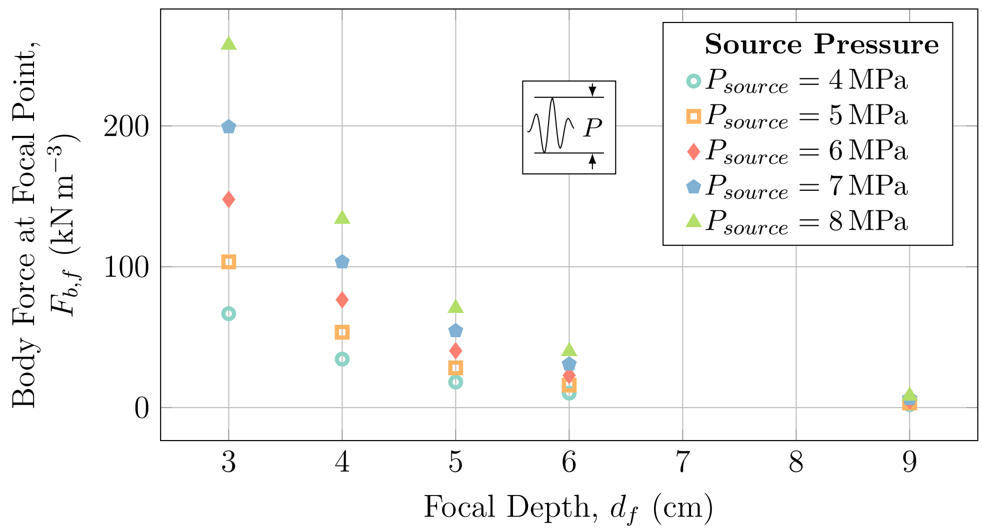

Fig. 4.7: Strong dependence on source pressure of focal point force

As Fig. 4.7 shows and as was expected, increasing the applied pressure results in greatly increasing the magnitude of the resultant acoustic radiation force developed in the tissue—doubling the applied pressure results in nearly quadrupling the magnitude of the acoustic radiation force at all depths. Note however that a critical measure of the safety of ultrasound is the cavitation pressure of the ultrasonic wave as it travels through the tissue. The safety of cavitation is described by the "mechanical index", MI, which is calculated according to equation 4.16 [96] where P_r is the peak rarefaction pressure in the