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## Results for all 8 cases

### 5.1 Data generated by PZT transducer

#### 5.1.1 Case 1

For case 1, the excitation signal is Ricker pulse, and each received signal at corresponding scanning point is averaged 16 times. The Ricker pulse and its Fourier spectrum are shown under.

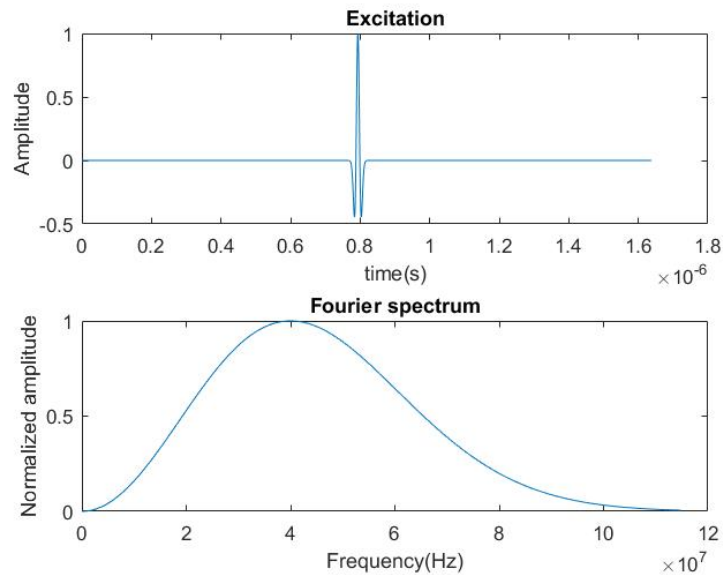


Figure 5.1: Ricker pulse and its Fourier spectrum

The received signals need to be calibrated and interpolated. The signals before and after time calibration are shown in Figure 5.2 (a) and (b). For time calibration, the used method of finding the pulse location is maximum method. The time delay and time compensation planes for the whole scanning area are shown in Figure 5.2 (c) and (d). The signal before and after interpolation is shown in Figure 5.3. The used interpolation method is cubic spline.

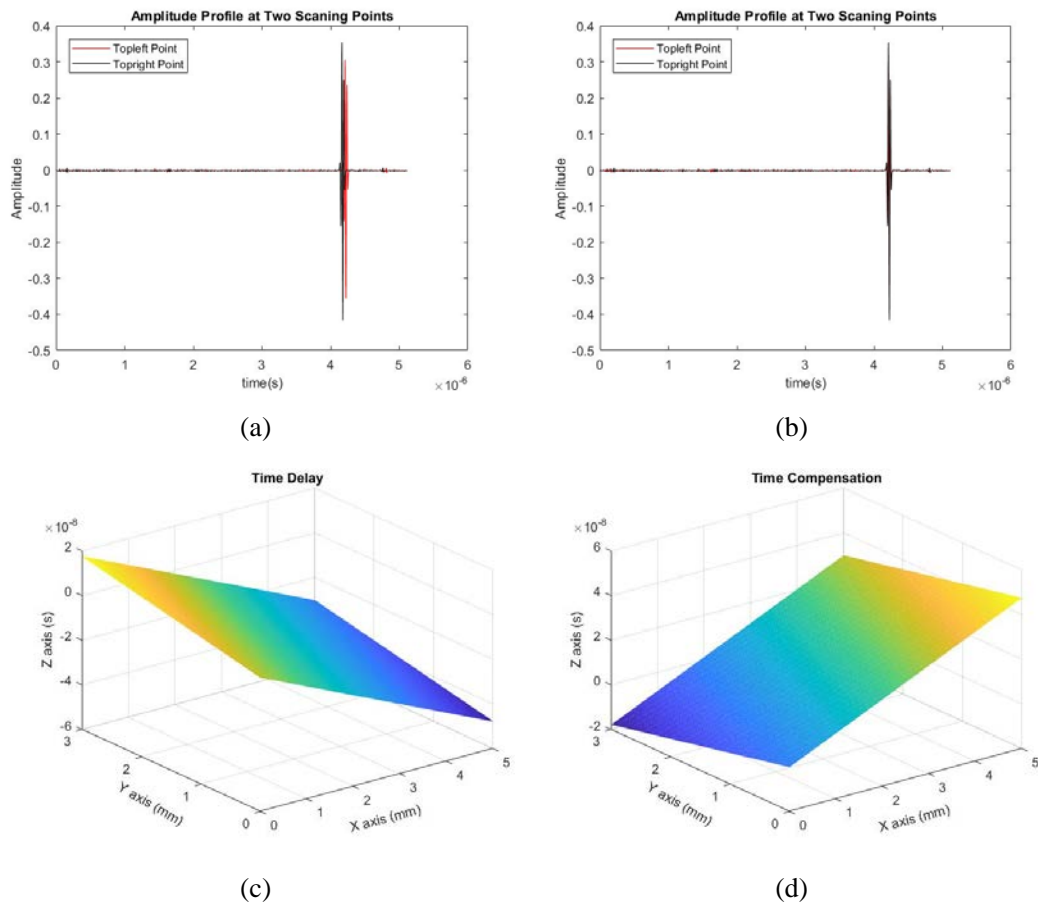


Figure 5.2: Time calibration. (a) Two signals before calibration. (b) Two signals after calibration. (c) Time delay plane. (d) Time compensation plane.

Two signals collected from top left and top right scanning points are used to illustrate the performance of the calibration. Since there is no cartilage at the two scanning points, the arriving time of the main bangs should be same if the two scanning points are at the same altitude. Before calibration the arriving time of the main bangs is obviously different because of the tiled platform or similar reasons. After calibration, the main bangs are overlapped which shows that the performance of time calibration is good enough. Cartilage image mapped by max value at every scanning point is shown in Figure 5.4. B scan images are taken along the four pink lines. The B scan images are generated from a time window centered around  $3.3 \mu\text{s}$ . If no otherwise specified, the B scan images are taken at same positions for all 8 cases.

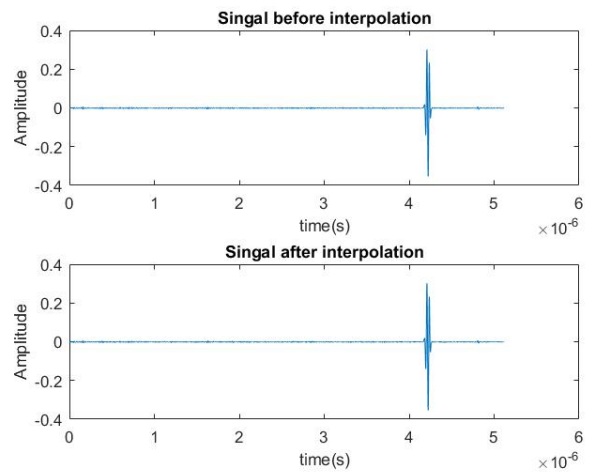


Figure 5.3: Interpolation

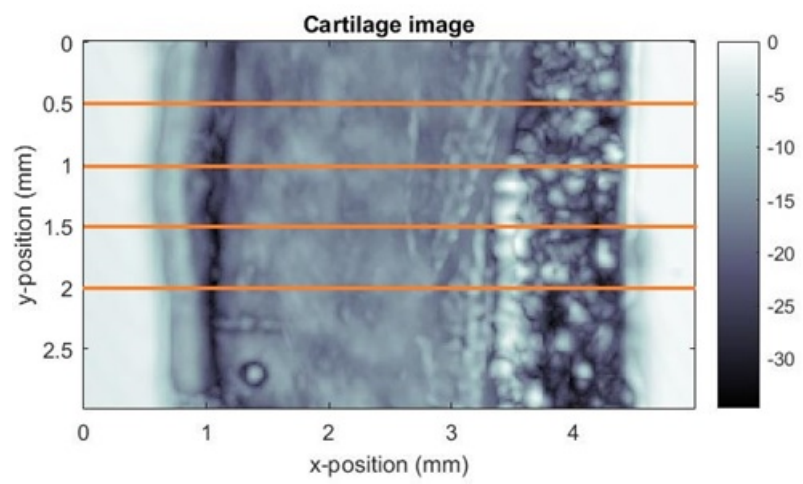
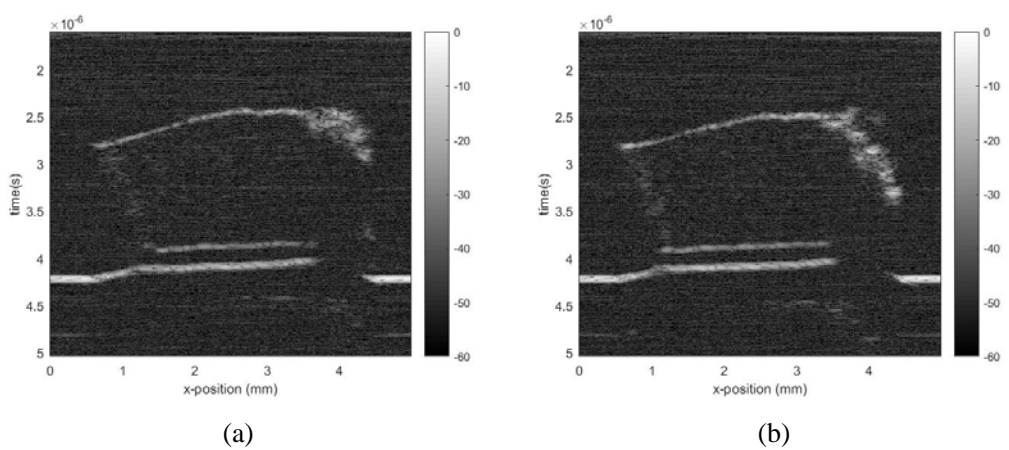


Figure 5.4: C scan images of cartilage



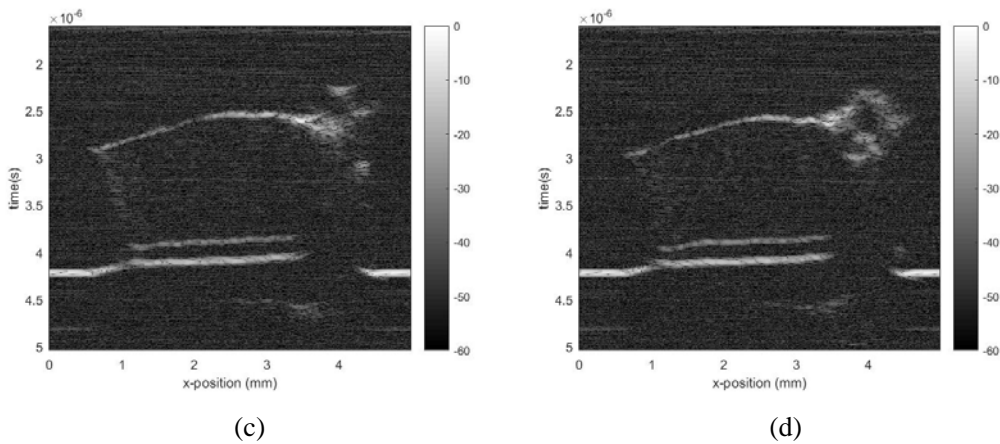


Figure 5.5: B scan. (a)  $y = 0.5 \text{ mm}$ . (b)  $y = 1 \text{ mm}$ . (c)  $y = 1.5 \text{ mm}$ . (d)  $y = 2 \text{ mm}$ .

It is too complicated to compute the SNR for signals of all the scanning points, but only computing mean value of SNR for ten signals as a reference is achievable. The mean value of SNR for signals received at ten scanning points is calculated. The ten scanning points are located in the top left corner of the cartilage image. The mean value of SNR is approximate 32.60.

### 5.1.2 Case 2

For case 2, the excitation signal is Ricker pulse, and each received signal at corresponding scanning point is without averaging. The Ricker pulse used in case 2 is same with the one used in case 1. The signals before and after time calibration are shown in Figure 5.6. For time calibration, maximum method is used to find the pulse location. From Figure 5.6 we can see that time calibration works well. Cartilage image mapped by max value at every scanning point is shown in Figure 5.7. The mean value of SNR for ten signals collected at top left corner is approximate 26.86.



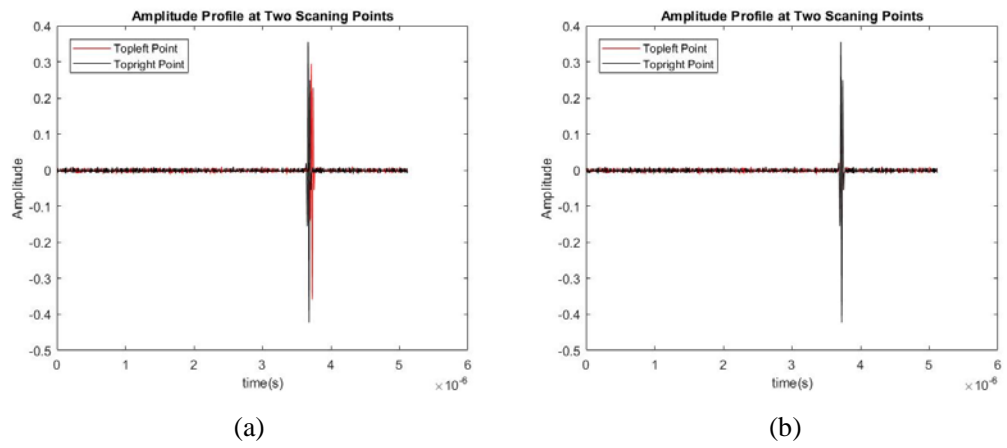


Figure 5.6: Time calibration

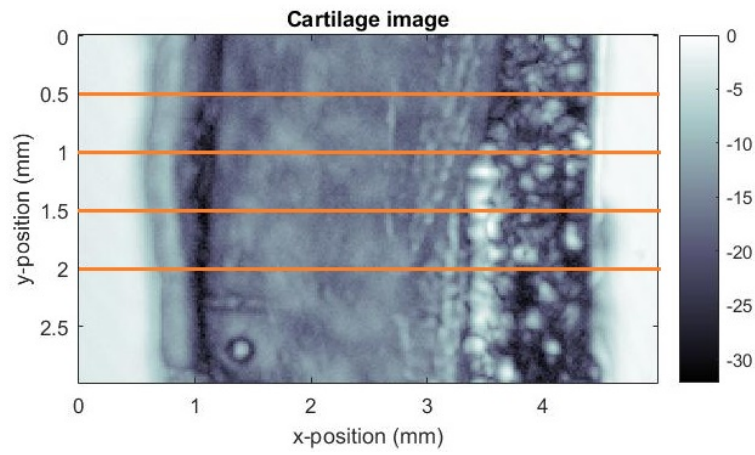
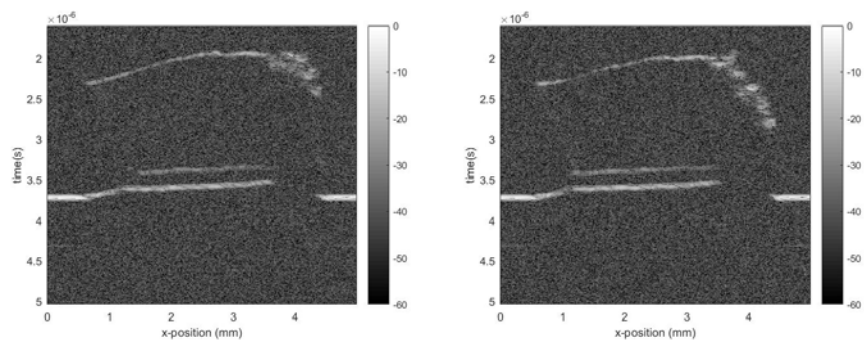


Figure 5.7: Cartilage image



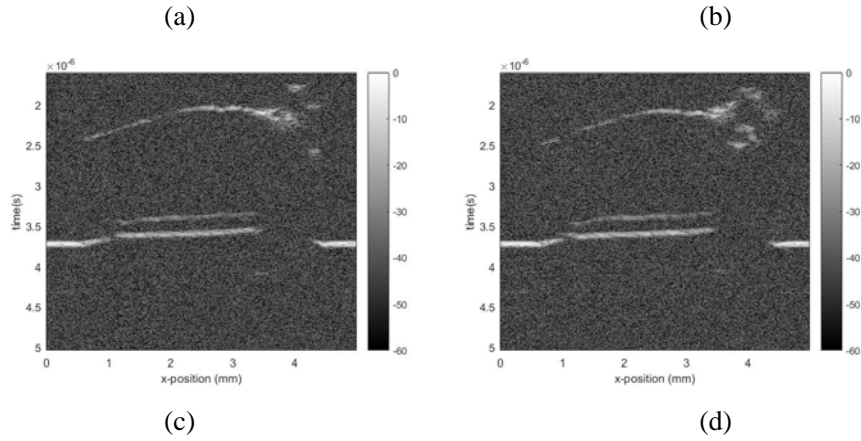


Figure 5.8: B scan. (a) (b) (c) (d) corresponding to  $y = 0.5, 1, 1.5, 2 \text{ mm}$ .

### 5.1.3 Case 3

For case 3, the excitation signal is Chirp signal, and each received signal at corresponding scanning point is averaged 16 times. Chirp signal is defined in the time domain as [98]:

$$Ch(\tau) = A \exp \left[ -\frac{(2\pi f)^2}{Q^2} (\tau - t)^2 \right] \exp \left\{ 2\pi i \left[ f(\tau - t) + \frac{d}{2} (\tau - t)^2 \right] \right\}, \quad (5.1)$$

where  $A = \left( \frac{8\pi f^2}{Q^2} \right)^{\frac{1}{4}}$ .  $t$  and  $f$  represent the center time and frequency respectively.  $Q$  is the dimensionless quality factor and in case 3  $Q$  is set to be 80. The Chirp signal used in the experiment is defined by the above equation instead of the simplest Chirp wave definition in section 3.3.3. This is because the above equation is more convenient for us to control the details of the waveform and generate the Chirp signal which is more suitable and practical for our ultrasonic scanning system. The Chirp signal used in case 3 and its Fourier spectrum is shown under.

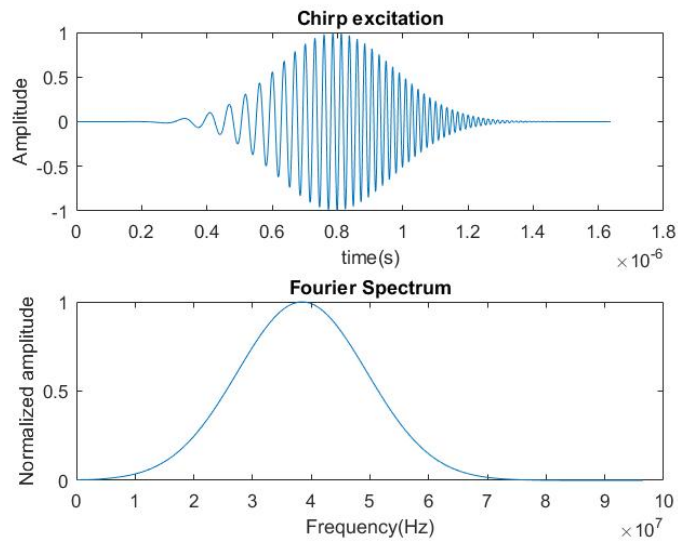


Figure 5.9: Chirp signal in time and Fourier domain

The received signals need to be calibrated and interpolated. The signals before and after time calibration are shown in Figure 5.10 (a) and (b). For time calibration, the method used for finding the pulse location is maximum method. The used interpolation method is cubic spline.

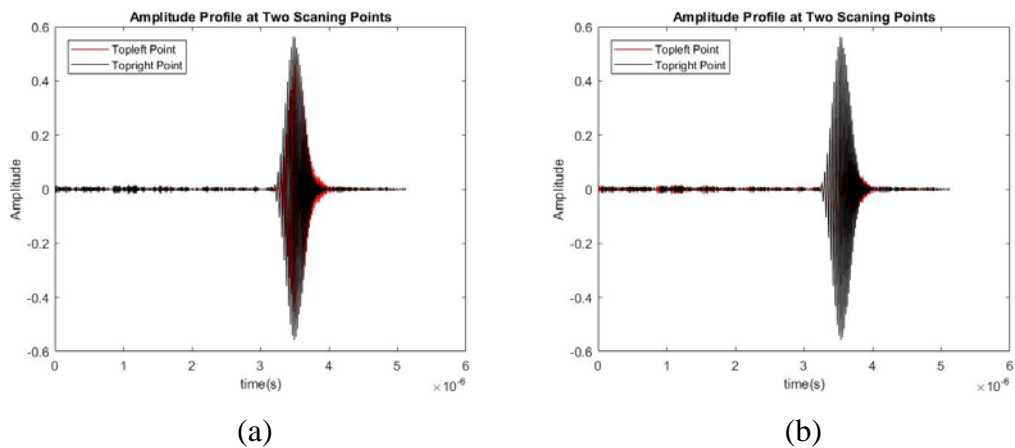


Figure 5.10: Time calibration. (a) Before calibration. (b) After calibration.

Two signals collected from top left and top right scanning points are used to illustrate the performance of the calibration. The reaching time of the main bangs should be same if the two scanning points are at the same altitude. Before calibration the main bangs are obviously not overlaid because of the tiled platform or similar reasons. After calibration, the most part of the main bangs are overlapped which shows that the time calibration

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works well.

In case 3 coded excitation is used, so decoding is needed. For matched filtering method, decoding can be applied in time domain or Fourier domain. Both excitation signal and reflected signal from areas without cartilage sample can also be used as matching template. There therefore are four different situations of matched filtering.

For the situations that the excitation signal is used as template, the signal scanned at first scanning point and its corresponding filtered signals are shown in Figure 5.11 (a) and the signal scanned at central scanning point and its corresponding filtered signals are shown in Figure 5.11 (b). The amplitude of filtered signals is in decibel scale. Filtering in time domain and Fourier domain should be same in theory. As is shown in Figure 5.11, the filtered signals are almost same that the difference cannot be distinguished by human eyes. Actually, they are not absolutely same because of the rounding operation in MATLAB. B scan images generated by filtered signals are shown in Figure 5.12. B scan images are taken at the same positions with case 2. The cartilage image mapped by max value of filtered signals at every scanning point is shown in Figure 5.13.

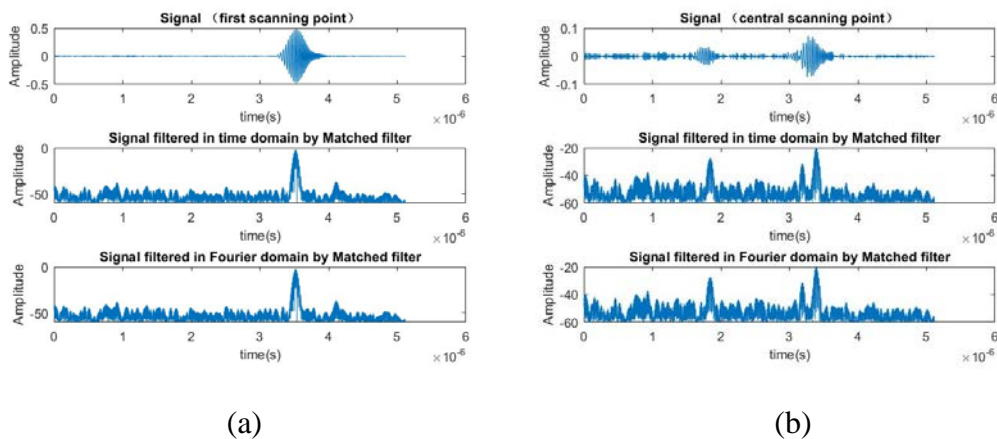


Figure 5.11: Matched filtering. (a) Signal of first scanning point. (b) Signal of central scanning point.

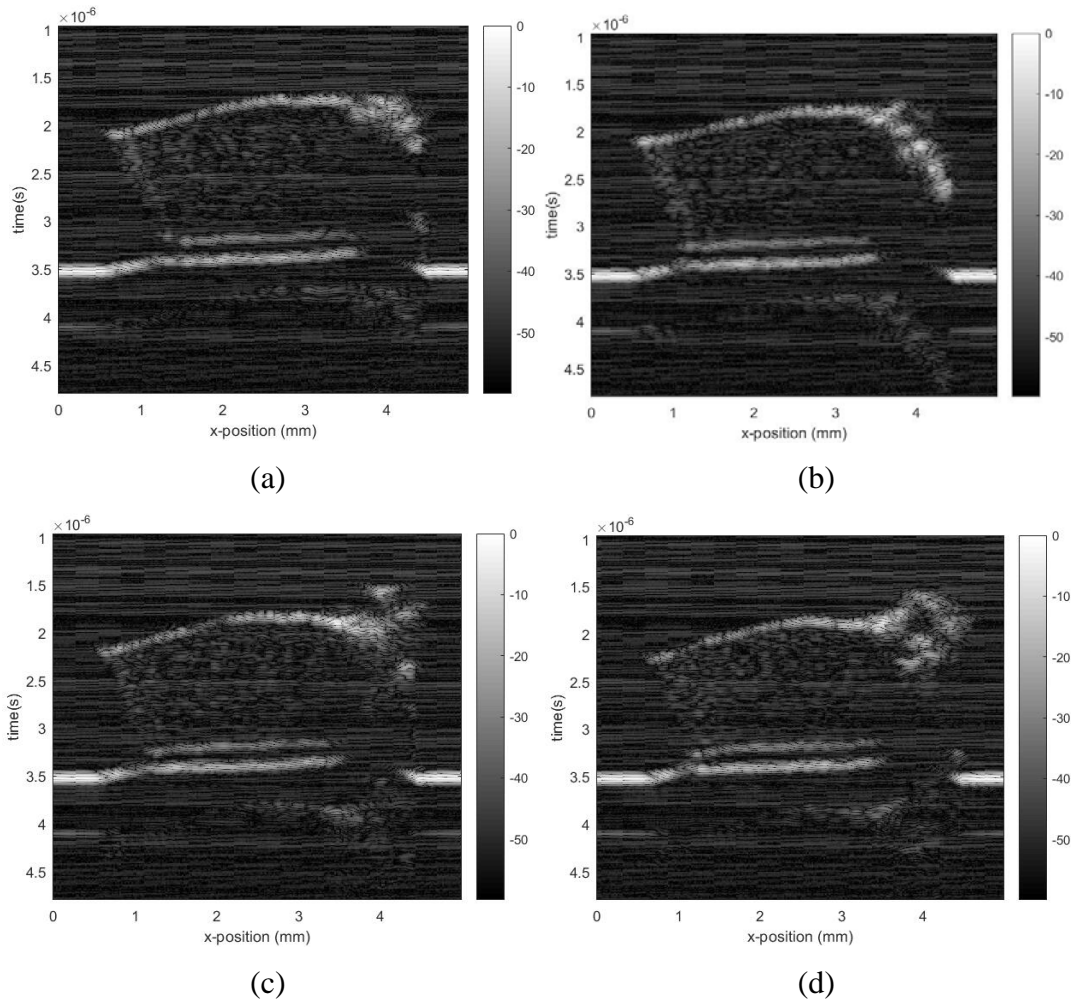


Figure 5.12: B scan. (a)  $y = 0.5 \text{ mm}$ . (b)  $y = 1 \text{ mm}$ . (c)  $y = 1.5 \text{ mm}$ . (d)  $y = 2 \text{ mm}$ .

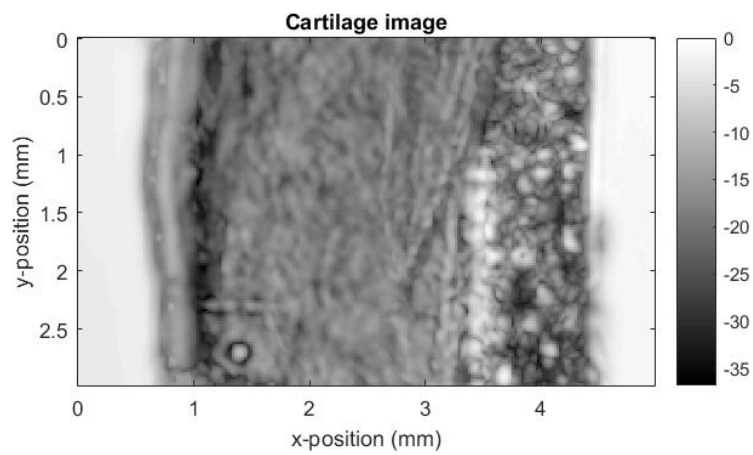


Figure 5.13: Cartilage image

For the situations that the reflected signal is used as template, the reflected signal at first

scanning point is used as matching template in practical, and only part of the signal which includes the main bang is used to save the computation resources. The template is shown in Figure 5.14. The signal collected at first scanning point and its corresponding filtered signals are shown in Figure 5.15 (a). The signal scanned at central scanning point and its corresponding filtered signals are shown in Figure 5.15 (b). B scan images generated by filtered signals are shown in Figure 5.16. B scan images are taken at the same positions with case 2. The cartilage image mapped by max value of filtered signals is shown in Figure 5.17.

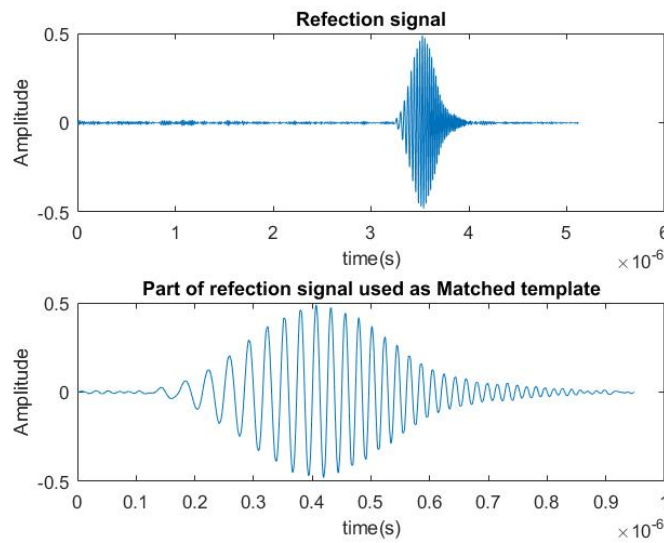


Figure 5.14: Matching template

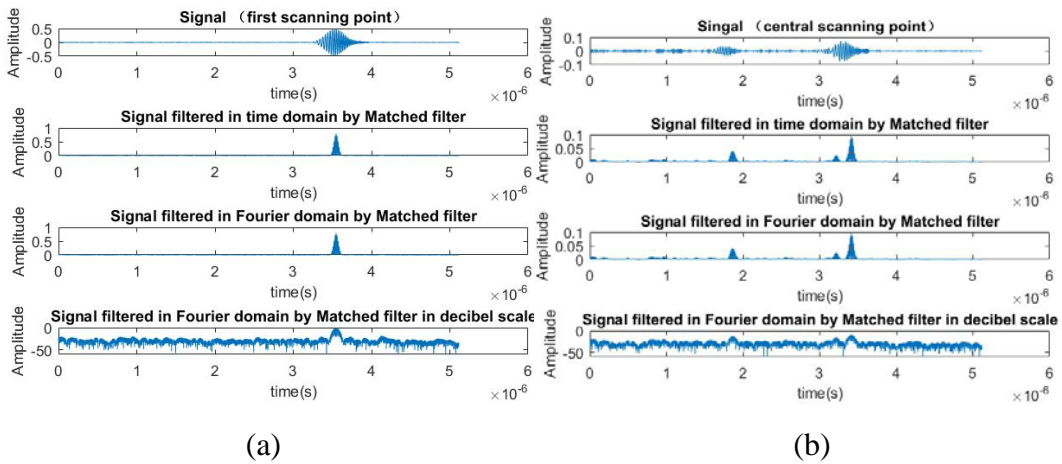


Figure 5.15: Filtered signals. (a) Signals of first scanning point. (b) Signals of central scanning point.

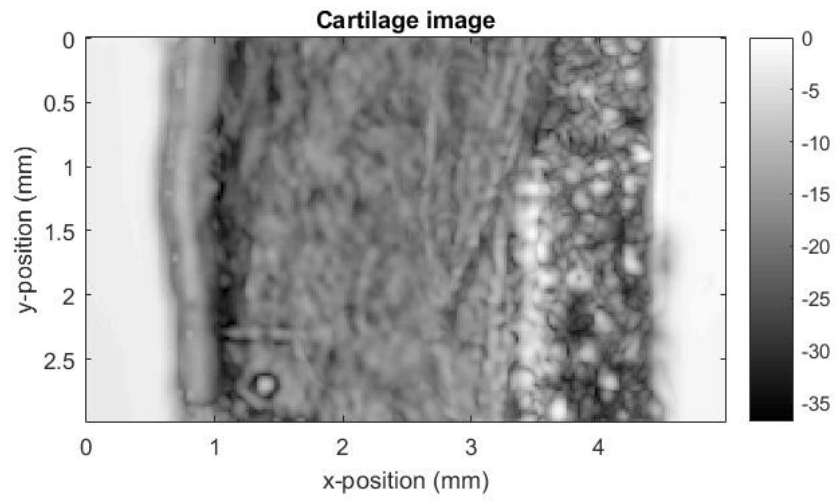


Figure 5.16: Cartilage image

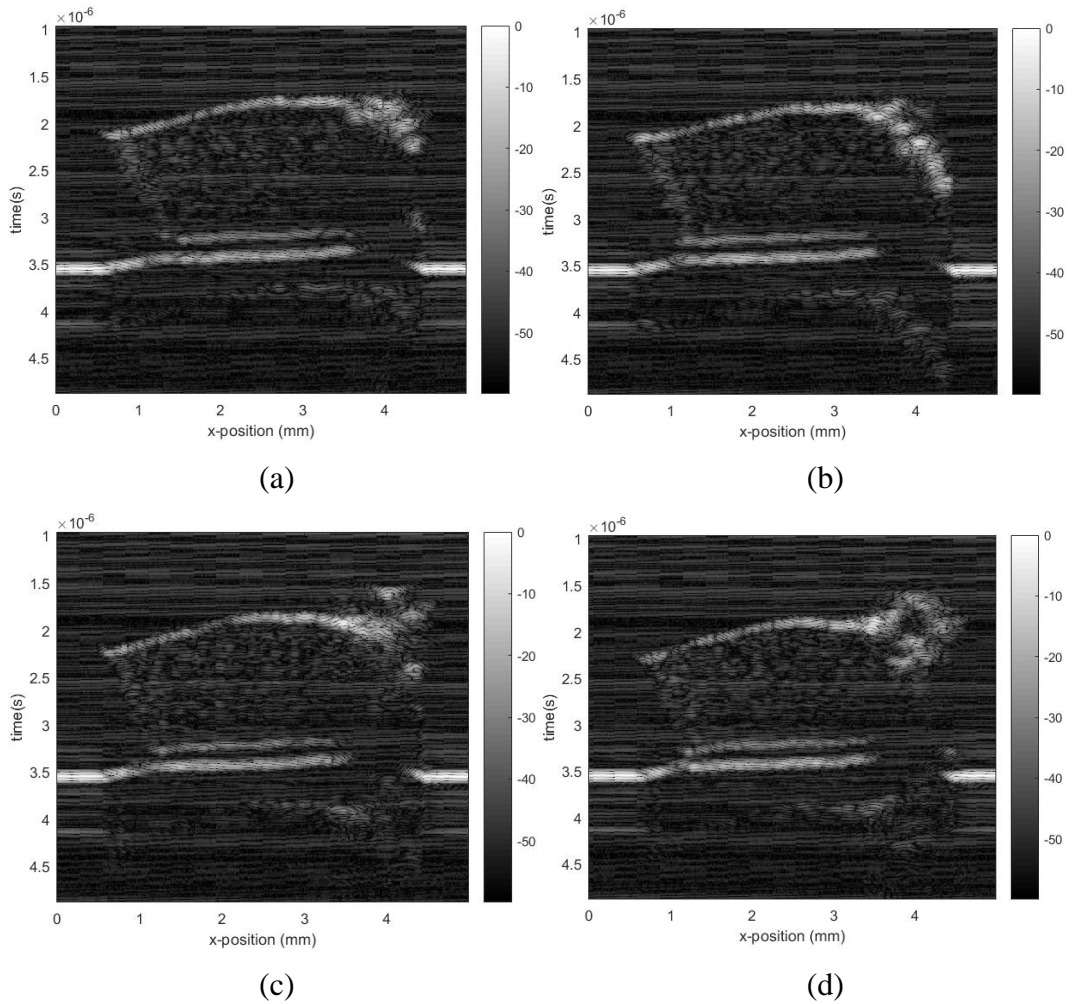


Figure 5.17: B scan. (a)  $y = 0.5 \text{ mm}$ . (b)  $y = 1 \text{ mm}$ . (c)  $y = 1.5 \text{ mm}$ . (d)  $y = 2 \text{ mm}$ .

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From Figure 5.15 we can see that the matched filter works very well and there is almost no sidelobes in decimal scale. If the signals are shown in decibel scale, the sidelobes are obvious to spot. The way of computing SNR is same with that of case 2. The SNR before matched filtering is approximate 28.42. The SNR after matched filtering with excitation as filter template is approximate 36.50. The SNR after matched filtering with reflection signal as filter template is approximate 35.41.

Wiener filtering is also used for decoding in case 3. Both excitation signal and reflected signal from areas without cartilage sample can be used to generate Wiener filter. There therefore are two situations for Wiener filtering. For the situation that the excitation signal is used to generate Wiener filter, the signal scanned at first scanning point and its corresponding filtered signals are shown in Figure 5.18. And the signal scanned at central scanning point and its corresponding filtered signals are shown in Figure 5.19. Wiener filter is generated based on equation 3.40. The parameter  $k_c$  is set to 1 and  $\lambda$  is set to 0.1, 1, 500 and 10000 respectively. If no otherwise specified, the parameters of Wiener filter in the experiment are same with that of case 3. For signals filtered by Wiener filter with  $k_c = 1$  and  $\lambda = 500$ , the corresponding B scan images are shown in Figure 5.21. The cartilage image mapped by max value of filtered signals at every scanning point is shown in Figure 5.20. The SNR of signals filtered by Wiener filter with  $k_c = 1$  and  $\lambda = 500$  for this situation is approximate 36.66.



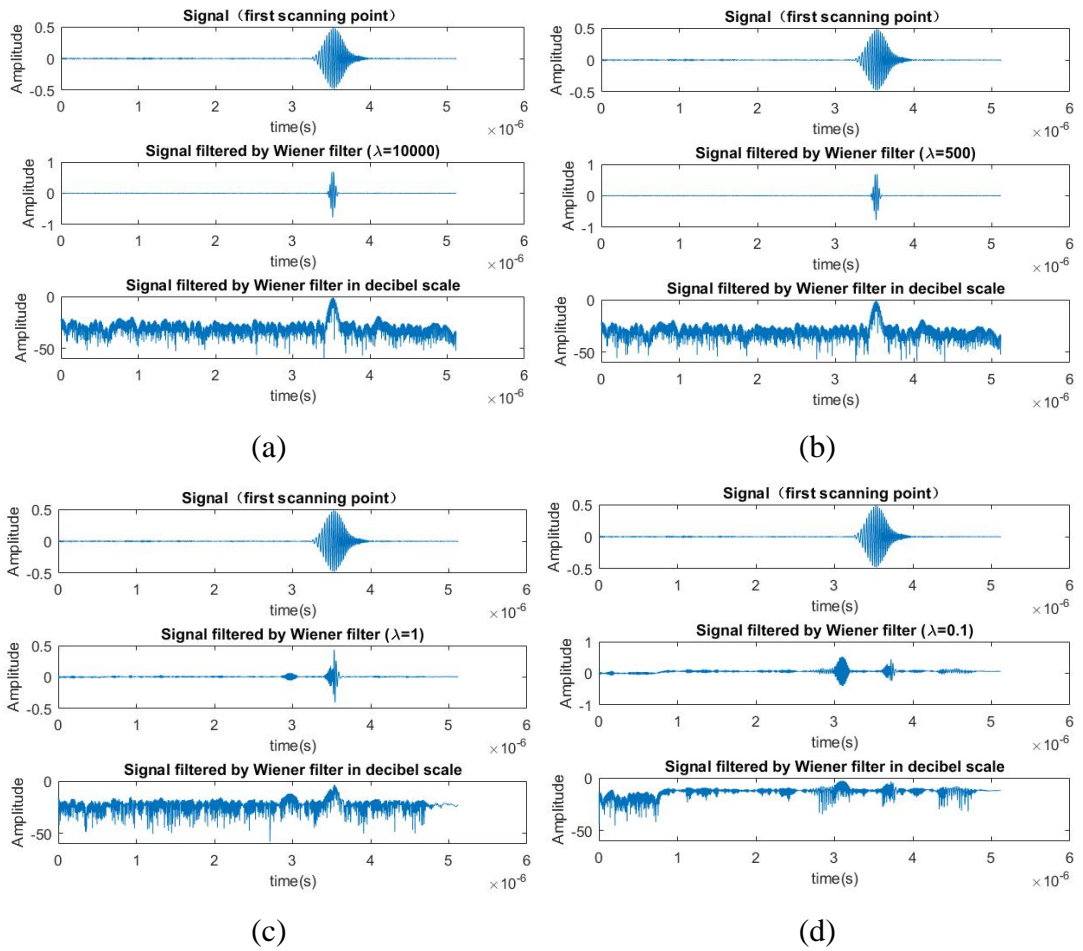


Figure 5.18: Filtered signals of first scanning point. (a)  $\lambda = 10000$ . (b)  $\lambda = 500$ .  
(c)  $\lambda = 1$ . (d)  $\lambda = 0.1$ .

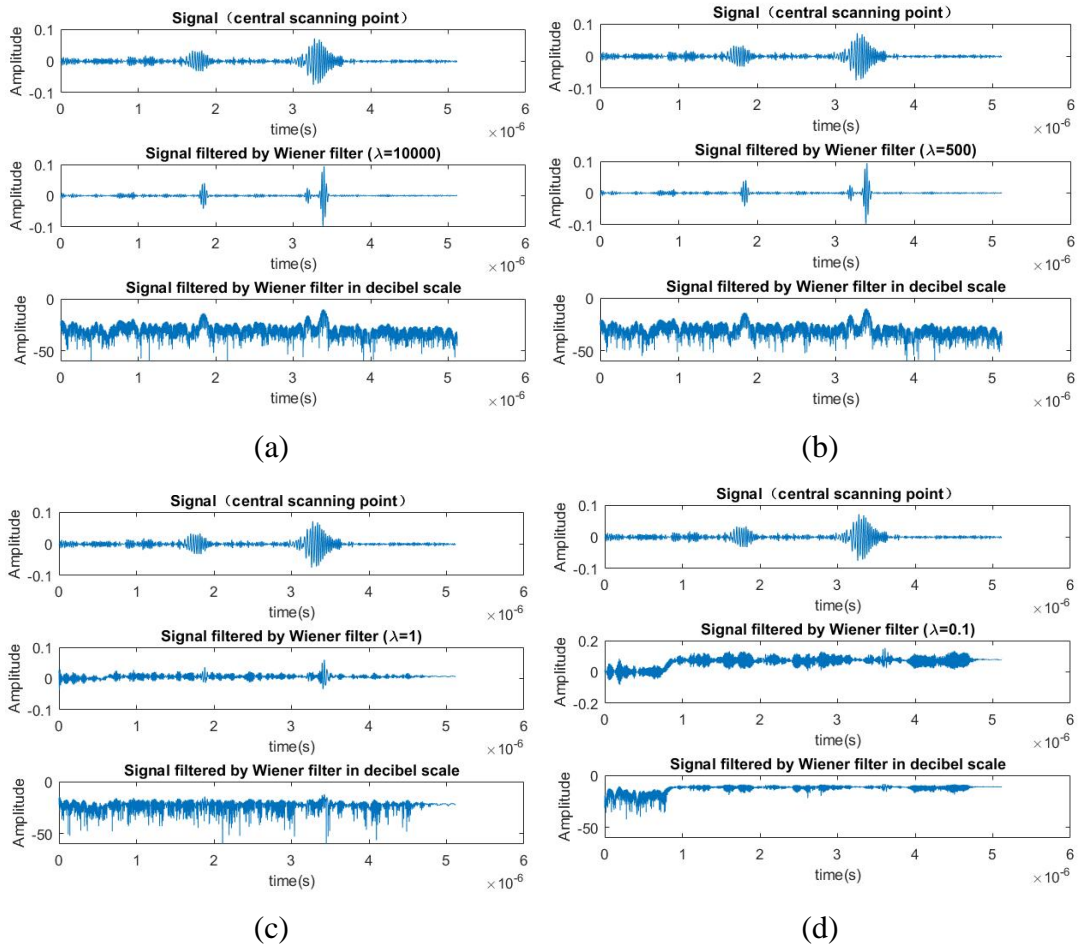


Figure 5.19: Filtered signals of central scanning point. (a)  $\lambda = 10000$ . (b)  $\lambda = 500$ . (c)  $\lambda = 1$ . (d)  $\lambda = 0.1$ .

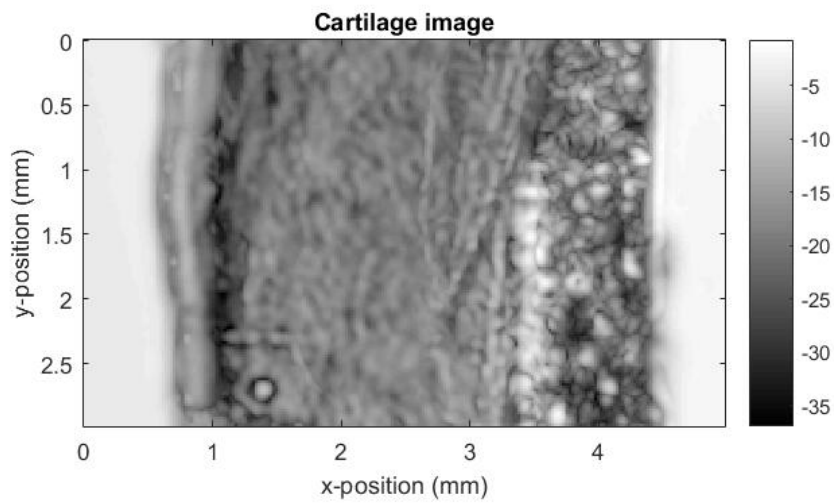


Figure 5.20: Cartilage image

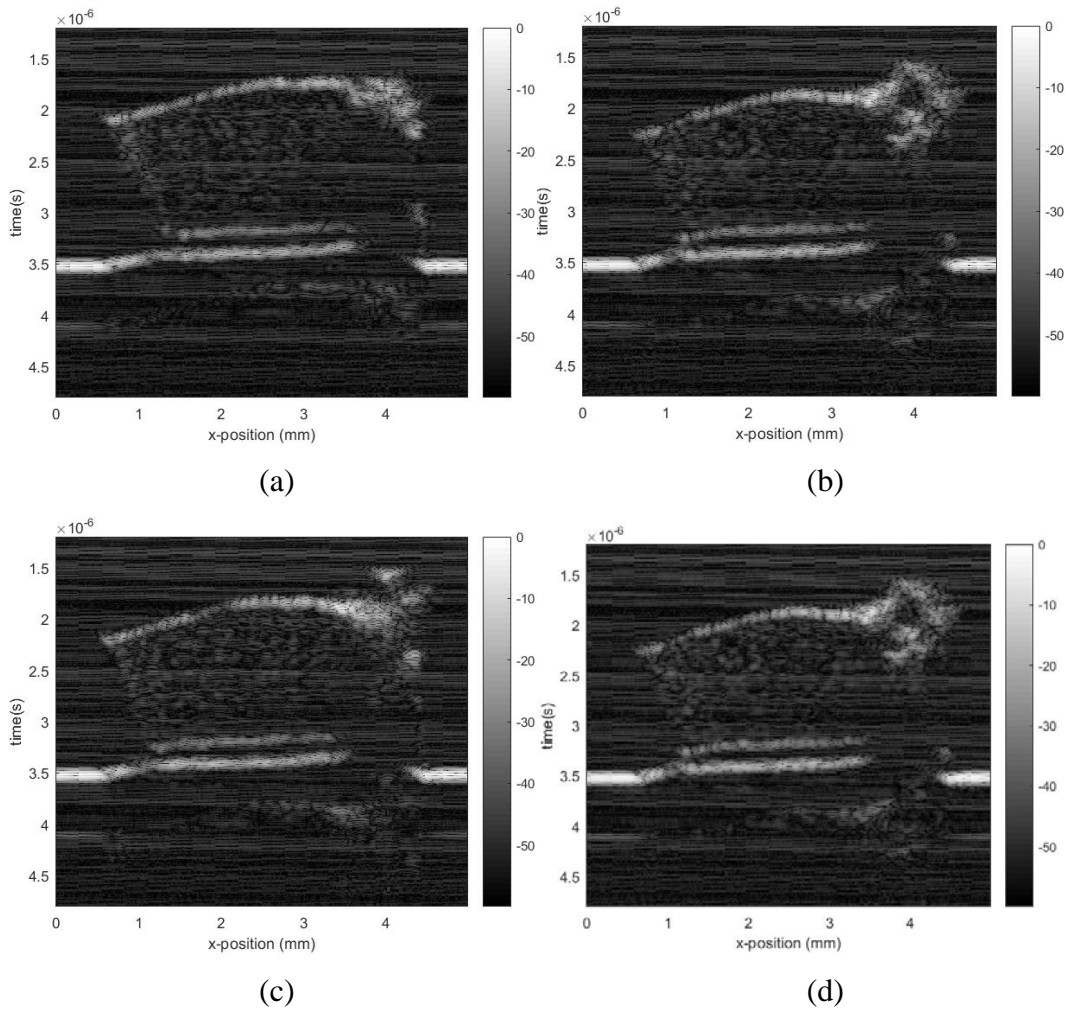


Figure 5.21: B scan. (a)  $y = 0.5 \text{ mm}$ . (b)  $y = 1 \text{ mm}$ . (c)  $y = 1.5 \text{ mm}$ . (d)  $y = 2 \text{ mm}$ .

For the situation that the reflected signal is used to generate Wiener filter. The signal collected at first scanning point and its corresponding filtered signals are shown in Figure 5.22. The signal scanned at central scanning point and its corresponding filtered signals are shown in Figure 5.23. For signals filtered by Wiener filter with  $k_c = 1$  and  $\lambda = 500$ , the corresponding B scan images are shown in Figure 5.25. The cartilage image mapped by max value of filtered signals at every scanning point is shown in Figure 5.24. The SNR of signals filtered by Wiener filter with  $k_c = 1$  and  $\lambda = 500$  for this situation is approximate 36.61.

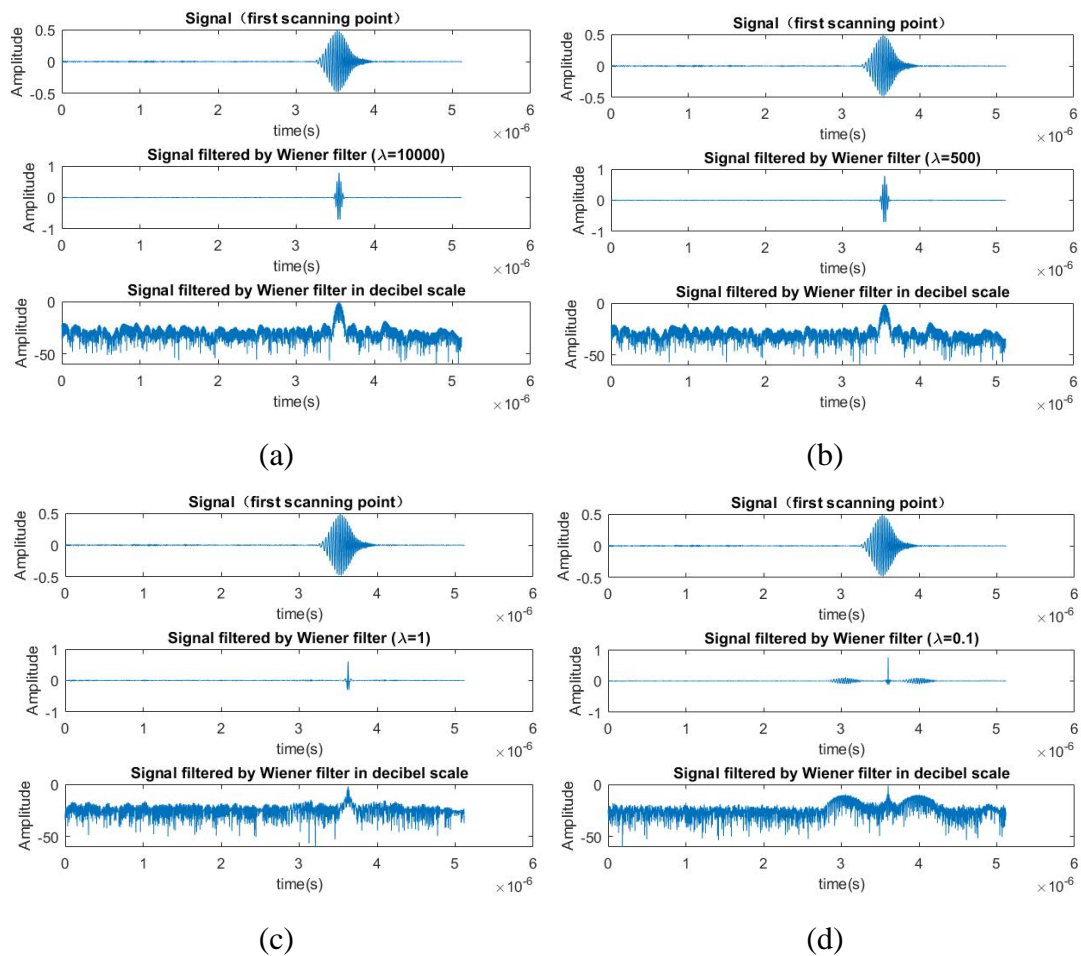


Figure 5.22: Filtered signals of first scanning point. (a)  $\lambda = 10000$ . (b)  $\lambda = 500$ .  
(c)  $\lambda = 1$ . (d)  $\lambda = 0.1$ .

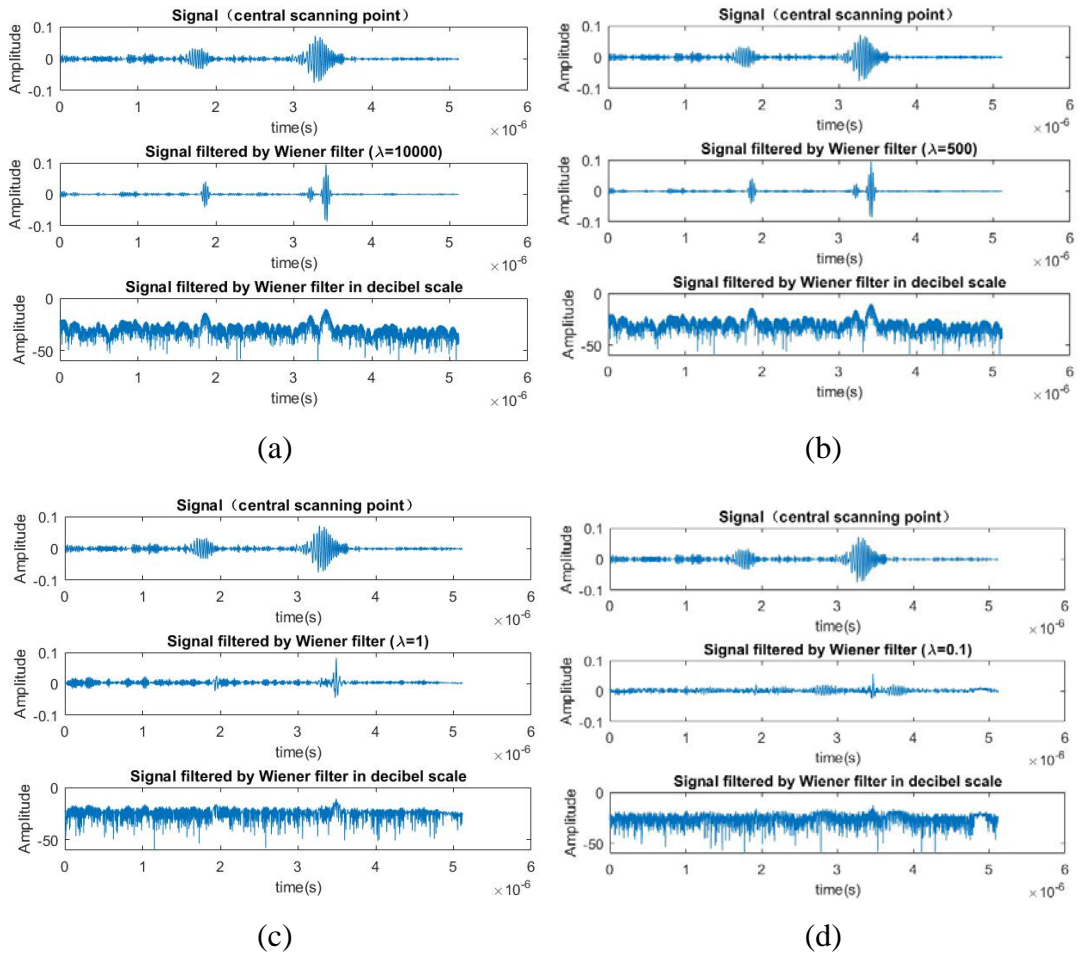


Figure 5.23: Filtered signals of central scanning point. (a)  $\lambda = 10000$ . (b)  $\lambda = 500$ . (c)  $\lambda = 1$ . (d)  $\lambda = 0.1$ .

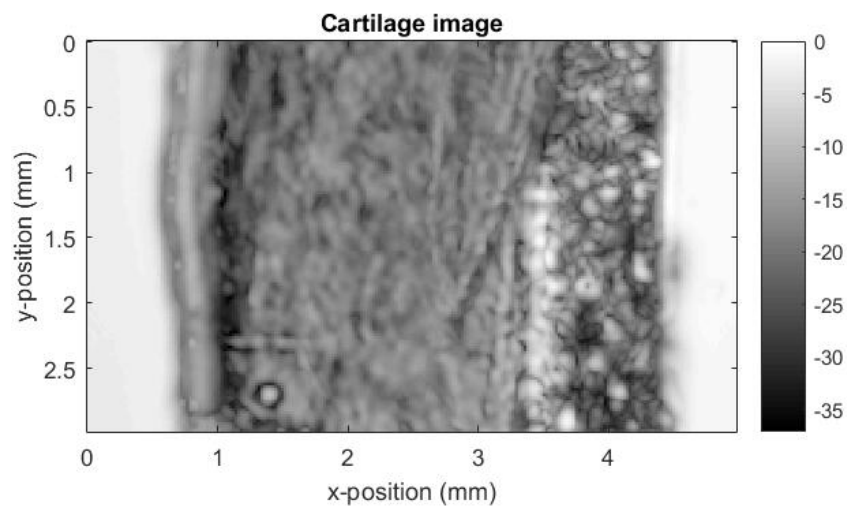


Figure 5.24: Cartilage image

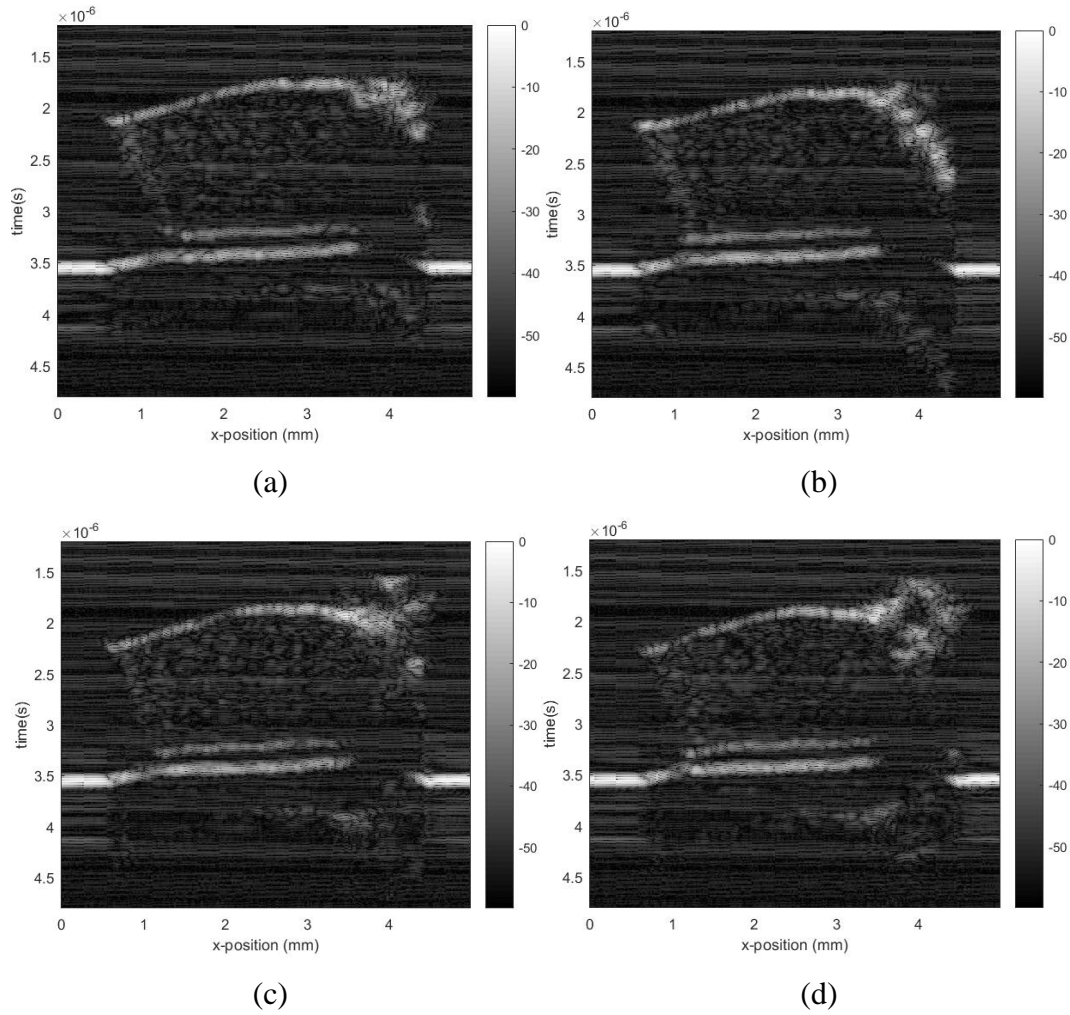


Figure 5.25: B scan. (a)  $y = 0.5 \text{ mm}$ . (b)  $y = 1 \text{ mm}$ . (c)  $y = 1.5 \text{ mm}$ . (d)  $y = 2 \text{ mm}$ .

#### 5.1.4 Case 4

For case 4, the excitation signal is Barker coded signal, and each received signal at corresponding scanning point is averaged 16 times. The length of Barker sequence used to generate Barker coded signal is 13, and the carrier wave is Ricker pulse. The Barker coded signal and its Fourier spectrum are shown in Figure 5.26. The received signals before and after time calibration are shown in Figure 5.27 (a) and (b). For time calibration, the method used for finding the pulse location is center of mass method. The used interpolation method is cubic spline. Two signals collected from top left and top right scanning points are used to illustrate the performance of the calibration. After calibration, the more part of the main bangs are overlapped which shows that the time calibration works in some degree.



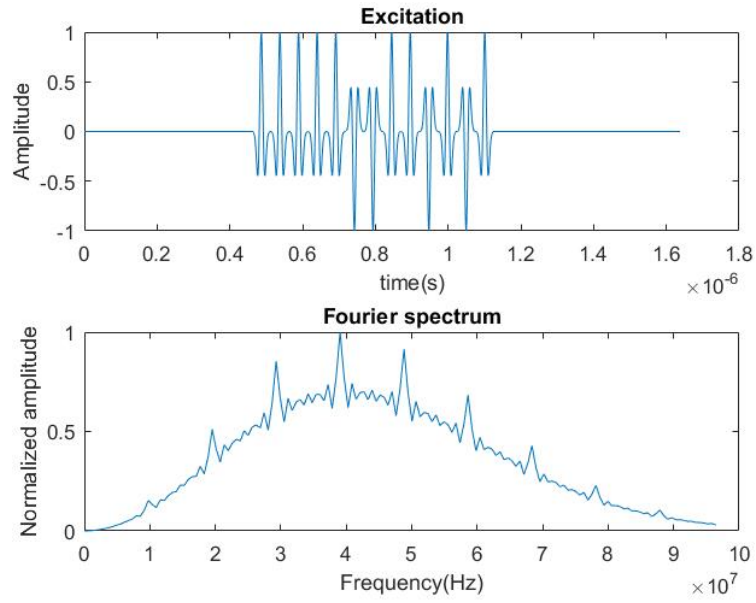
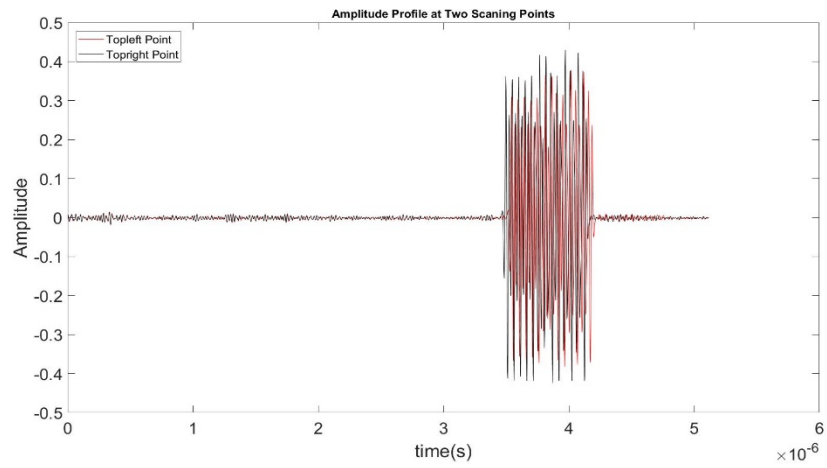
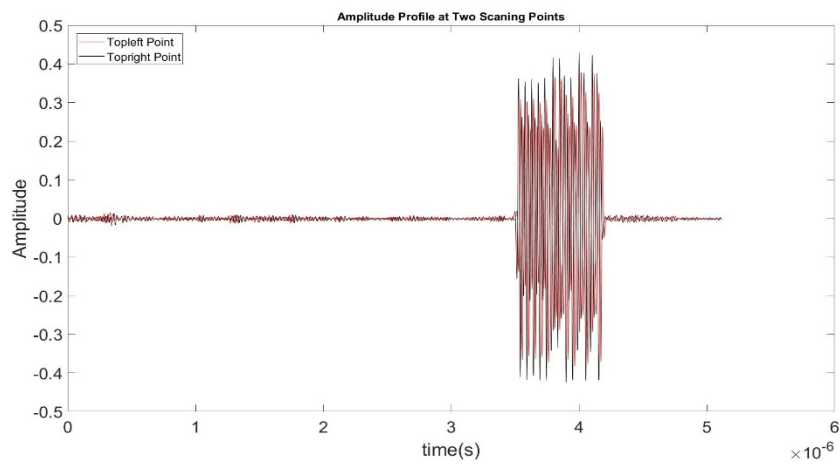


Figure 5.26: Barker coded signal in time and Fourier domain



(a)



(b)

Figure 5.27: Time calibration. (a) Before calibration. (b) After calibration.

In case 4 both Wiener filter and Matched filter are used to decode. For matched filtering method, decoding can be applied in time domain or Fourier domain. Both excitation signal and reflected signal from areas without cartilage sample can also be used as matching template. There therefore are four different situations of matched filtering.

For the situations that the excitation signal is used as template, the signal scanned at first scanning point and its corresponding filtered signals are shown in Figure 5.28 (a) and the signal scanned at central scanning point and its corresponding filtered signals are shown in Figure 5.28 (b). B scan images generated by filtered signals are shown in Figure 5.30. B scan images are taken at the same positions with case 2. The cartilage image mapped by max value of filtered signals at every scanning point is shown in Figure 5.29.

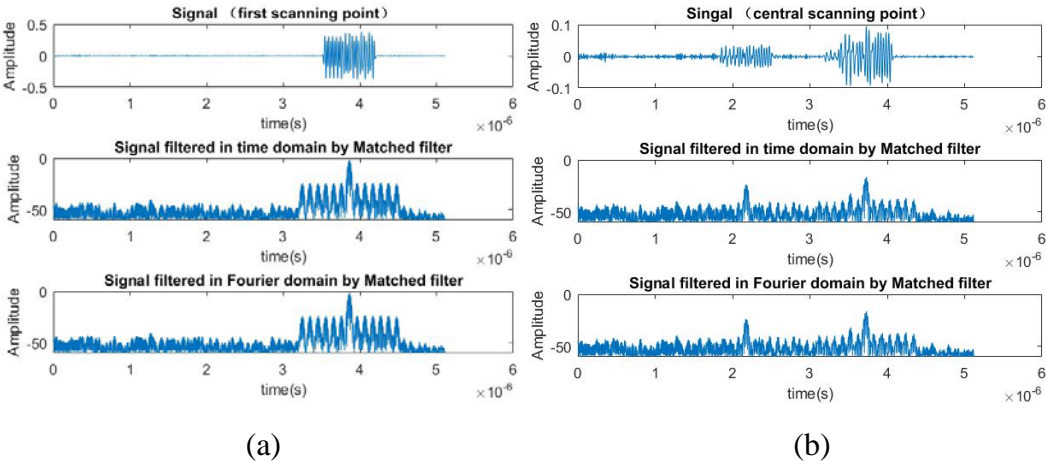


Figure 5.28: Matched filtering. (a) First scanning point. (b) Central scanning point.

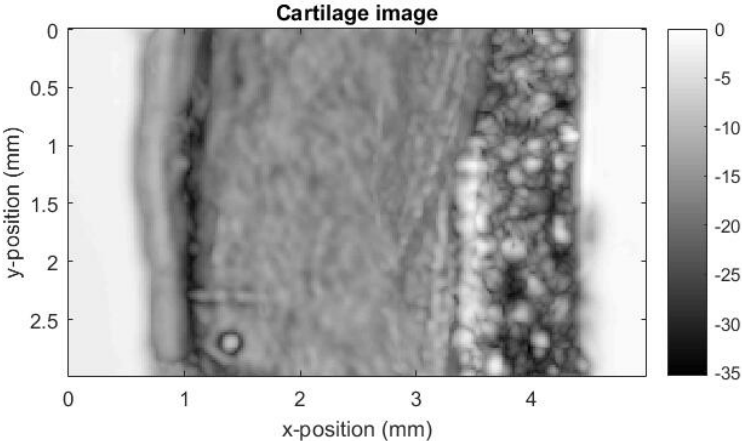


Figure 5.29: Cartilage image



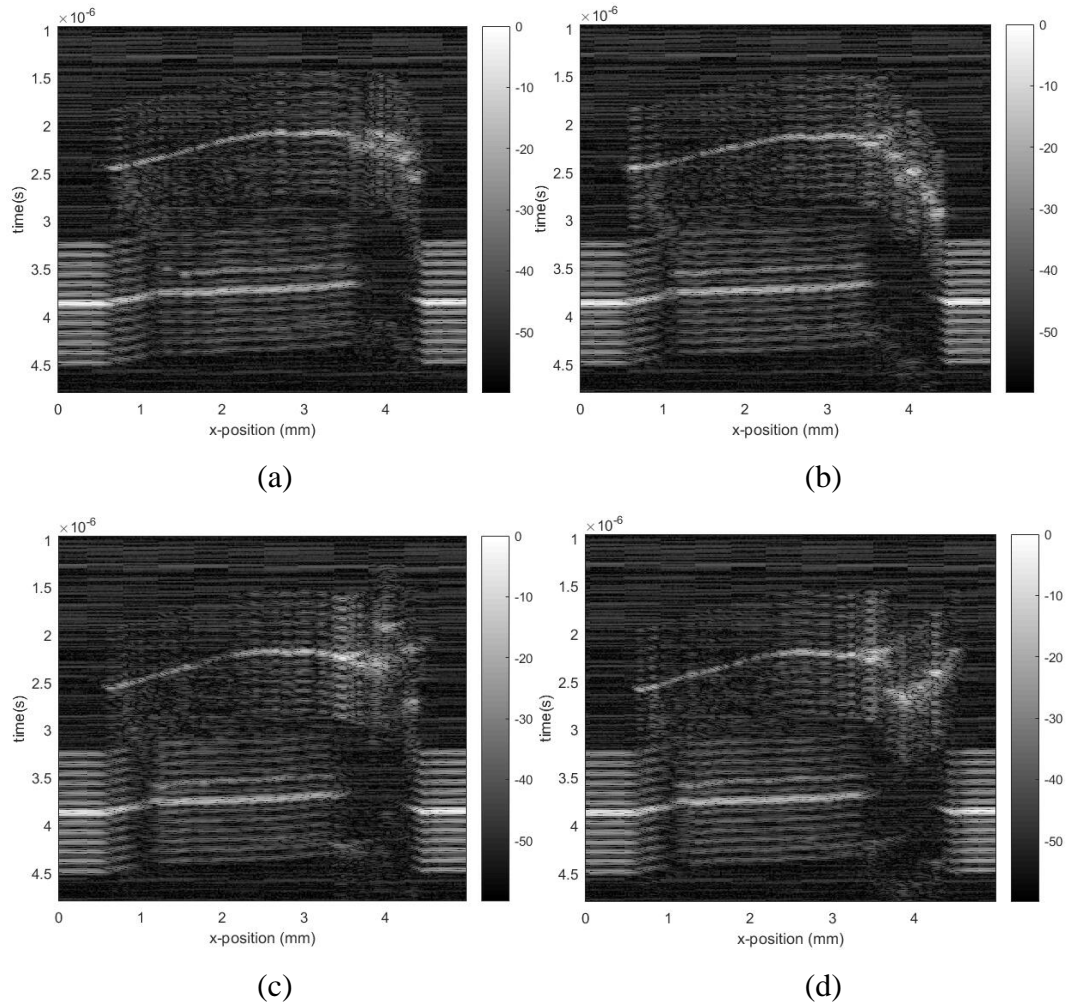


Figure 5.30: B scan. (a)  $y = 0.5 \text{ mm}$ . (b)  $y = 1 \text{ mm}$ . (c)  $y = 1.5 \text{ mm}$ . (d)  $y = 2 \text{ mm}$ .

For the situations that the reflected signal is used as template, only part of the reflected signal is used in practical, and the template is shown in Figure 5.31. The signal collected at first scanning point and its corresponding filtered signals are shown in Figure 5.32 (a). The signal scanned at central scanning point and its corresponding filtered signals are shown in Figure 5.32 (b). B scan images generated by filtered signals are shown in Figure 5.34. B scan images are taken at the same positions with case 2. The cartilage image mapped by max value of filtered signals is shown in Figure 5.33. The SNR of signals filtered by Matched filter with excitation as template is approximate 31.13. The SNR of signals filtered by Matched filter with reflected signal as template is approximate 34.49.

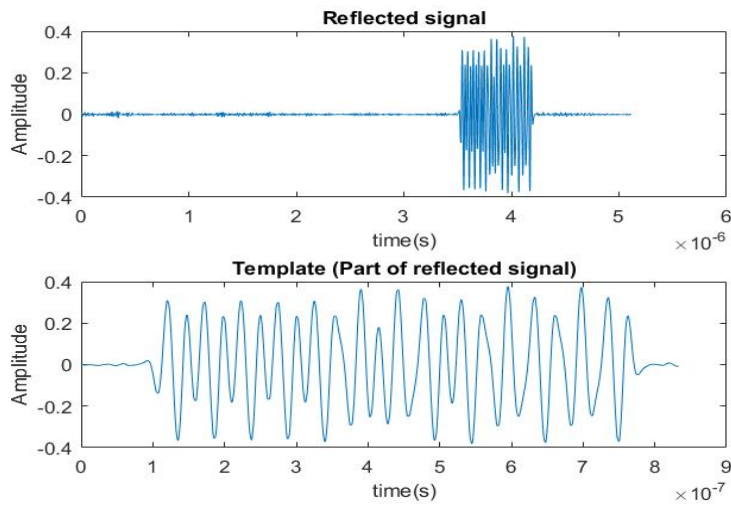


Figure 5.31: Matching template

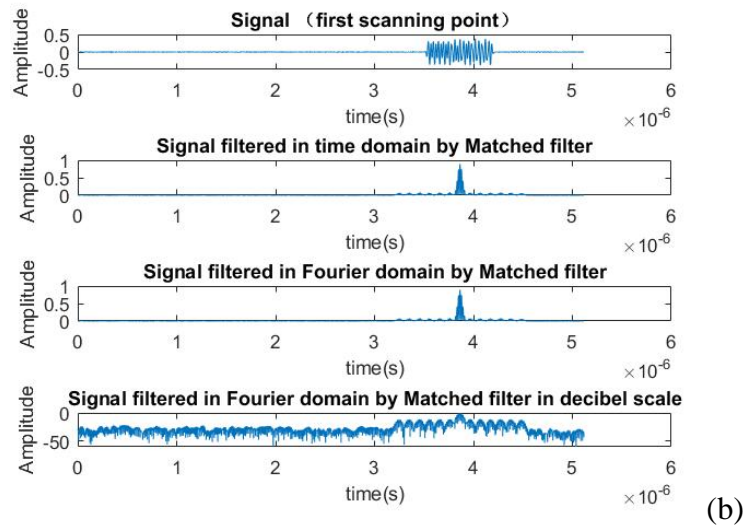
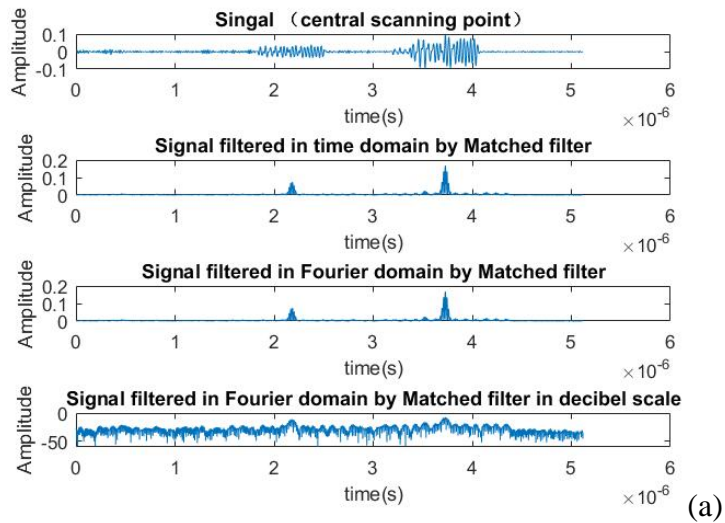


Figure 5.32: Matched filtering. (a) First scanning point. (b) Central scanning point.

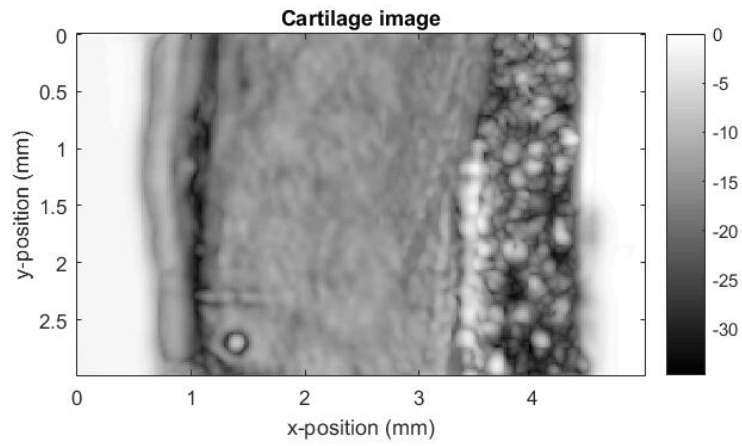


Figure 5.33: Cartilage image

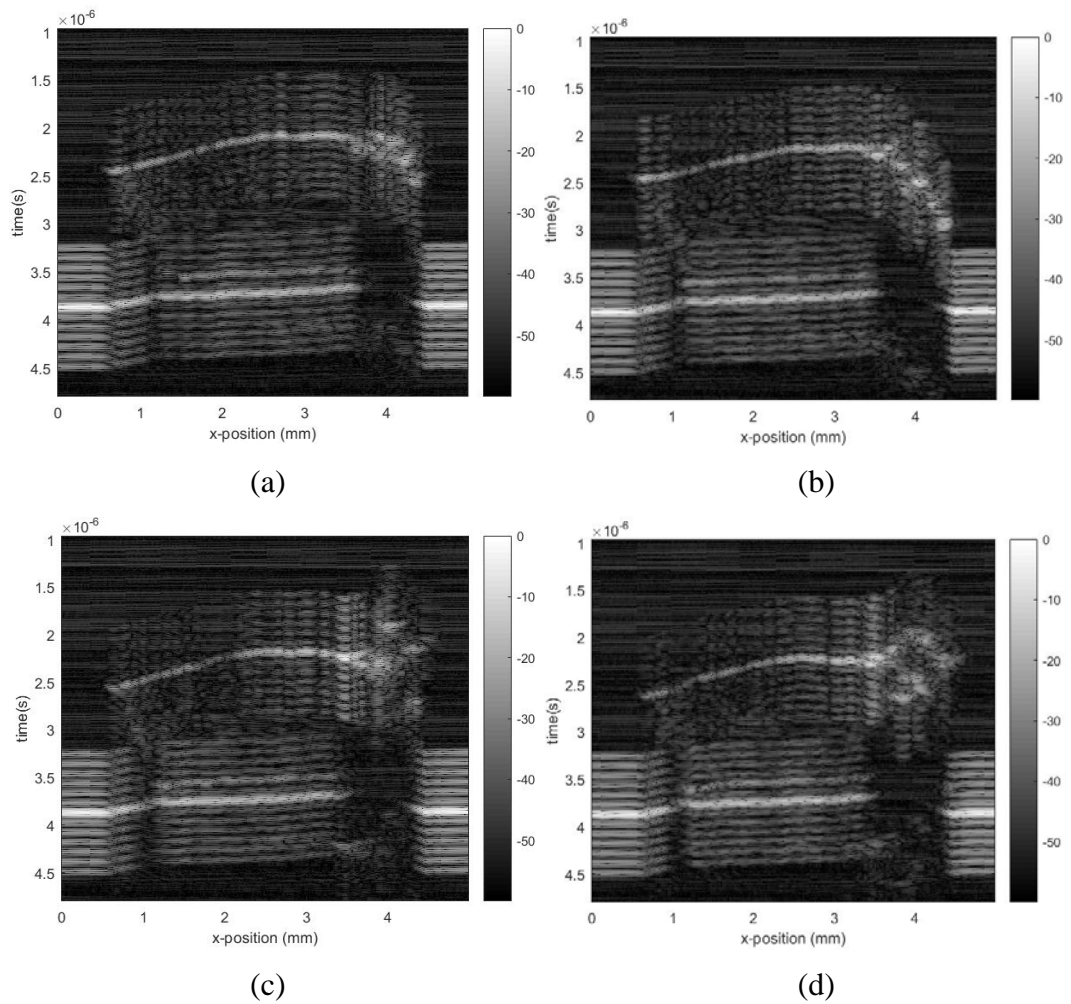


Figure 5.34: B scan. (a)  $y = 0.5 \text{ mm}$ . (b)  $y = 1 \text{ mm}$ . (c)  $y = 1.5 \text{ mm}$ . (d)  $y = 2 \text{ mm}$ .

In case 4 both excitation signal and reflected signal can be used to generate Wiener filter.

There therefore are two situations for Wiener filtering method. For the situation that the excitation signal is used to generate Wiener filter, the signal scanned at first scanning point and its corresponding filtered signals are shown in Figure 5.35. And the signal scanned at central scanning point and its corresponding filtered signals are shown in Figure 5.36. For signals filtered by Wiener filter with  $k_c = 1$  and  $\lambda = 500$ , the corresponding B scan images are shown in Figure 5.38. The cartilage image mapped by max value of filtered signals at every scanning point is shown in Figure 5.37. The SNR of signals filtered by Wiener filter with  $k_c = 1$  and  $\lambda = 500$  for this situation is approximate 31.28.

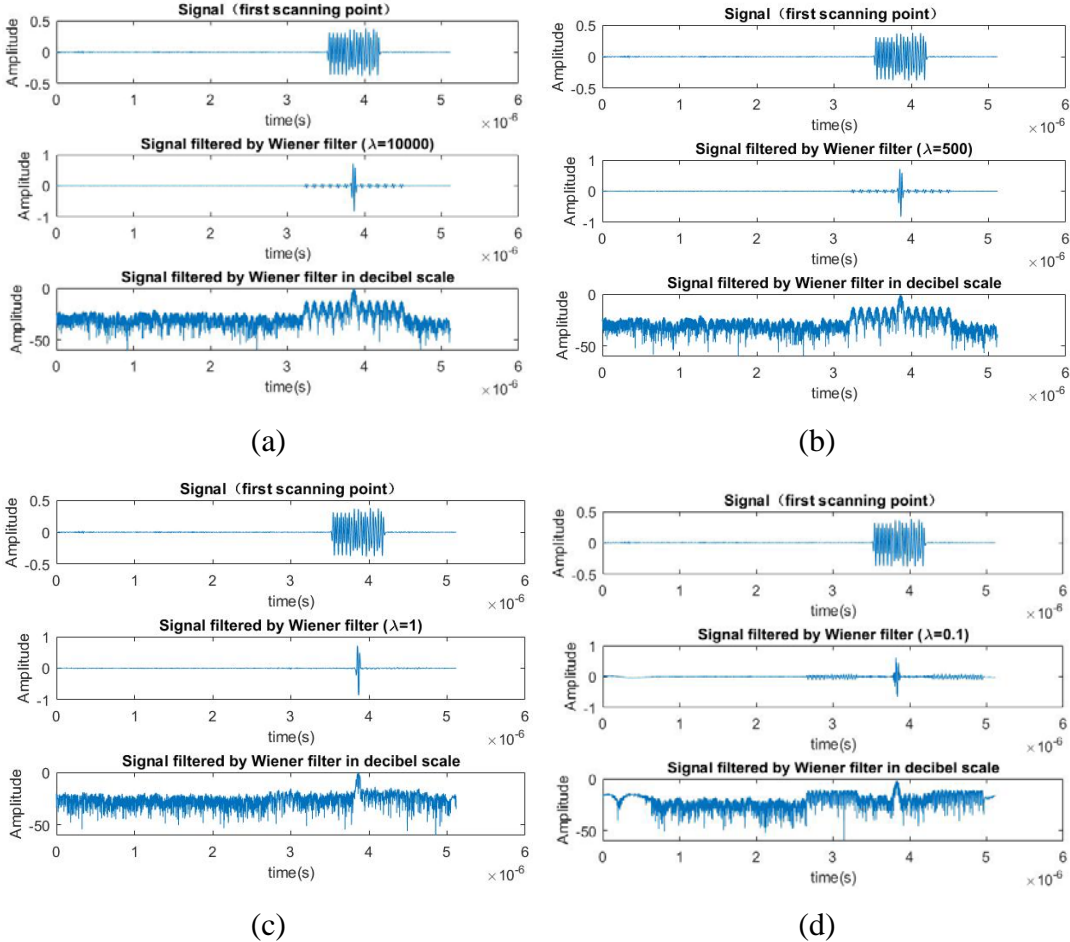


Figure 5.35: Filtered signals of first scanning point. (a)  $\lambda = 10000$ . (b)  $\lambda = 500$ .  
(c)  $\lambda = 1$ . (d)  $\lambda = 0.1$ .

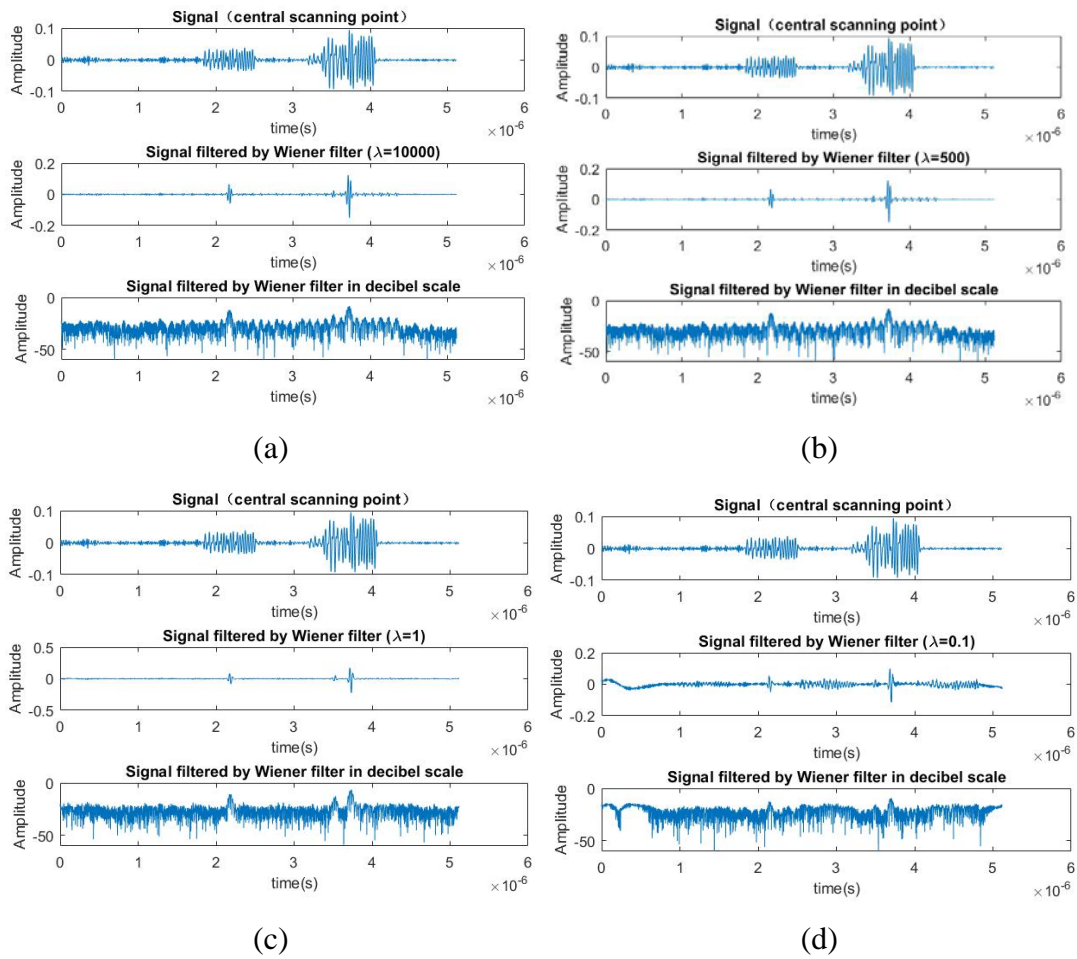


Figure 5.36: Filtered signals of central scanning point. (a)  $\lambda = 10000$ . (b)  $\lambda = 500$ . (c)  $\lambda = 1$ . (d)  $\lambda = 0.1$ .

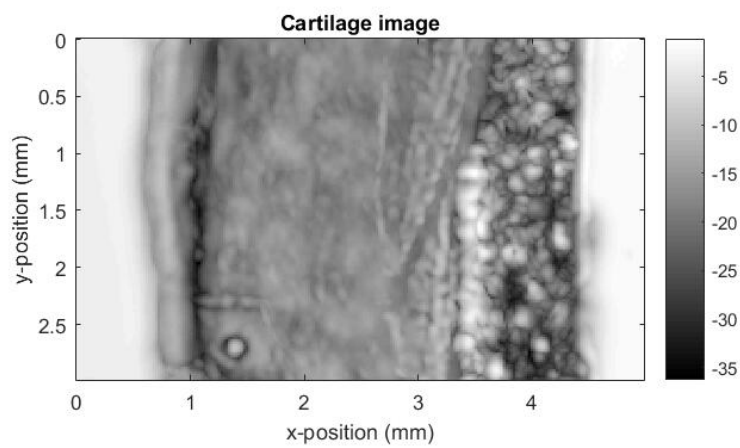


Figure 5.37: Cartilage image

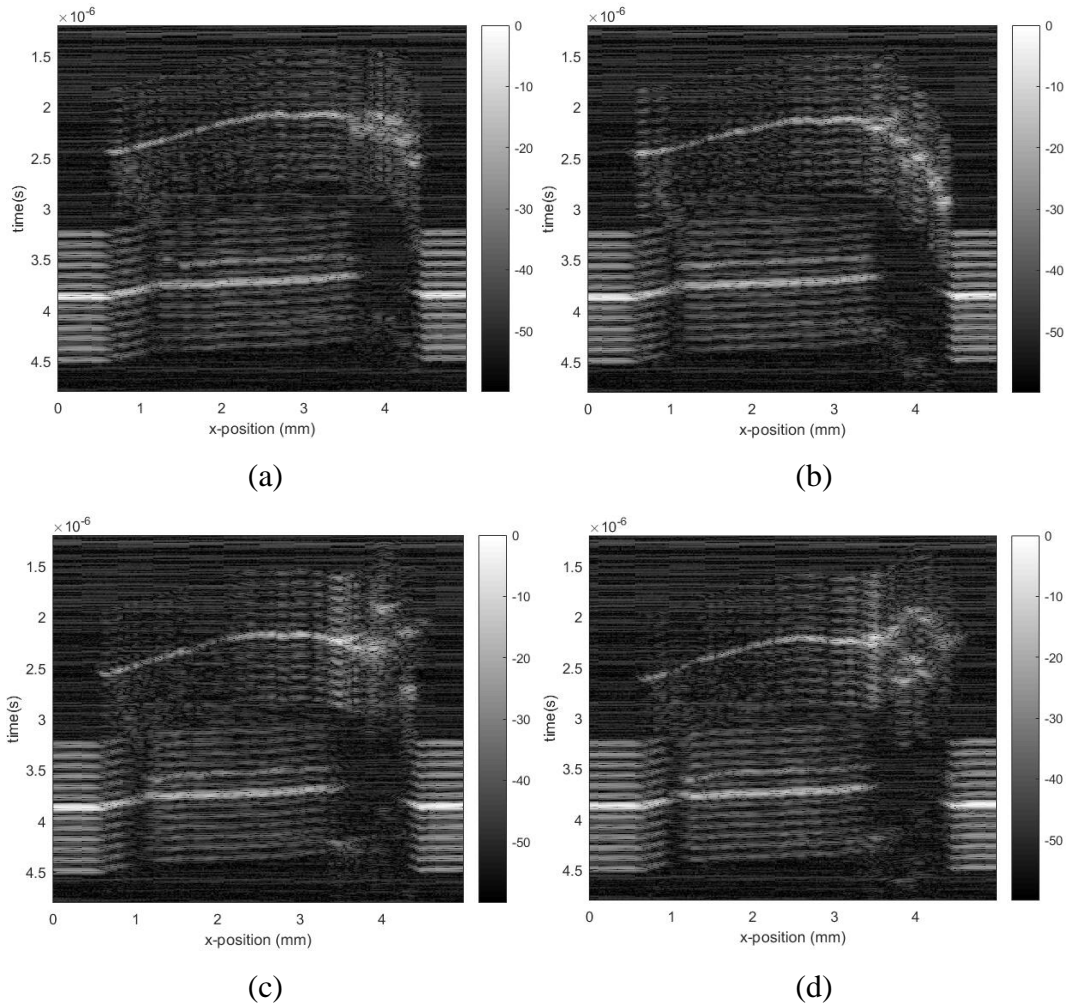


Figure 5.38: B scan. (a)  $y = 0.5 \text{ mm}$ . (b)  $y = 1 \text{ mm}$ . (c)  $y = 1.5 \text{ mm}$ . (d)  $y = 2 \text{ mm}$ .

For the situation that the reflected signal is used to generate Wiener filter. The signal collected at first scanning point and its corresponding filtered signals are shown in Figure 5.39. The signal scanned at central scanning point and its corresponding filtered signals are shown in Figure 5.40. For signals filtered by Wiener filter with  $k_c = 1$  and  $\lambda = 500$ , the corresponding B scan images are shown in Figure 5.42. The cartilage image mapped by max value of filtered signals at every scanning point is shown in Figure 5.41. The SNR of signals filtered by Wiener filter with  $k_c = 1$  and  $\lambda = 500$  for this situation is approximate 34.57.



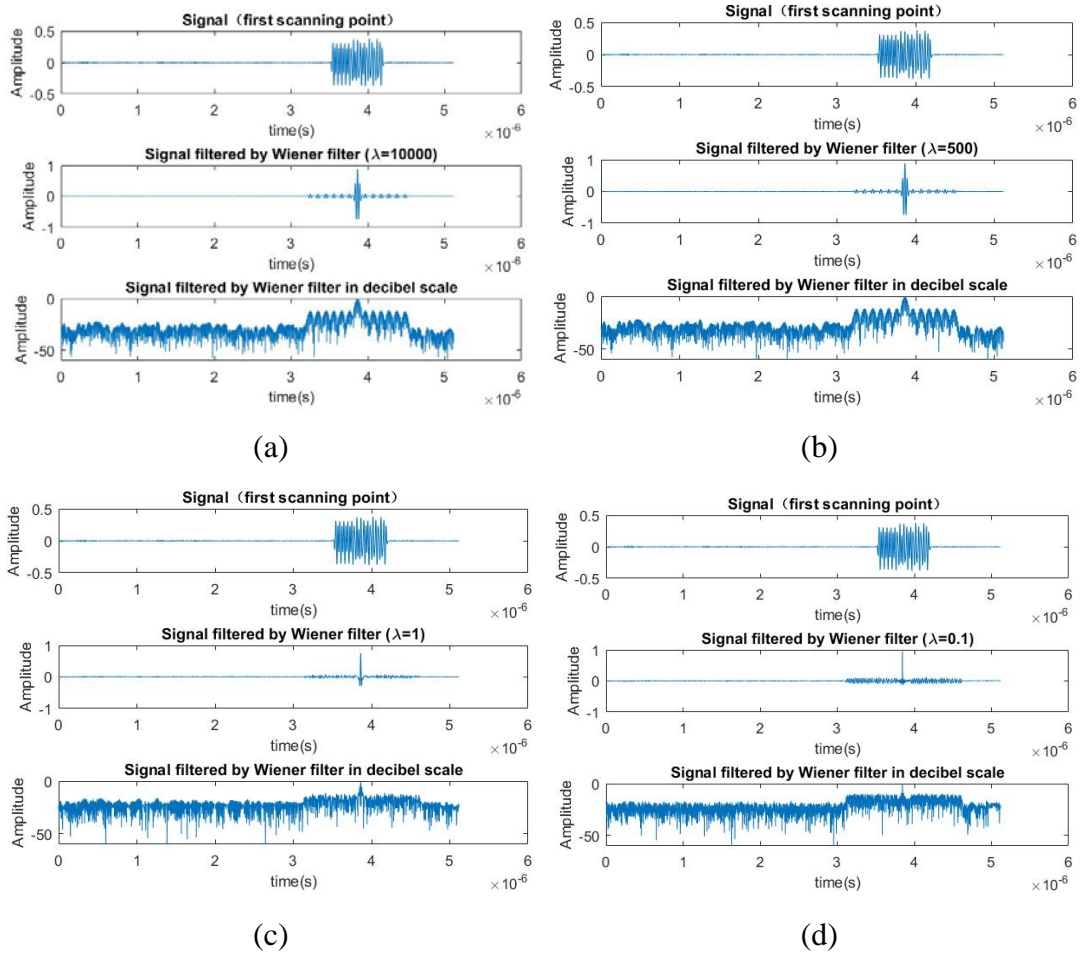


Figure 5.39: Filtered signals of first scanning point. (a)  $\lambda = 10000$ . (b)  $\lambda = 500$ .  
(c)  $\lambda = 1$ . (d)  $\lambda = 0.1$ .

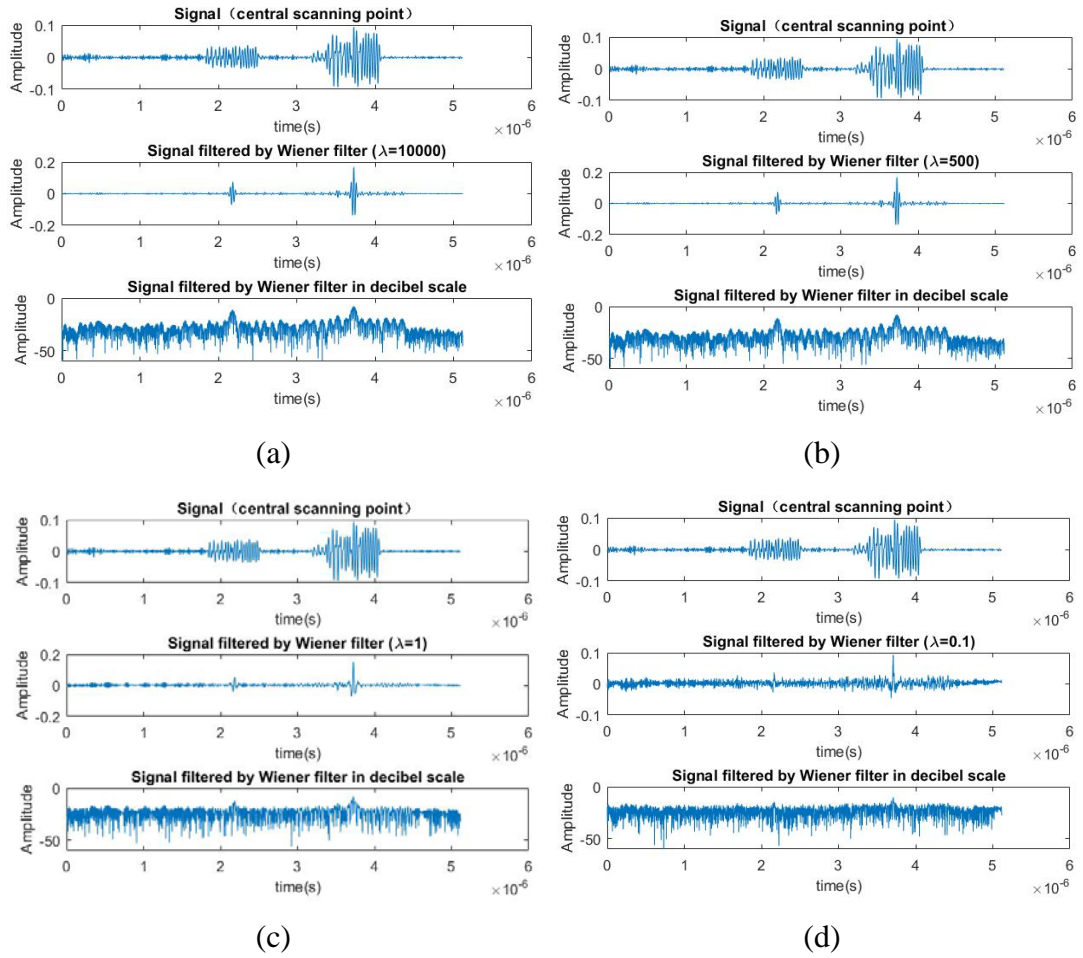


Figure 5.40: Filtered signals of central scanning point. (a)  $\lambda = 10000$ . (b)  $\lambda = 500$ . (c)  $\lambda = 1$ . (d)  $\lambda = 0.1$ .

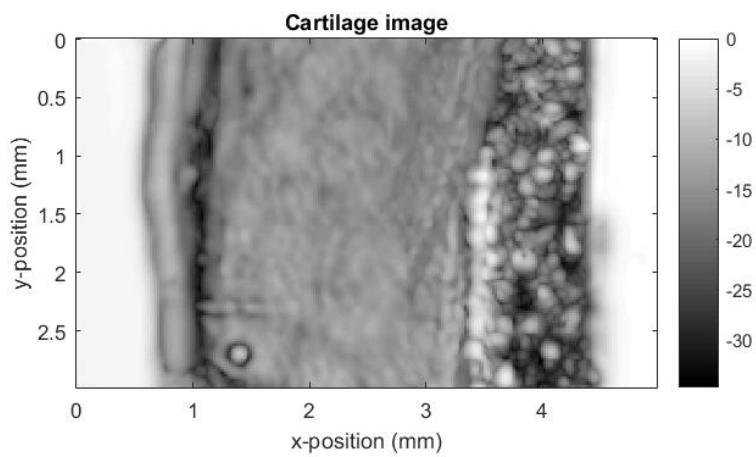


Figure 5.41: Cartilage image



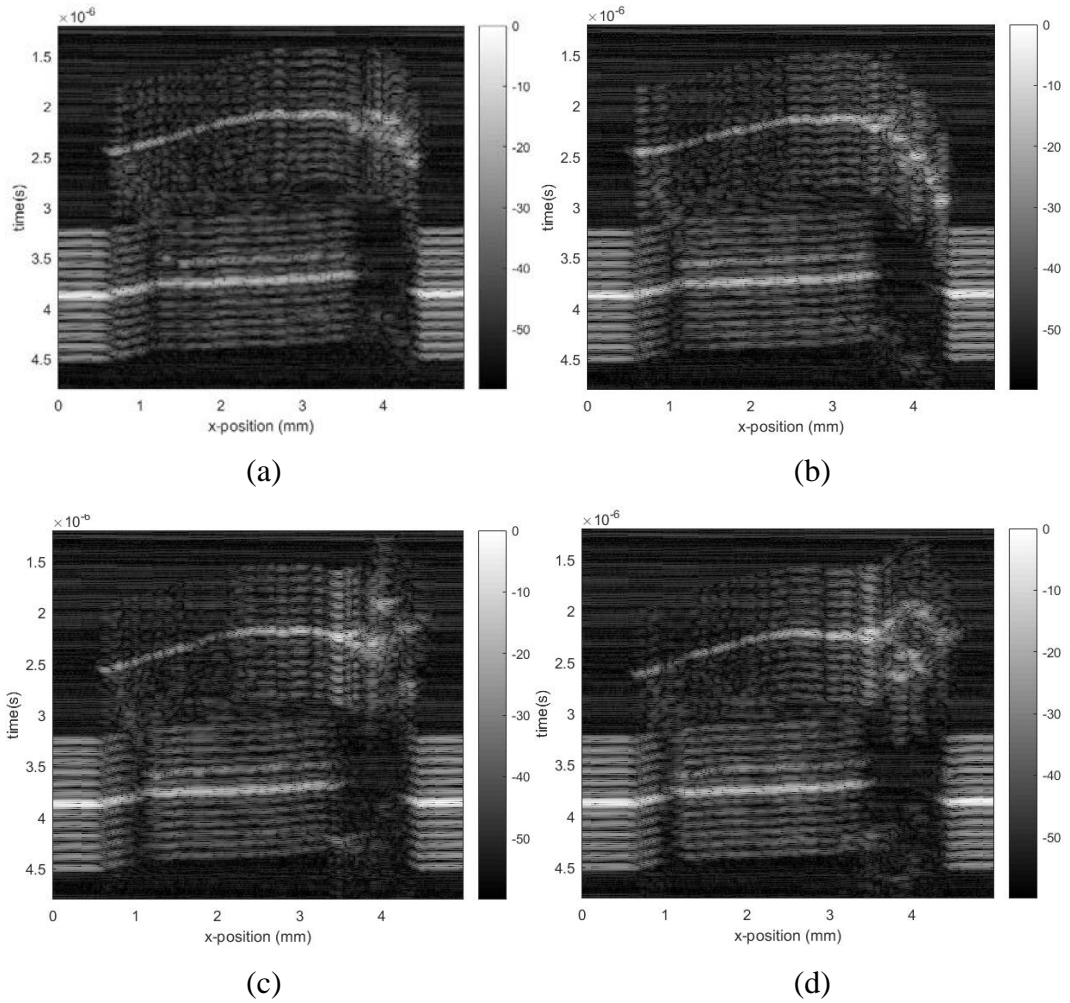


Figure 5.42: B scan. (a)  $y = 0.5 \text{ mm}$ . (b)  $y = 1 \text{ mm}$ . (c)  $y = 1.5 \text{ mm}$ . (d)  $y = 2 \text{ mm}$ .

## 5.2 Data generated by PVDF transducer

### 5.2.1 Case 5

For case 5, all the experiment conditions are same with that of case 1 except that the used transducer is PVDF transducer. The received signals before and after time calibration are shown in Figure 5.43 (a) and (b). Cartilage image mapped by max value at every scanning point is shown in Figure 5.44. The B scan images are generated from a time window centered around  $3.3 \mu\text{s}$ . B scan images are shown in Figure 5.45. The way of how to compute SNR is same with that of case 1. The SNR is approximate 43.43.

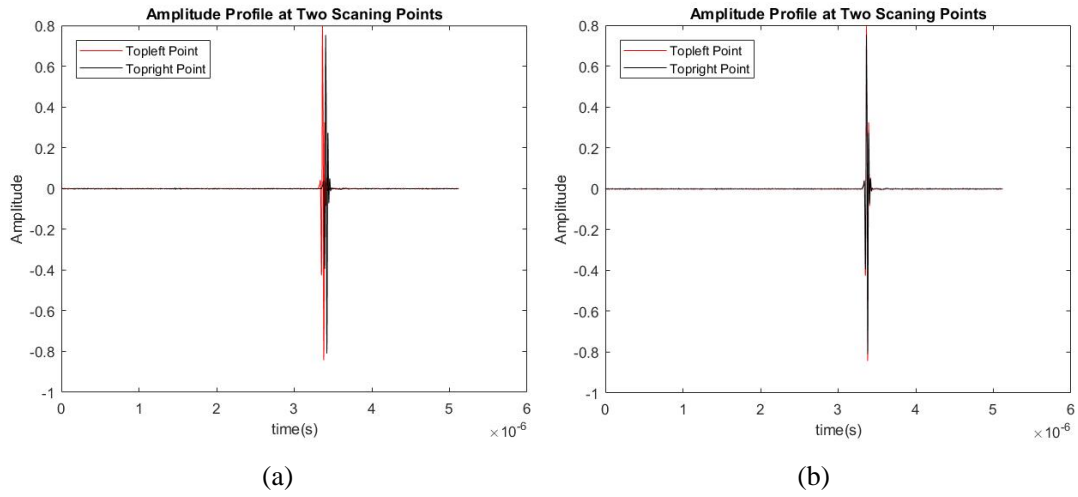


Figure 5.43: Time calibration. (a) Two signals before calibration. (b) Two signals after calibration.

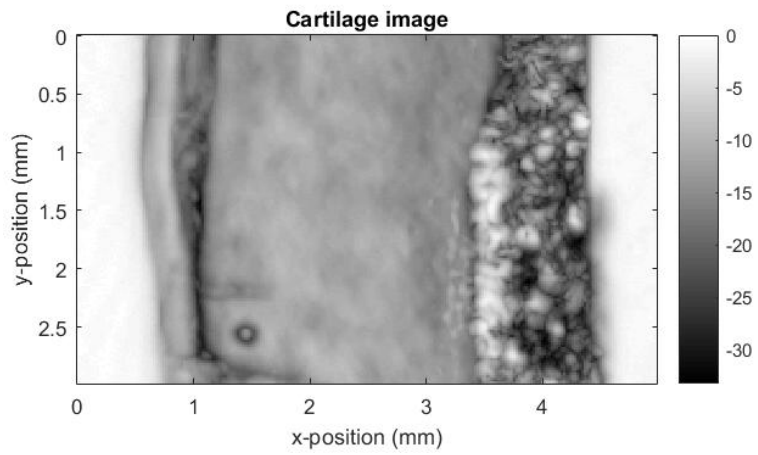


Figure 5.44: Cartilage

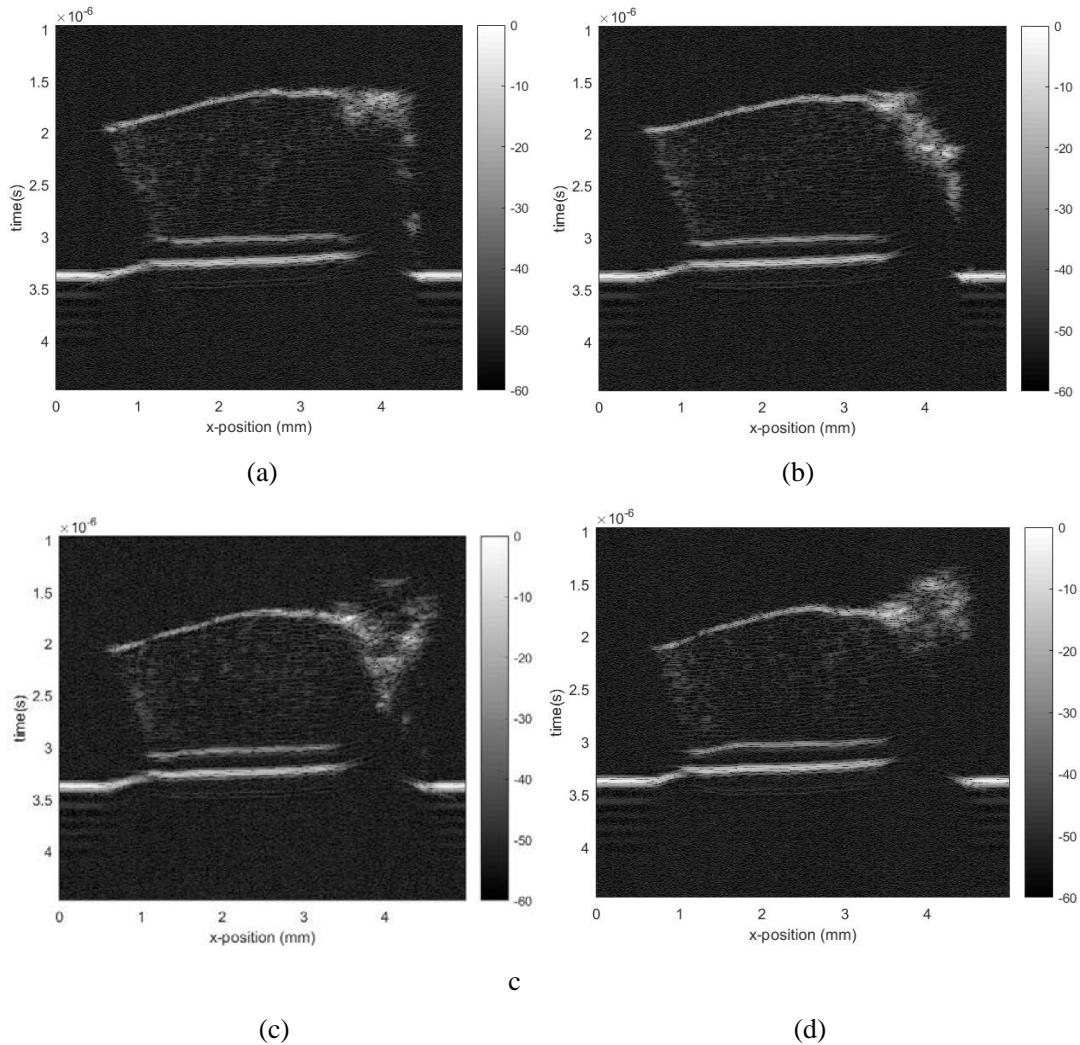


Figure 5.45: B scan. (a)  $y = 0.5 \text{ mm}$ . (b)  $y = 1 \text{ mm}$ . (c)  $y = 1.5 \text{ mm}$ . (d)  $y = 2 \text{ mm}$ .

### 5.2.2 Case 6

For case 6, all the experiment conditions are same with that of case 2 except that the used transducer is PVDF transducer. The signals before and after time calibration are shown in Figure 5.46. For time calibration, maximum method is used to find the pulse location. Cartilage image mapped by max value at every scanning point is shown in Figure 5.58. B scan images are shown in Figure 5.47. The way of how to compute SNR is same with that of case 1. The SNR is approximate 36.97.

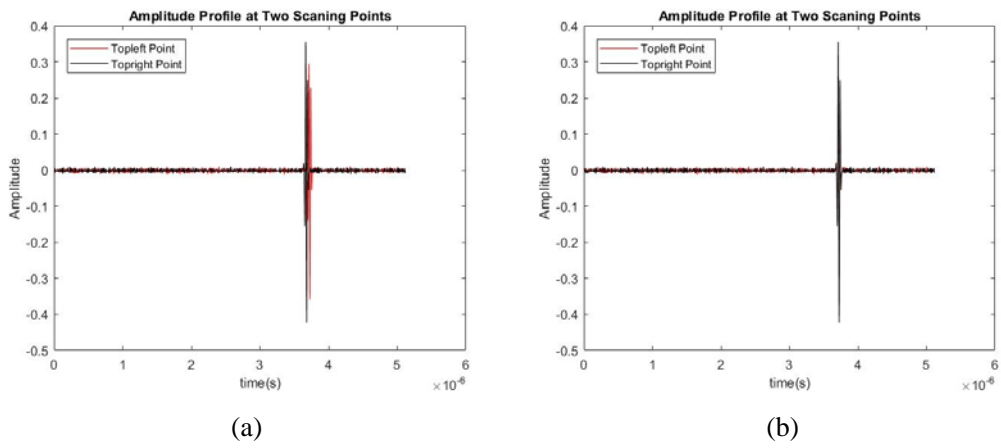


Figure 5.46: Time calibration. (a) Before calibration. (b) After calibration.

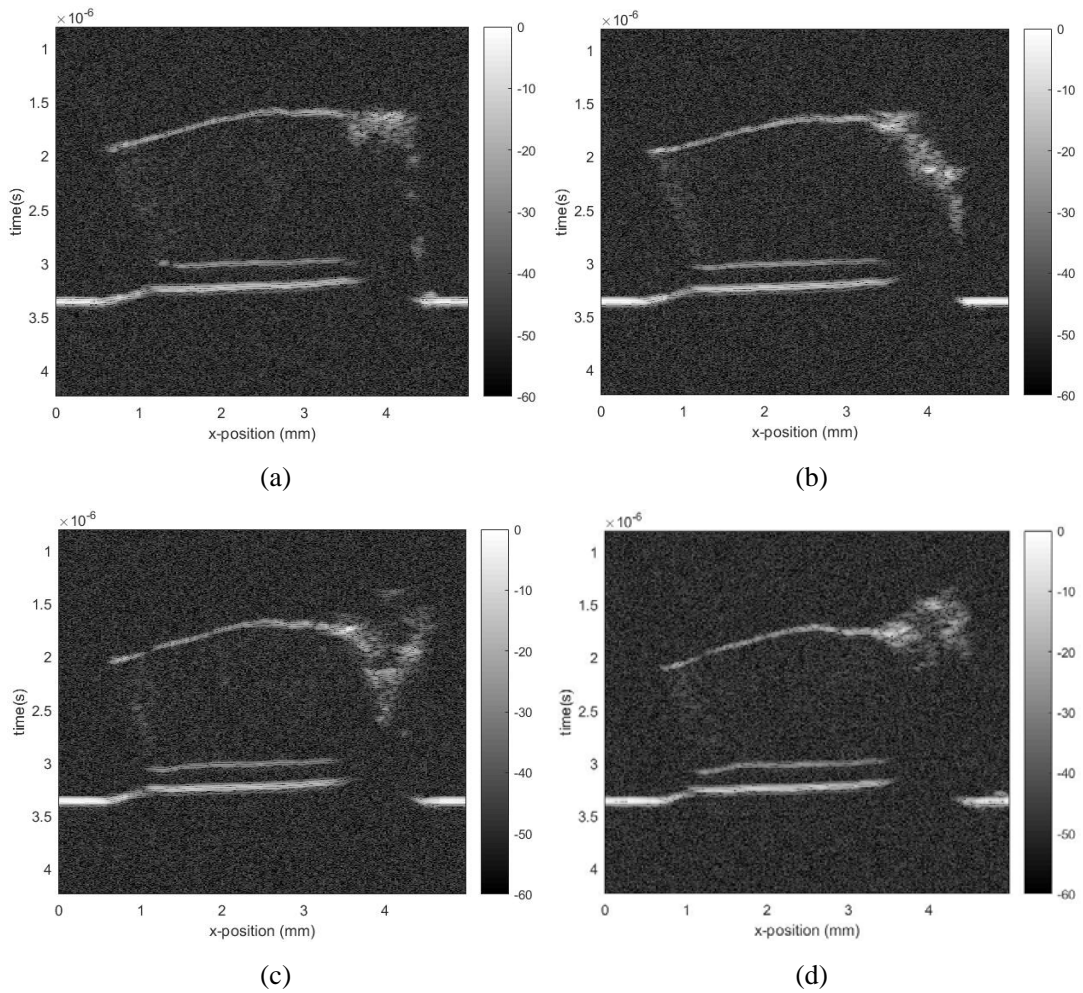


Figure 5.47: B scan. (a) (b) (c) (d) corresponding to  $y = 0.5, 1, 1.5, 2 \text{ mm}$ .

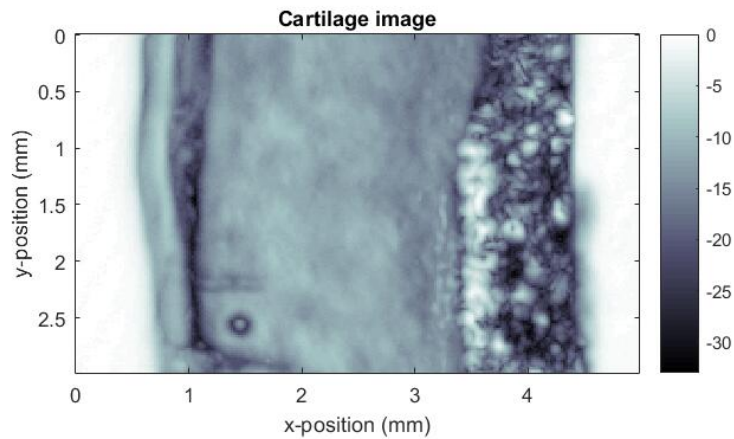


Figure 5.48: Cartilage image

### 5.2.3 Case 7

For case 7, all the experiment conditions are same with that of case 3 except that the used transducer is PVDF transducer. The signals before and after time calibration are shown in Figure 5.49 (a) and (b). For time calibration, the method used for finding the pulse location is center of mass method. The used interpolation method is cubic spline.

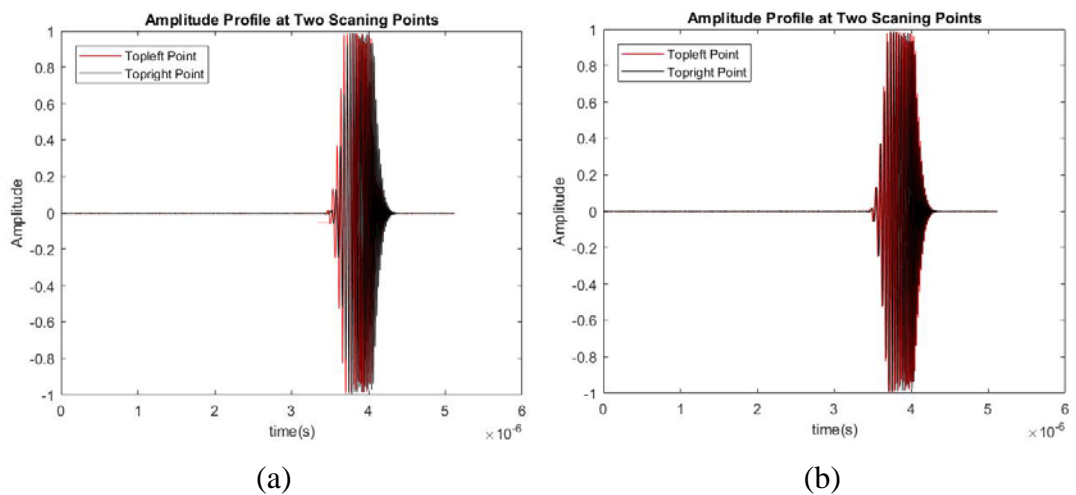


Figure 5.49: Time calibration. (a) Before calibration. (b) After calibration.

In case 7 both Wiener filter and Matched filter are used for decoding. For matched filtering method, decoding can be applied in time domain or Fourier domain. Both excitation signal and reflected signal can be used as matching template. There therefore are four different situations of matched filtering.

For the situations that the excitation signal is used as template, the signal scanned at first scanning point and its corresponding filtered signals are shown in Figure 5.50 (a), and the signal scanned at central scanning point and its corresponding filtered signals are shown in Figure 5.50 (b). B scan images generated by filtered signals are shown in Figure 5.52. The cartilage image mapped by max value of filtered signals at every scanning point is shown in Figure 5.51.

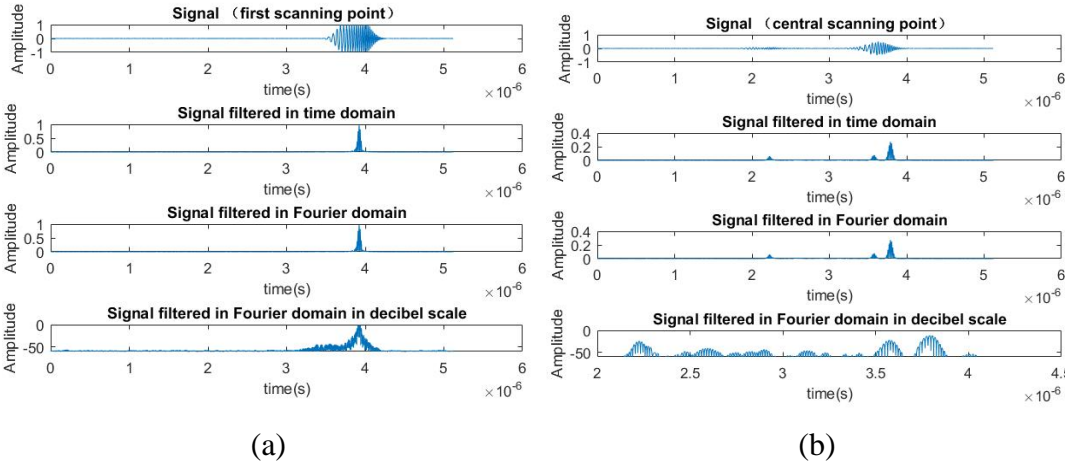


Figure 5.50: Matched filtering. (a) Signal of first scanning point. (b) Signal of central scanning point.

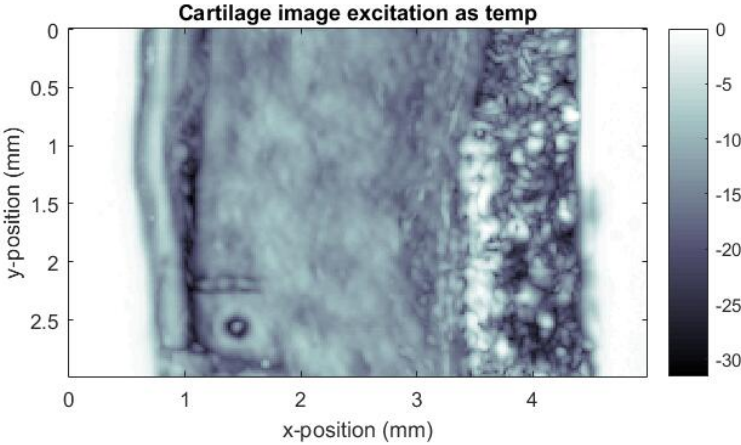


Figure 5.51: Cartilage image



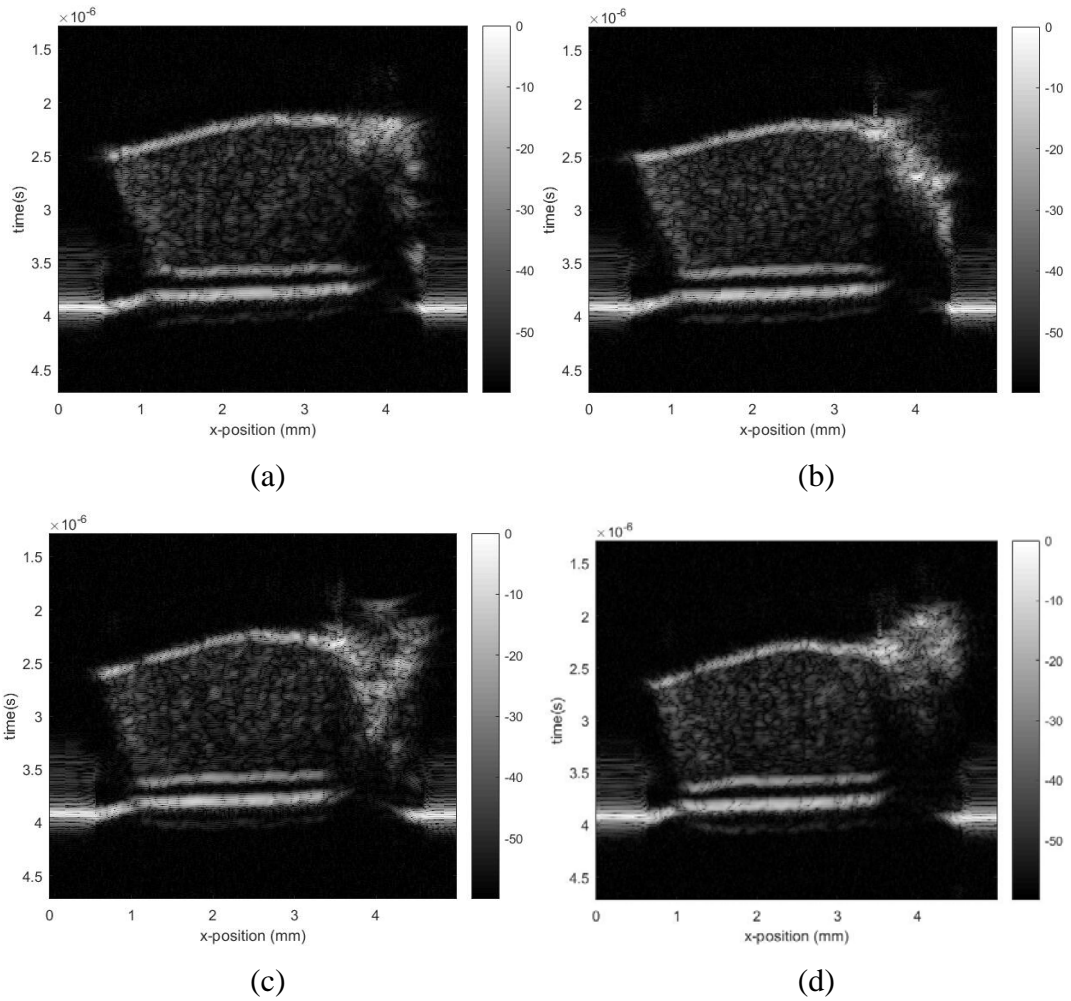


Figure 5.52: B scan. (a)  $y = 0.5 \text{ mm}$ . (b)  $y = 1 \text{ mm}$ . (c)  $y = 1.5 \text{ mm}$ . (d)  $y = 2 \text{ mm}$ .

For the situations that the reflected signal is used as template, part of the reflected signal at first scanning point is used as matching template in practical. The template is shown in Figure 5.53. The signal collected at first scanning point and its corresponding filtered signals are shown in Figure 5.54 (a). The signal scanned at central scanning point and its corresponding filtered signals are shown in Figure 5.54 (b). B scan images generated by filtered signals are shown in Figure 5.56. The cartilage image mapped by max value of filtered signals is shown in Figure 5.55. The SNR before matched filtering is approximate 50.61. The SNR after matched filtering with excitation as filter template is approximate 59.77. The SNR after matched filtering with reflection signal as filter template is approximate 60.35.

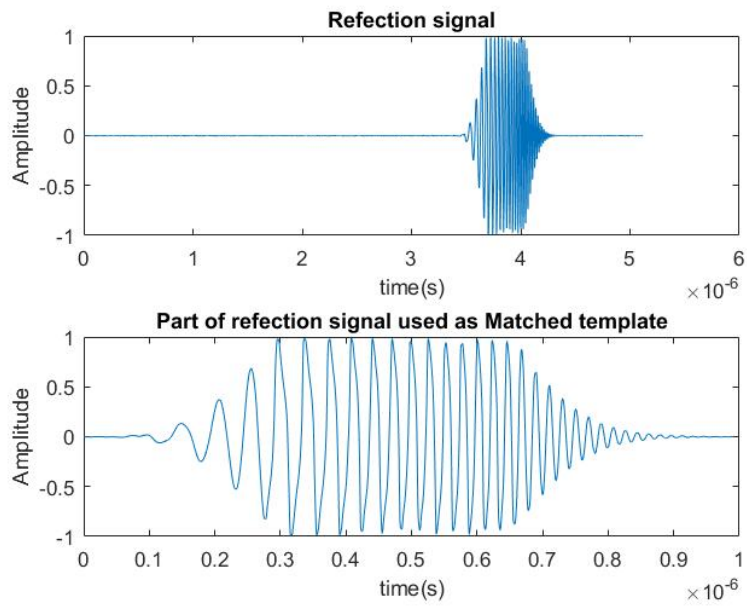


Figure 5.53: Matching template

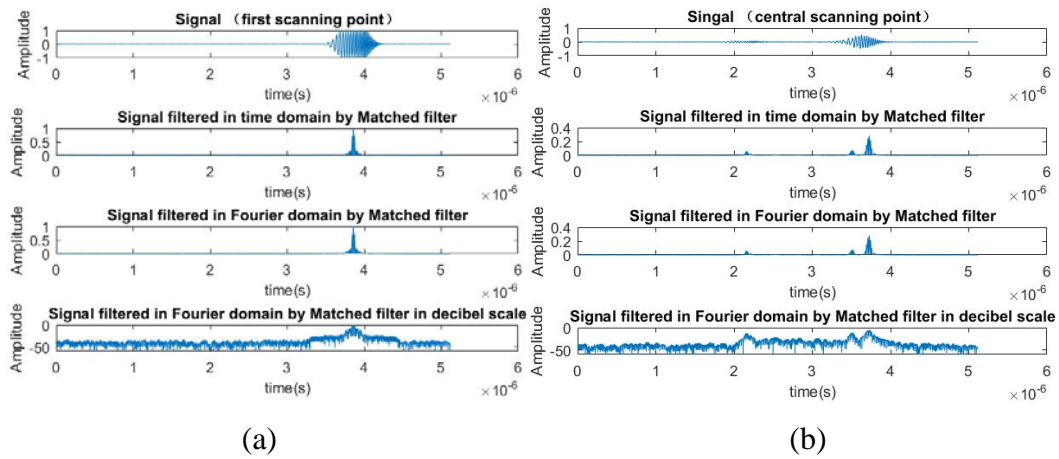


Figure 5.54: Filtered signals. (a) Signals of first scanning point. (b) Signals of central scanning point.



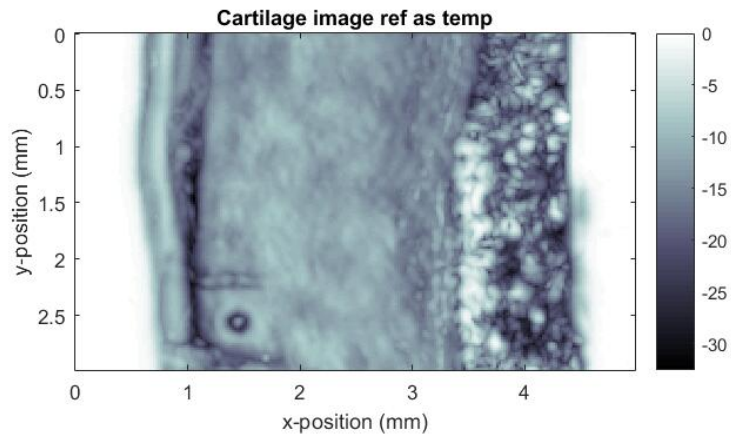


Figure 5.55: Cartilage image

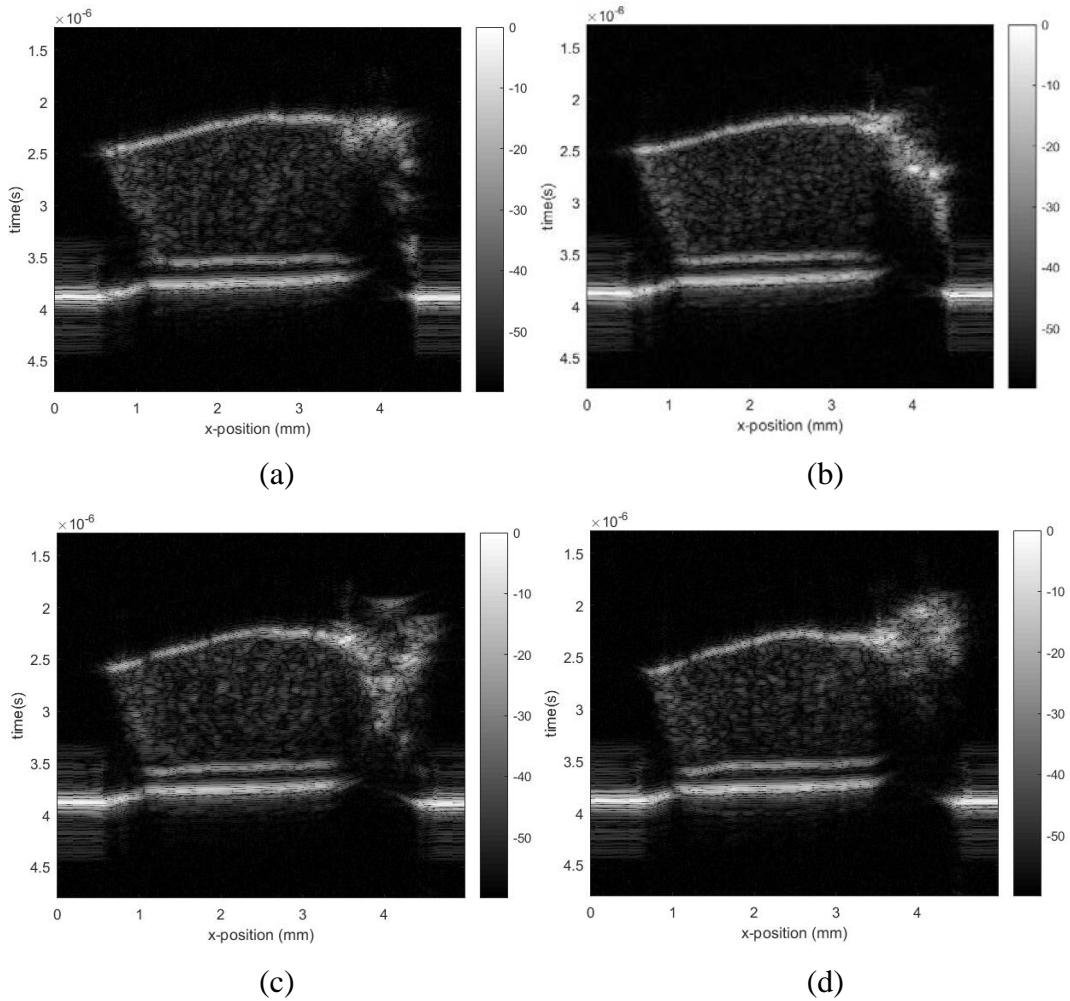


Figure 5.56: B scan. (a)  $y = 0.5 \text{ mm}$ . (b)  $y = 1 \text{ mm}$ . (c)  $y = 1.5 \text{ mm}$ . (d)  $y = 2 \text{ mm}$ .

For Wiener filtering in case 7, both excitation signal and reflected signal can be used to generate Wiener filter. There therefore are two situations for Wiener filtering. For the situation that the excitation signal is used to generate Wiener filter, the signal scanned at first scanning point and its corresponding filtered signals are shown in Figure 5.57. And the signal scanned at central scanning point and its corresponding filtered signals are shown in Figure 5.58. For signals filtered by Wiener filter with  $k_c = 1$  and  $\lambda = 500$ , the corresponding B scan images are shown in Figure 5.60. The cartilage image mapped by max value of filtered signals at every scanning point is shown in Figure 5.59. The SNR of signals filtered by Wiener filter with  $k_c = 1$  and  $\lambda = 500$  for this situation is approximate 61.23.

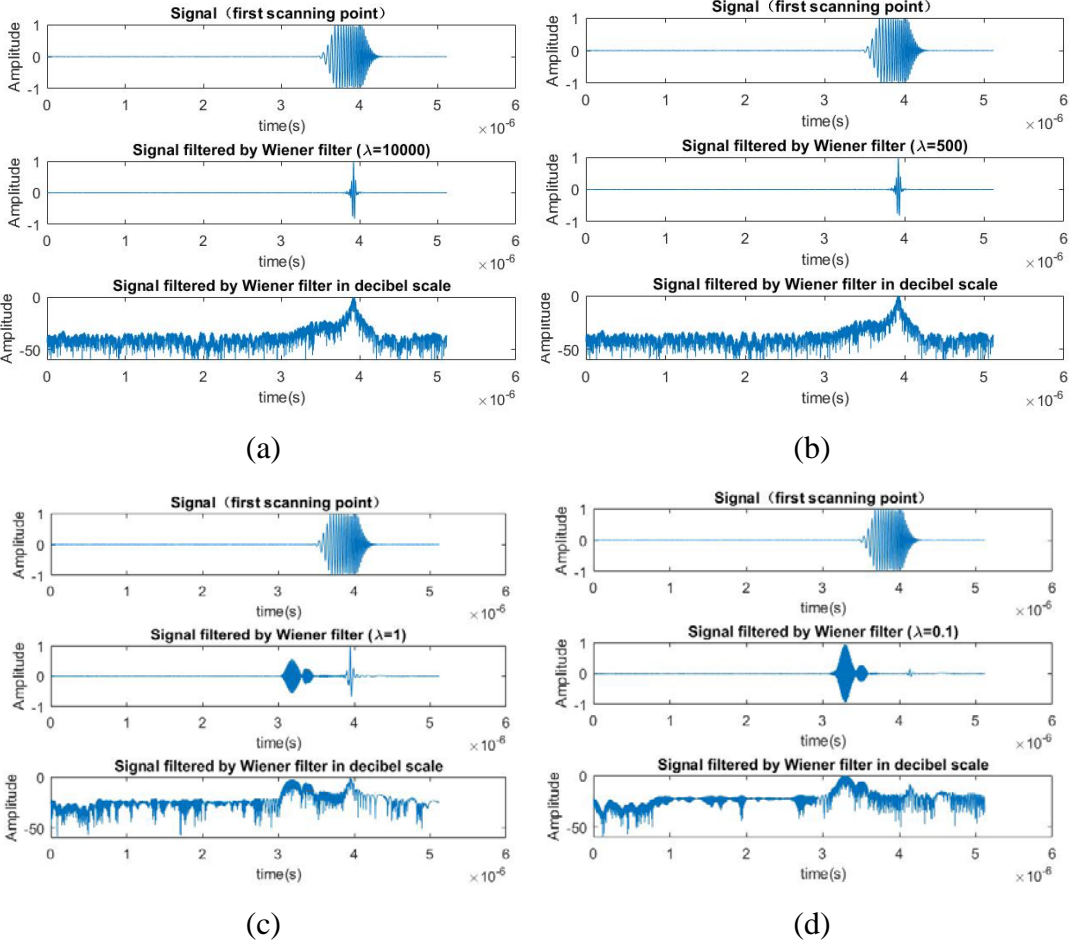


Figure 5.57: Filtered signals of first scanning point. (a)  $\lambda = 10000$ . (b)  $\lambda = 500$ . (c)  $\lambda = 1$ . (d)  $\lambda = 0.1$ .

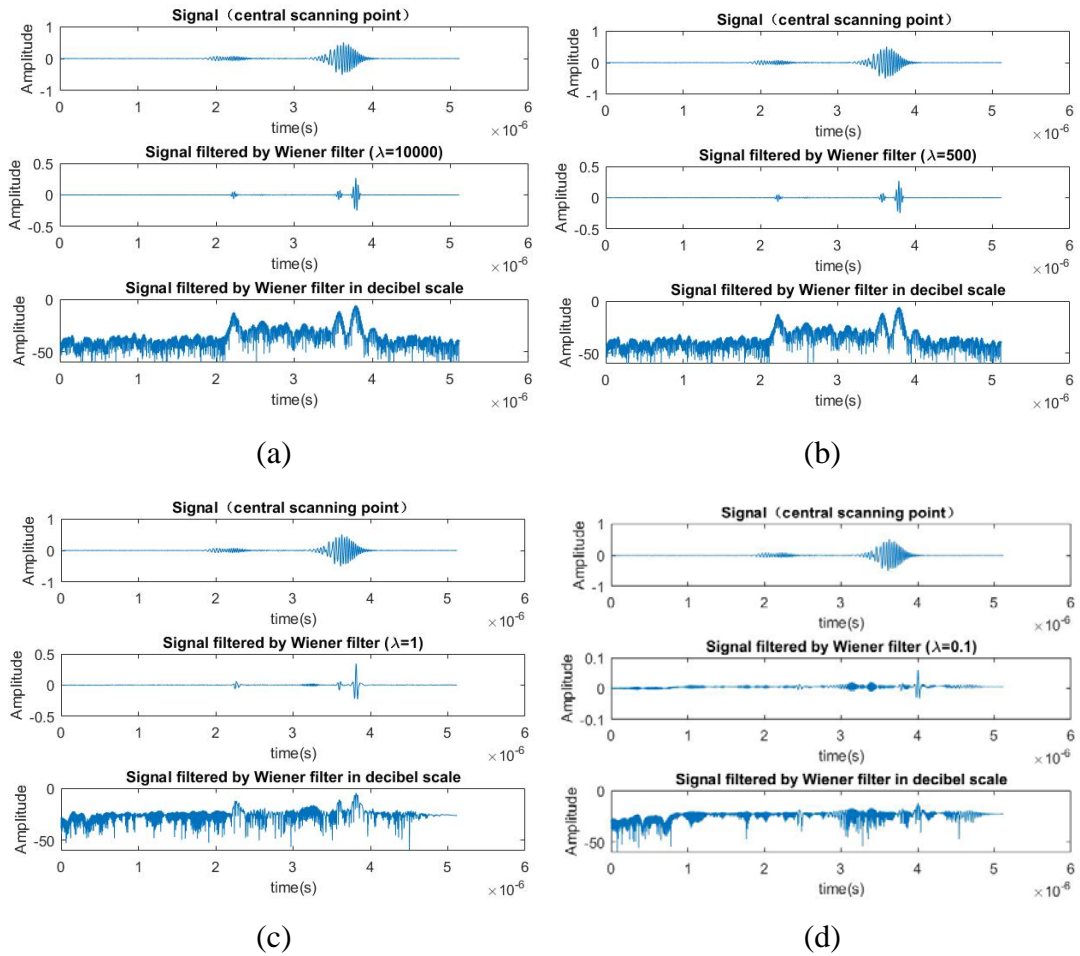


Figure 5.58: Filtered signals of central scanning point. (a)  $\lambda = 10000$ . (b)  $\lambda = 500$ . (c)  $\lambda = 1$ . (d)  $\lambda = 0.1$ .

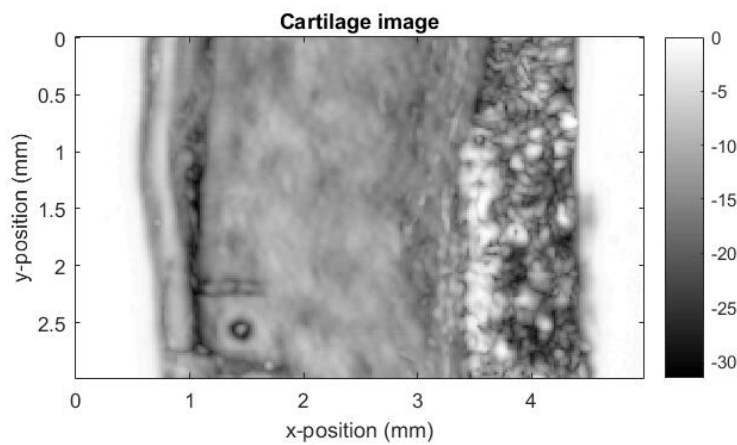


Figure 5.59: Cartilage image

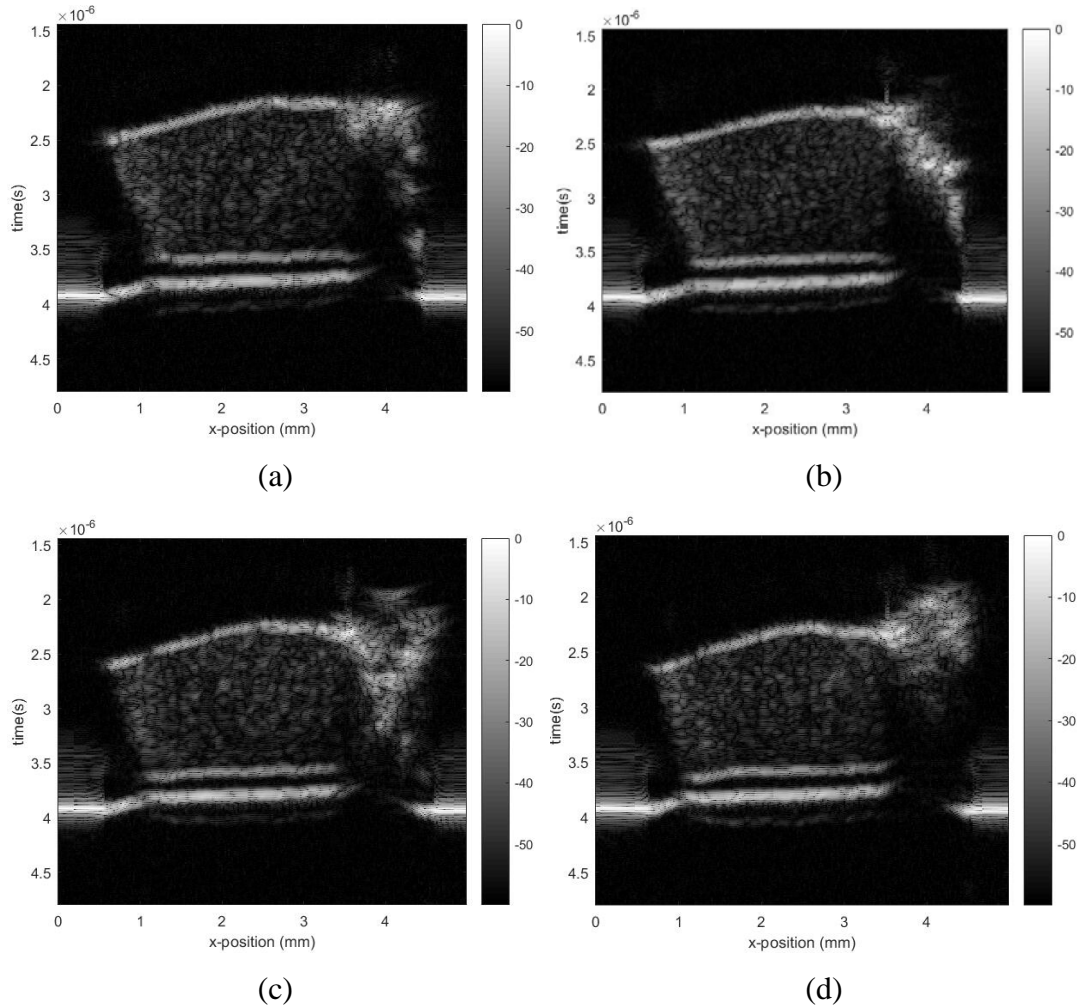


Figure 5.60: B scan. (a)  $y = 0.5 \text{ mm}$ . (b)  $y = 1 \text{ mm}$ . (c)  $y = 1.5 \text{ mm}$ . (d)  $y = 2 \text{ mm}$ .

For the situation that the reflected signal is used to generate Wiener filter. The signal collected at first scanning point and its corresponding filtered signals are shown in Figure 5.61. The signal scanned at central scanning point and its corresponding filtered signals are shown in Figure 5.62. For signals filtered by Wiener filter with  $k_c = 1$  and  $\lambda = 500$ , the corresponding B scan images are shown in Figure 5.64. The cartilage image mapped by max value of filtered signals at every scanning point is shown in Figure 5.63. The SNR of signals filtered by Wiener filter with  $k_c = 1$  and  $\lambda = 500$  for this situation is approximate 60.99.

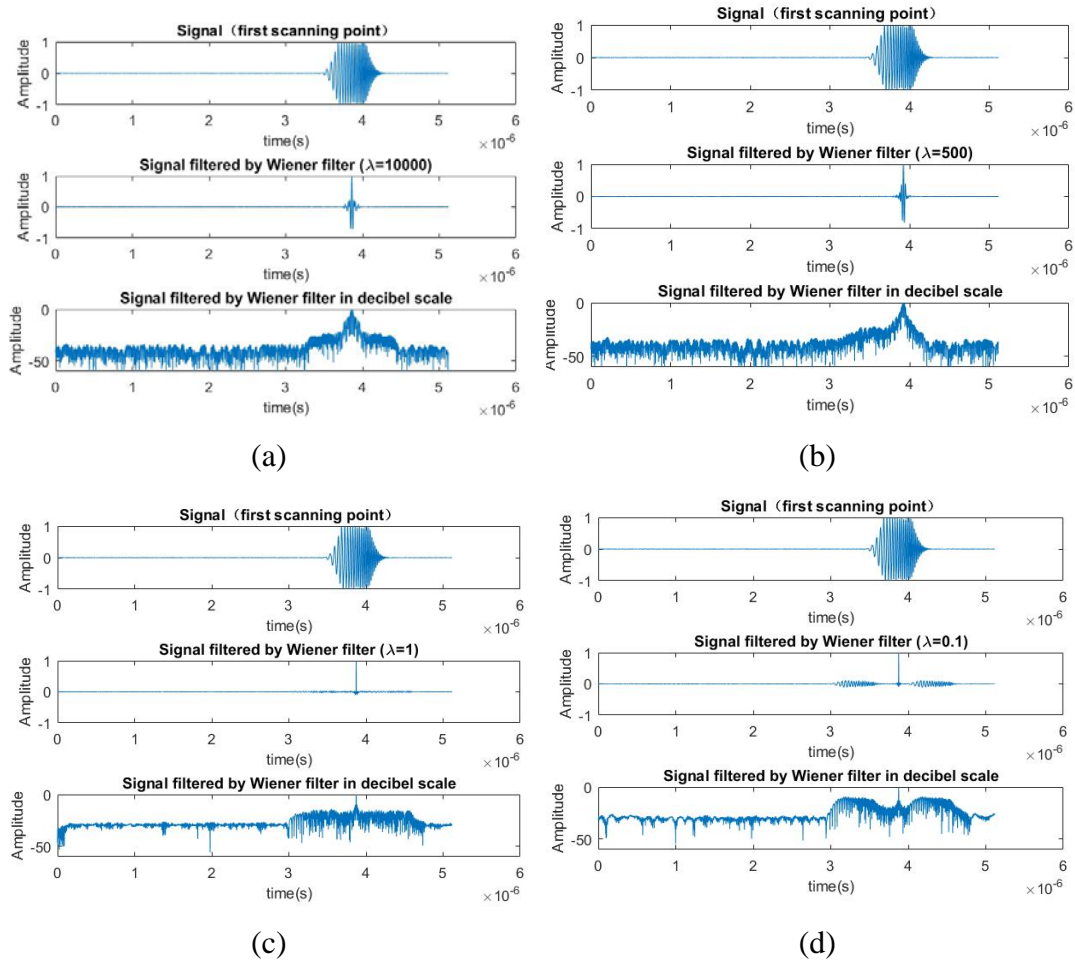


Figure 5.61: Filtered signals of first scanning point. (a)  $\lambda = 10000$ . (b)  $\lambda = 500$ .  
(c)  $\lambda = 1$ . (d)  $\lambda = 0.1$ .

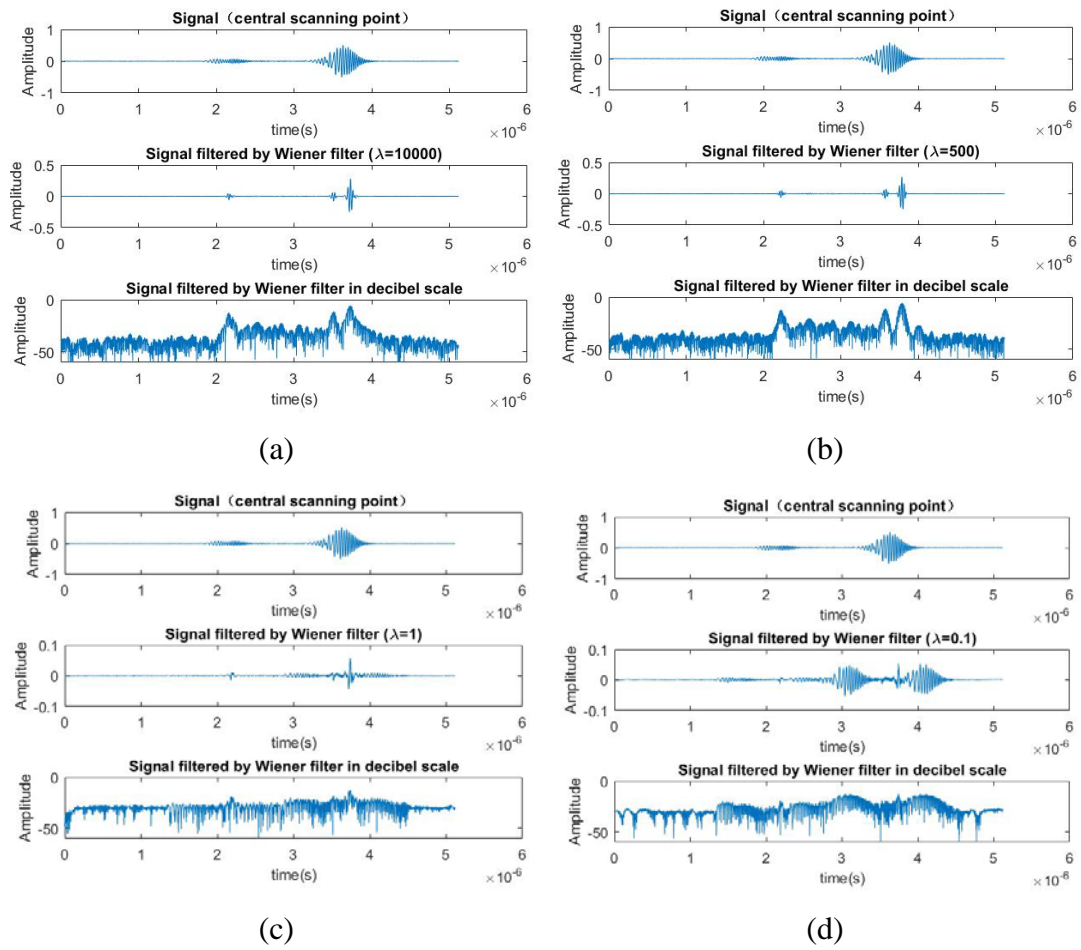


Figure 5.62: Filtered signals of central scanning point. (a)  $\lambda = 10000$ . (b)  $\lambda = 500$ . (c)  $\lambda = 1$ . (d)  $\lambda = 0.1$ .

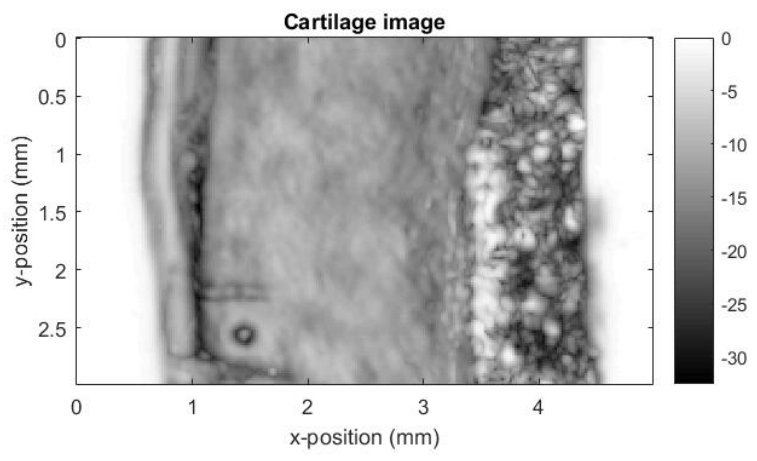


Figure 5.63: Cartilage image



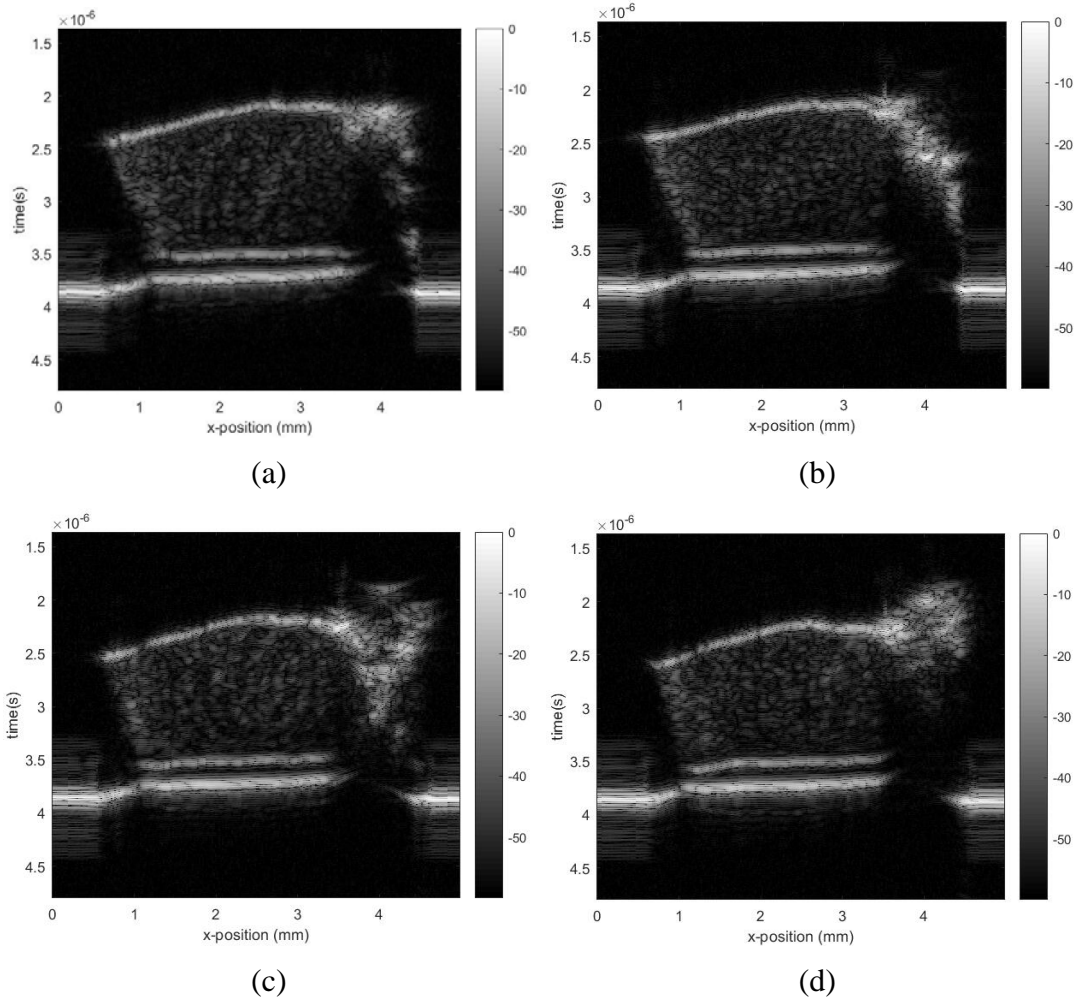
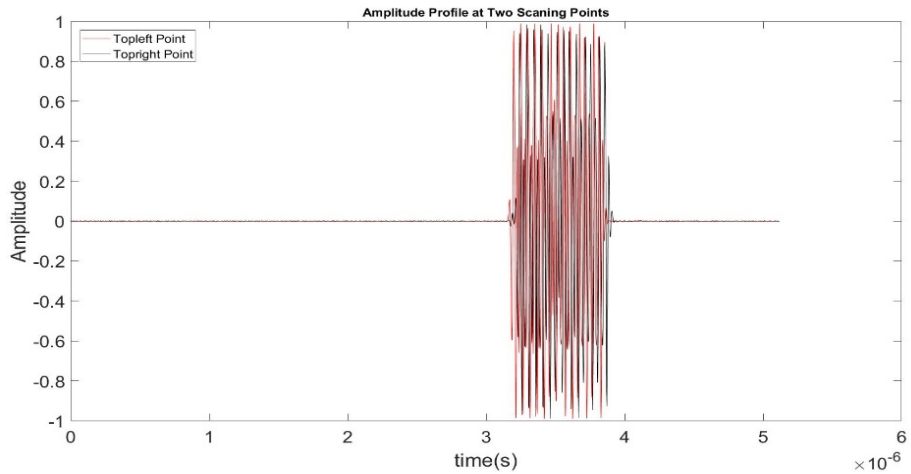


Figure 5.64: B scan. (a)  $y = 0.5$  mm. (b)  $y = 1$  mm. (c)  $y = 1.5$  mm. (d)  $y = 2$  mm.

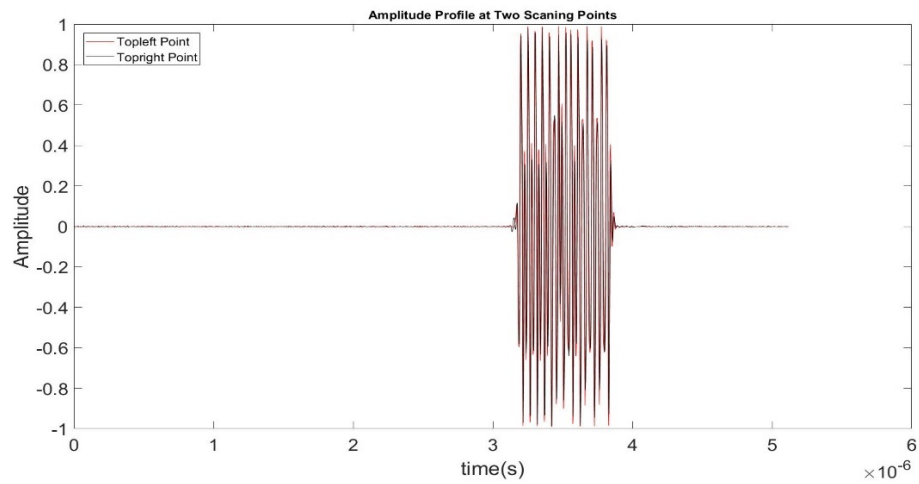
### 5.2.4 Case 8

For case 8, all the experiment conditions are same with that of case 4 except that the used transducer is PVDF transducer. The received signals before and after time calibration are shown in Figure 5.65 (a) and (b). For time calibration, the method used for finding the pulse location is center of mass method. The method for interpolation is cubic spline. In case 8 both Wiener filter and Matched filter are used for decoding. For matched filtering method, decoding can be applied in time domain or Fourier domain and both excitation signal and reflected signal can be used as matching template. There therefore are four different situations for matched filtering method.





(a)



(b)

Figure 5.65: Time calibration. (a) Before calibration. (b) After calibration.

For the situations that the excitation signal is used as template, the signal scanned at first scanning point and its corresponding filtered signals are shown in Figure 5.66 (a) and the signal scanned at central scanning point and its corresponding filtered signals are shown in Figure 5.66 (b). B scan images generated by filtered signals are shown in Figure 5.67. The cartilage image mapped by max value of filtered signals at every scanning point is shown in Figure 5.68.

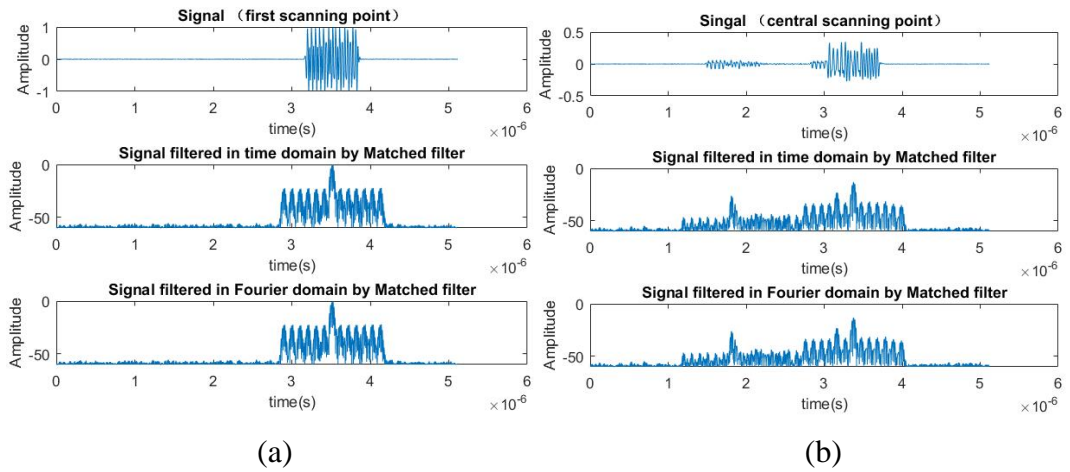


Figure 5.66: Matched filtering. (a) First scanning point. (b) Central scanning point.

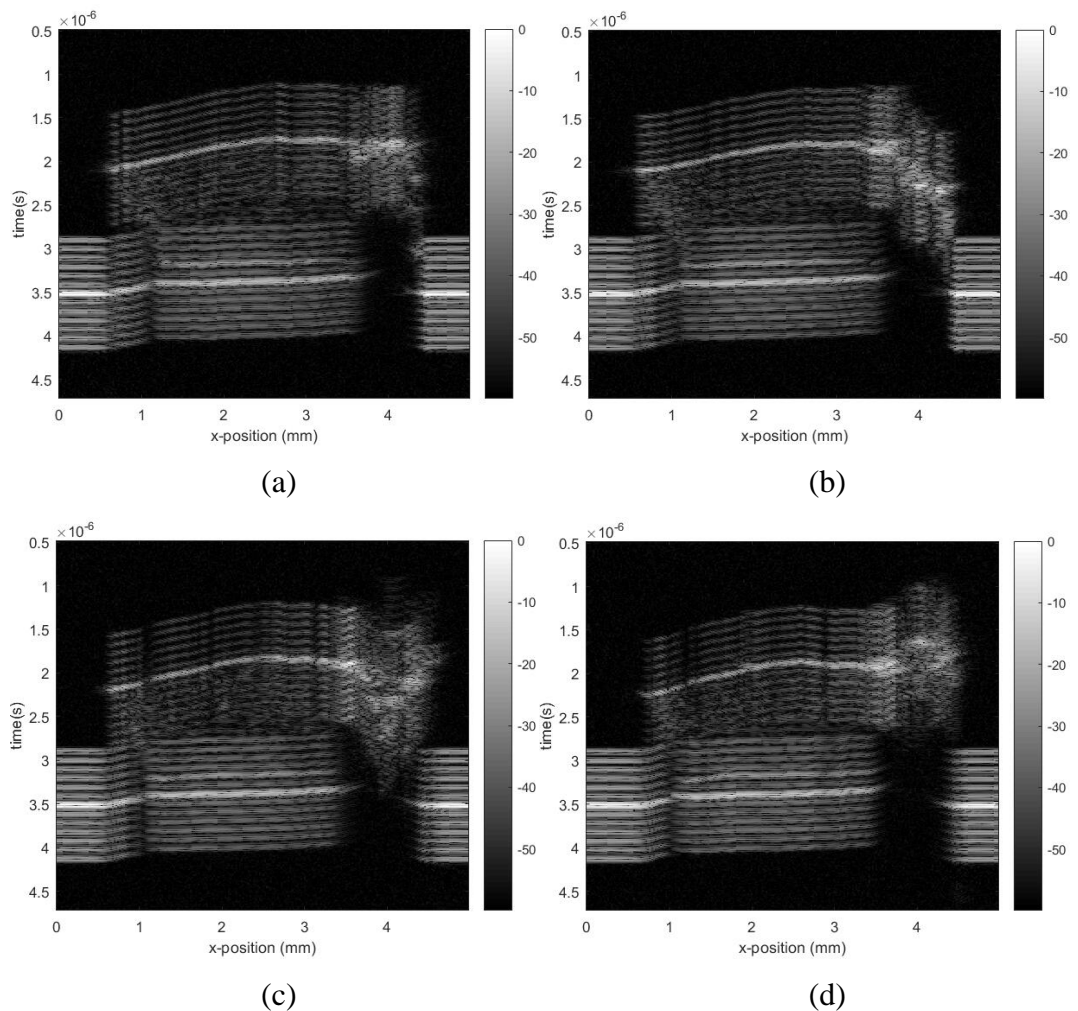


Figure 5.67: B scan. (a)  $y = 0.5 \text{ mm}$ . (b)  $y = 1 \text{ mm}$ . (c)  $y = 1.5 \text{ mm}$ . (d)  $y = 2 \text{ mm}$ .

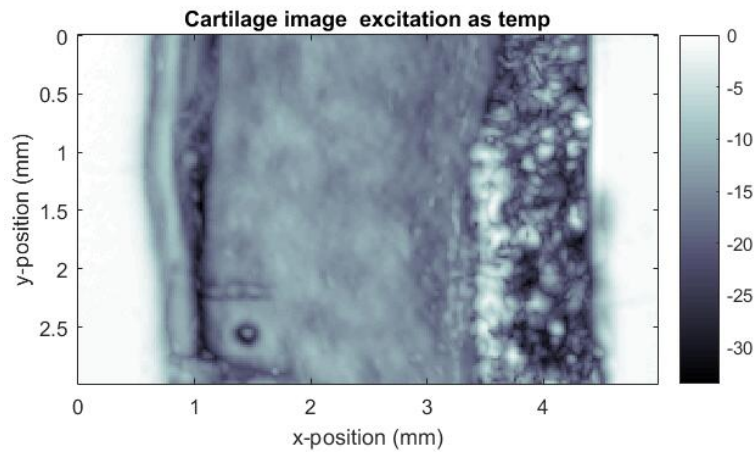


Figure 5.68: Cartilage image

For the situations that the reflected signal is used as template, only part of the reflected signal is used in practical, and the template is shown in Figure 5.69. The signal collected at first scanning point and its corresponding filtered signals are shown in Figure 5.70 (a). The signal scanned at central scanning point and its corresponding filtered signals are shown in Figure 5.70 (b). B scan images generated by filtered signals are shown in Figure 5.72. The cartilage image mapped by max value of filtered signals is shown in Figure 5.71. The SNR of signals filtered by Matched filter with excitation as template is approximate 55.27. The SNR of signals filtered by Matched filter with reflected signal as template is approximate 58.03.

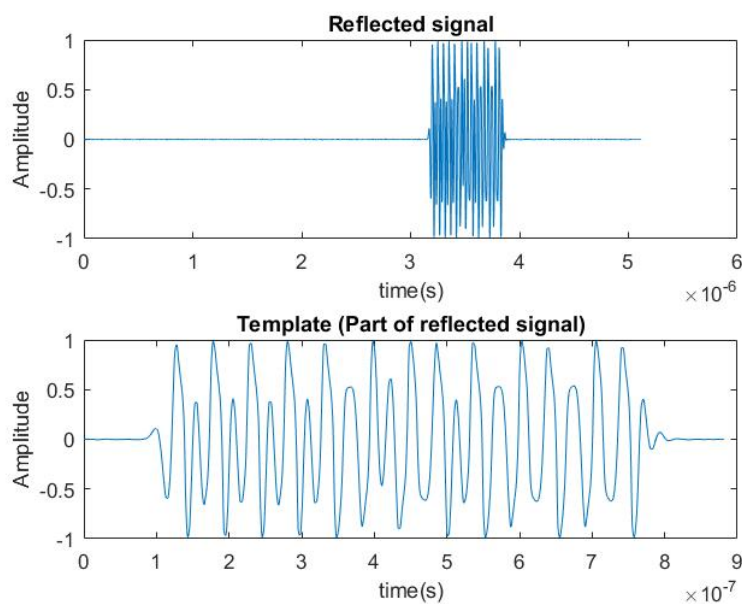
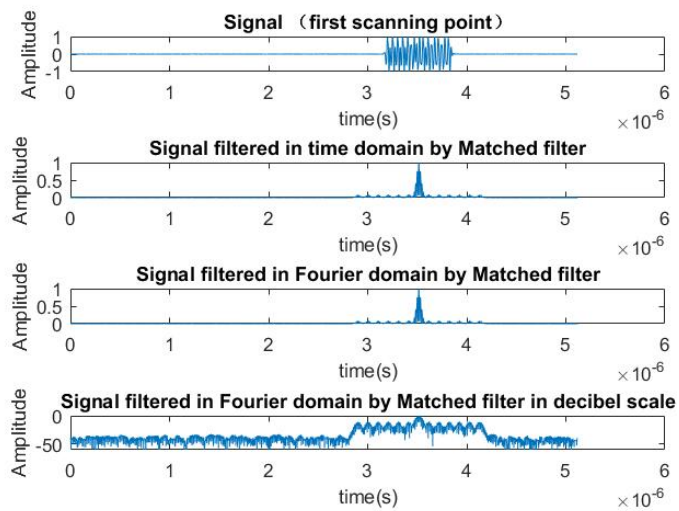
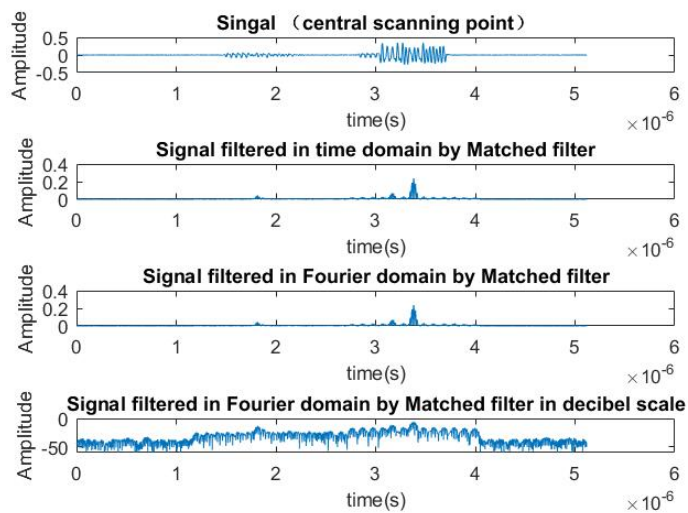


Figure 5.69: Matched template



(a)



(b)

Figure 5.70: Matched filtering. (a) First scanning point. (b) Central scanning point.

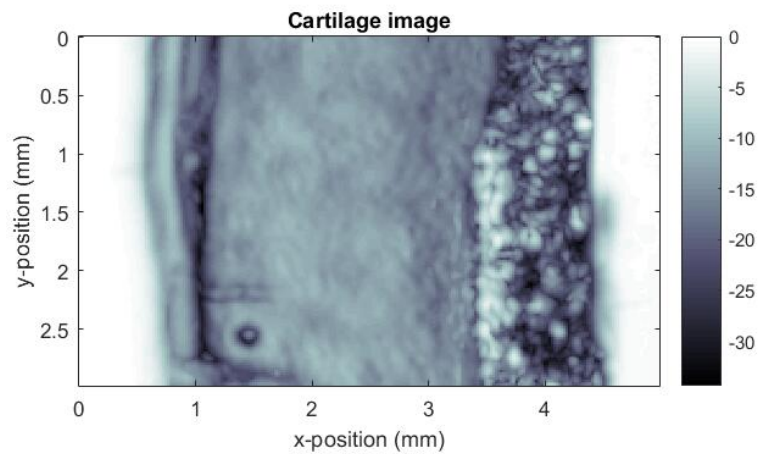


Figure 5.71: Cartilage image

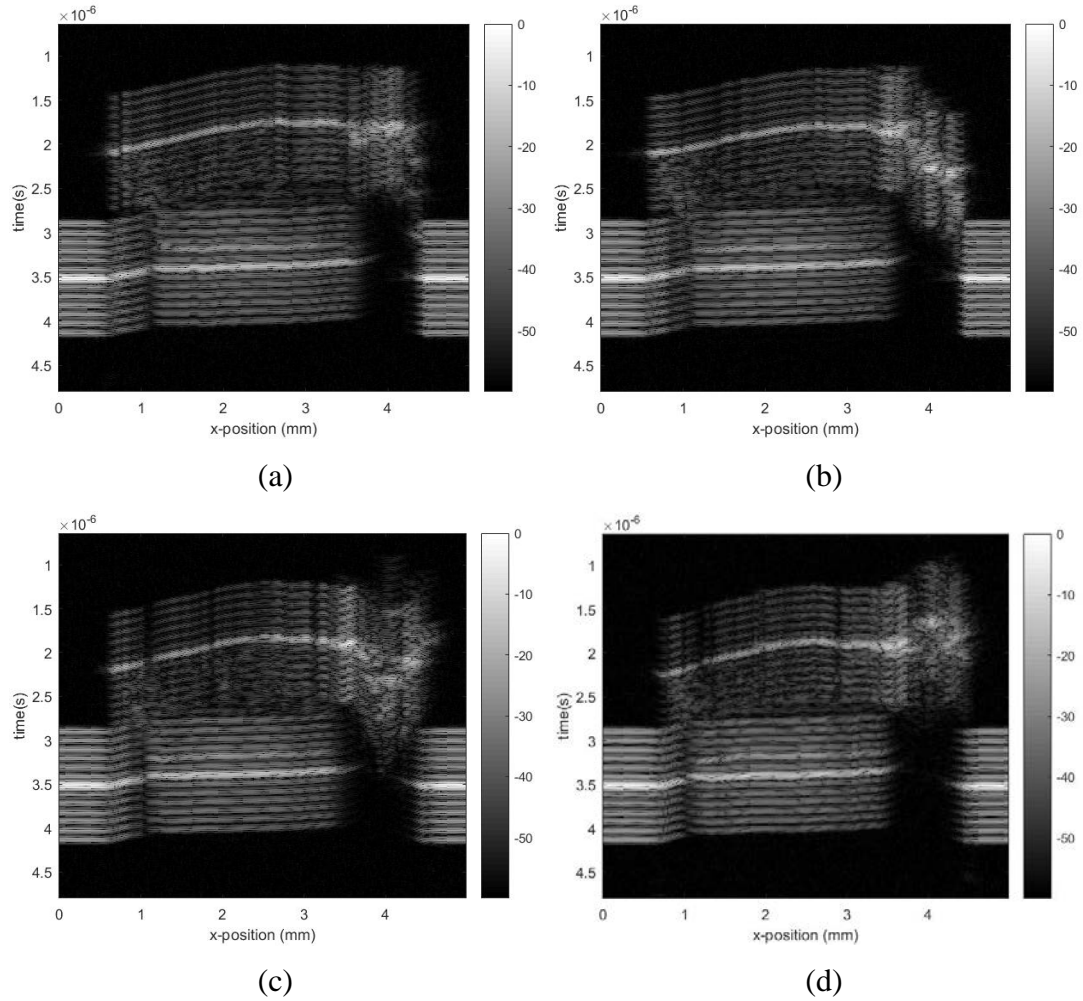


Figure 5.72: B scan. (a)  $y = 0.5 \text{ mm}$ . (b)  $y = 1 \text{ mm}$ . (c)  $y = 1.5 \text{ mm}$ . (d)  $y = 2 \text{ mm}$ .

In case 8 both excitation signal and reflected signal can be used to generate Wiener filter. There therefore are two situations for Wiener filtering method. For the situation that the excitation signal is used to generate Wiener filter, the signal scanned at first scanning point and its corresponding filtered signals are shown in Figure 5.73. And the signal scanned at central scanning point and its corresponding filtered signals are shown in Figure 5.74. For signals filtered by Wiener filter with  $k_c = 1$  and  $\lambda = 500$ , the corresponding B scan images are shown in Figure 5.76. The cartilage image mapped by max value of filtered signals at every scanning point is shown in Figure 5.75. The SNR of signals filtered by Wiener filter with  $k_c = 1$  and  $\lambda = 500$  for this situation is approximate 55.26.

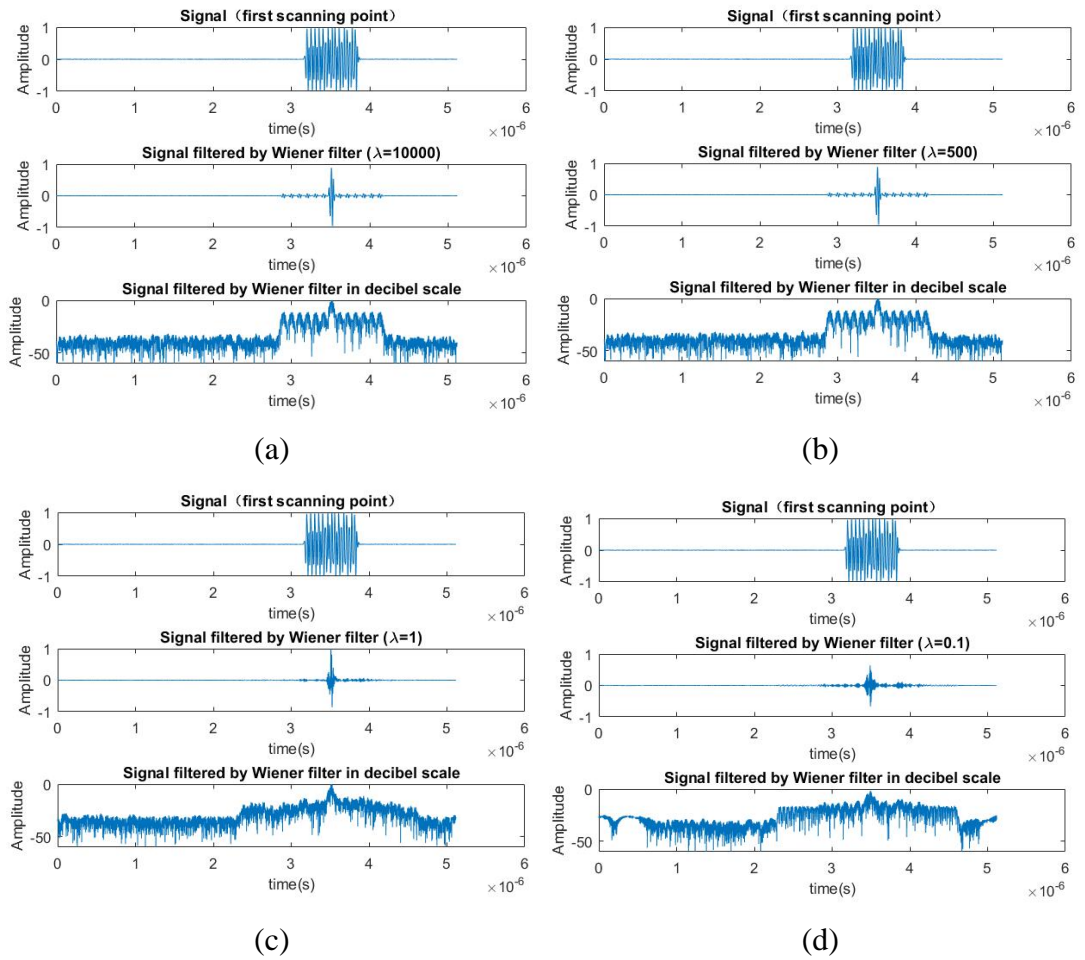


Figure 5.73: Filtered signals of first scanning point. (a)  $\lambda = 10000$ . (b)  $\lambda = 500$ .

(c)  $\lambda = 1$ . (d)  $\lambda = 0.1$ .



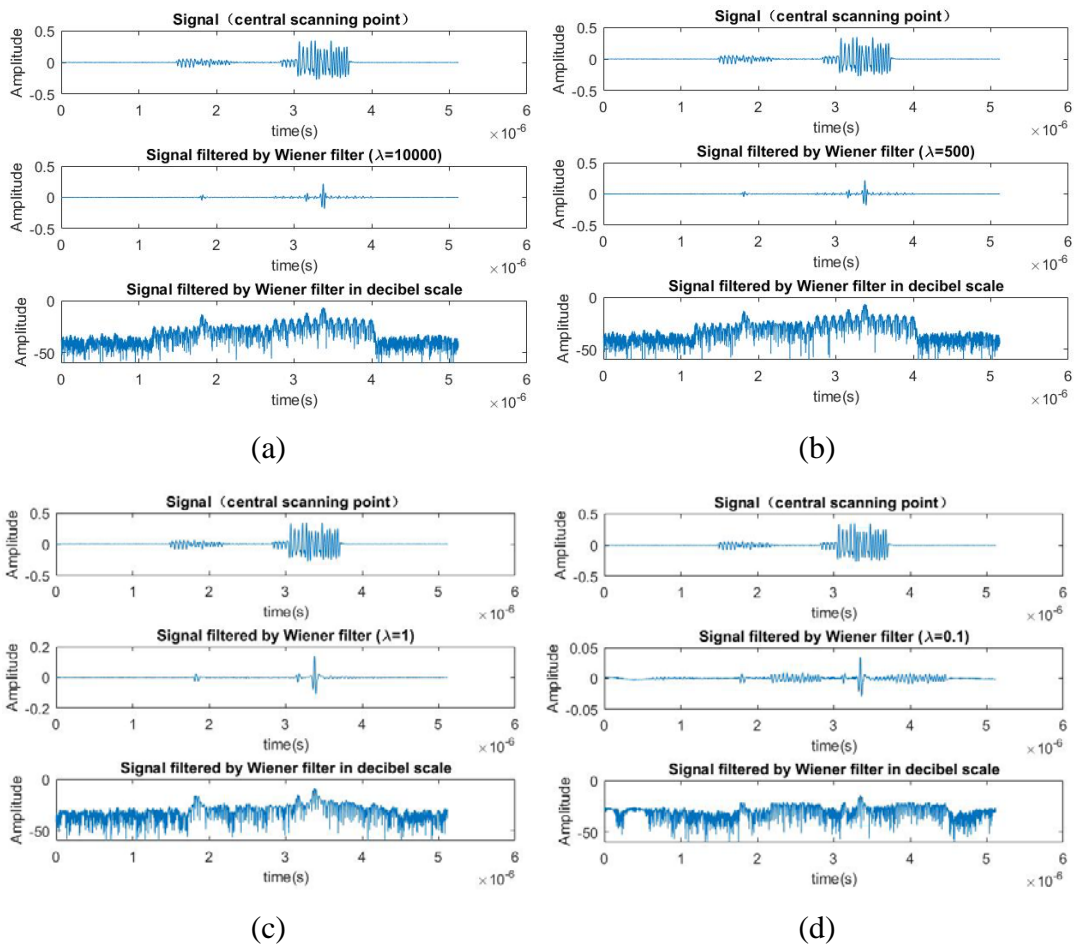


Figure 5.74: Filtered signals of central scanning point. (a)  $\lambda = 10000$ . (b)  $\lambda = 500$ . (c)  $\lambda = 1$ . (d)  $\lambda = 0.1$ .

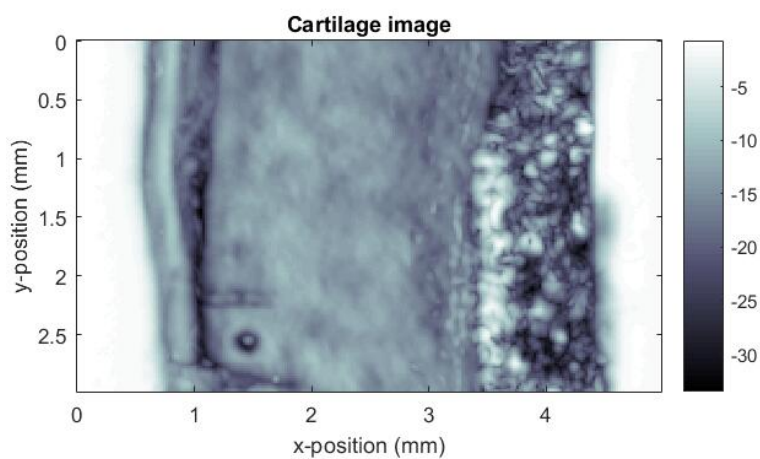


Figure 5.75: Cartilage image



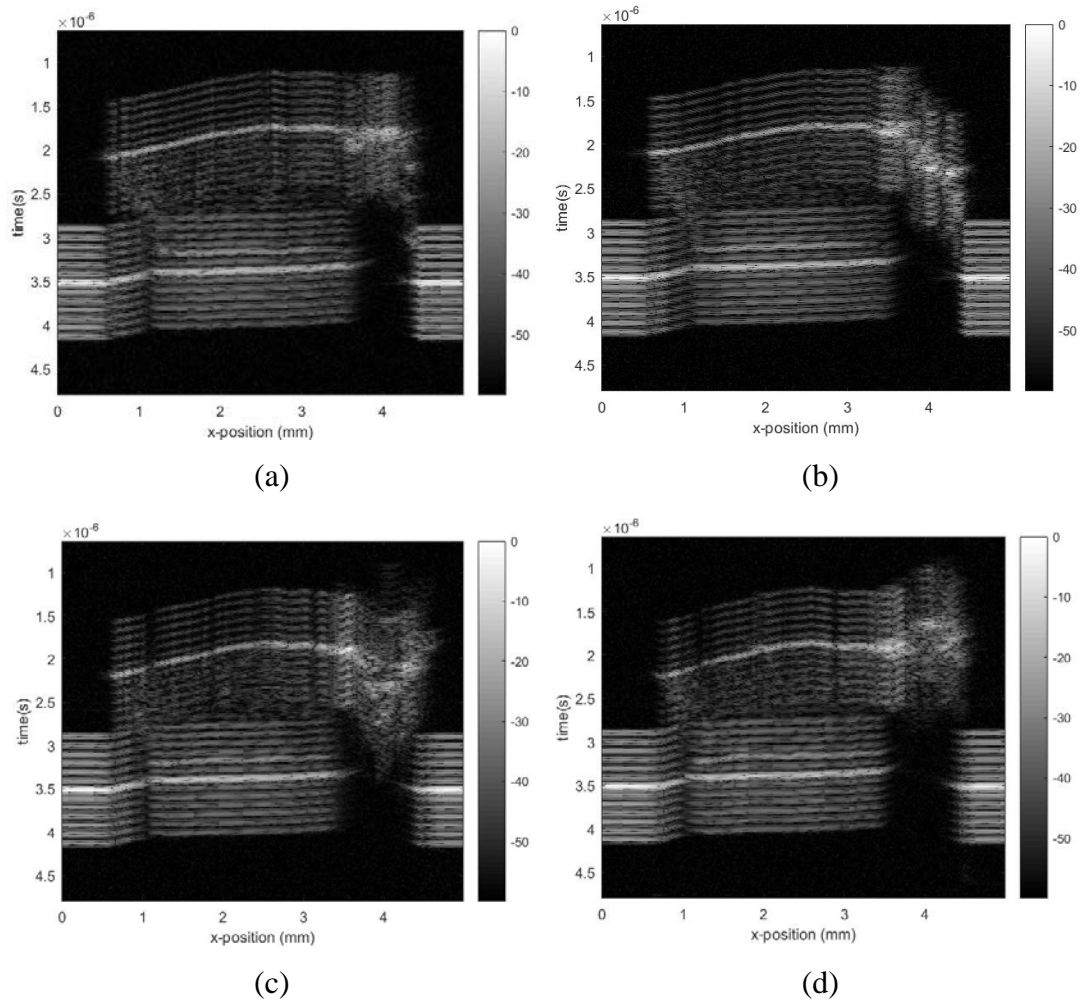


Figure 5.76: B scan. (a)  $y = 0.5 \text{ mm}$ . (b)  $y = 1 \text{ mm}$ . (c)  $y = 1.5 \text{ mm}$ . (d)  $y = 2 \text{ mm}$ .

For the situation that the reflected signal is used to generate Wiener filter. The signal collected at first scanning point and its corresponding filtered signals are shown in Figure 5.77. The signal scanned at central scanning point and its corresponding filtered signals are shown in Figure 5.78. For signals filtered by Wiener filter with  $k_c = 1$  and  $\lambda = 500$ , the corresponding B scan images are shown in Figure 5.80. The cartilage image mapped by max value of filtered signals at every scanning point is shown in Figure 5.79. The SNR of signals filtered by Wiener filter with  $k_c = 1$  and  $\lambda = 500$  for this situation is approximate 58.01.

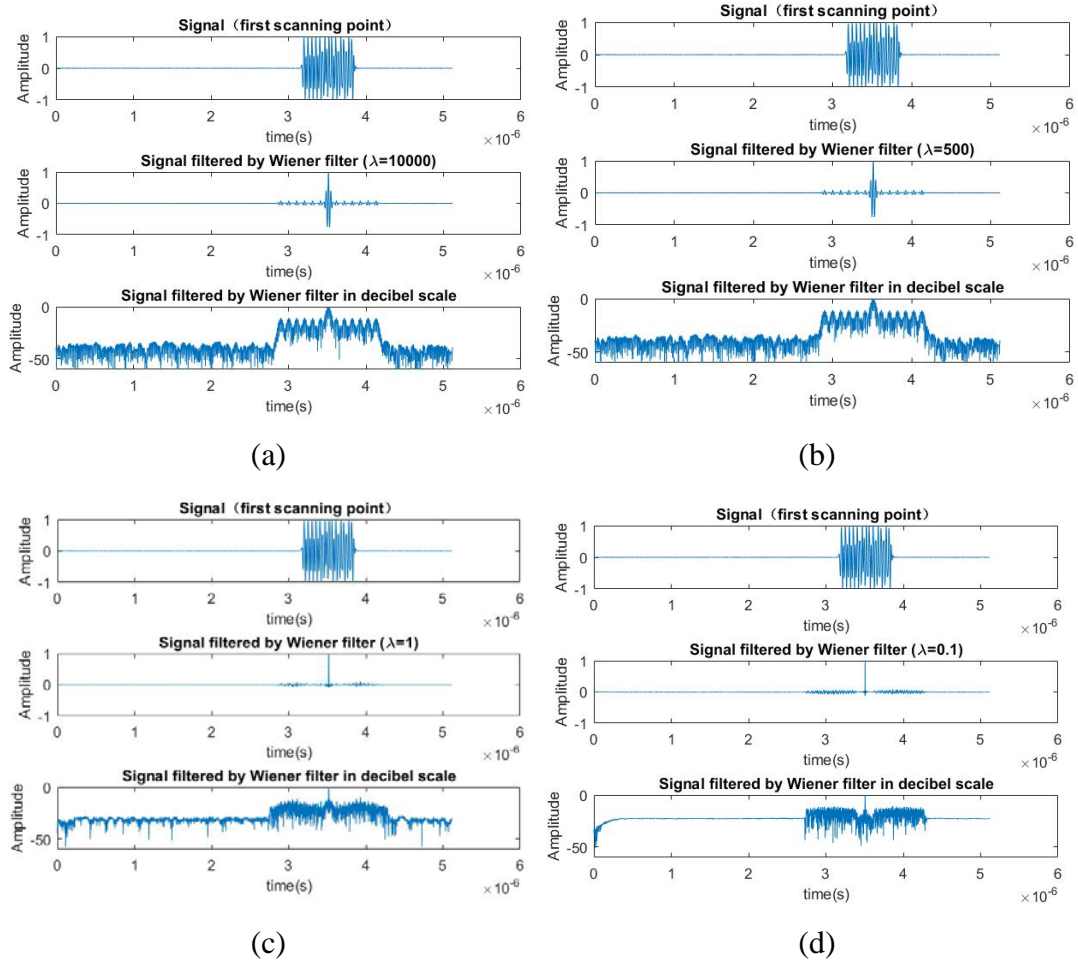


Figure 5.77: Filtered signals of first scanning point. (a)  $\lambda = 10000$ . (b)  $\lambda = 500$ .  
(c)  $\lambda = 1$ . (d)  $\lambda = 0.1$ .

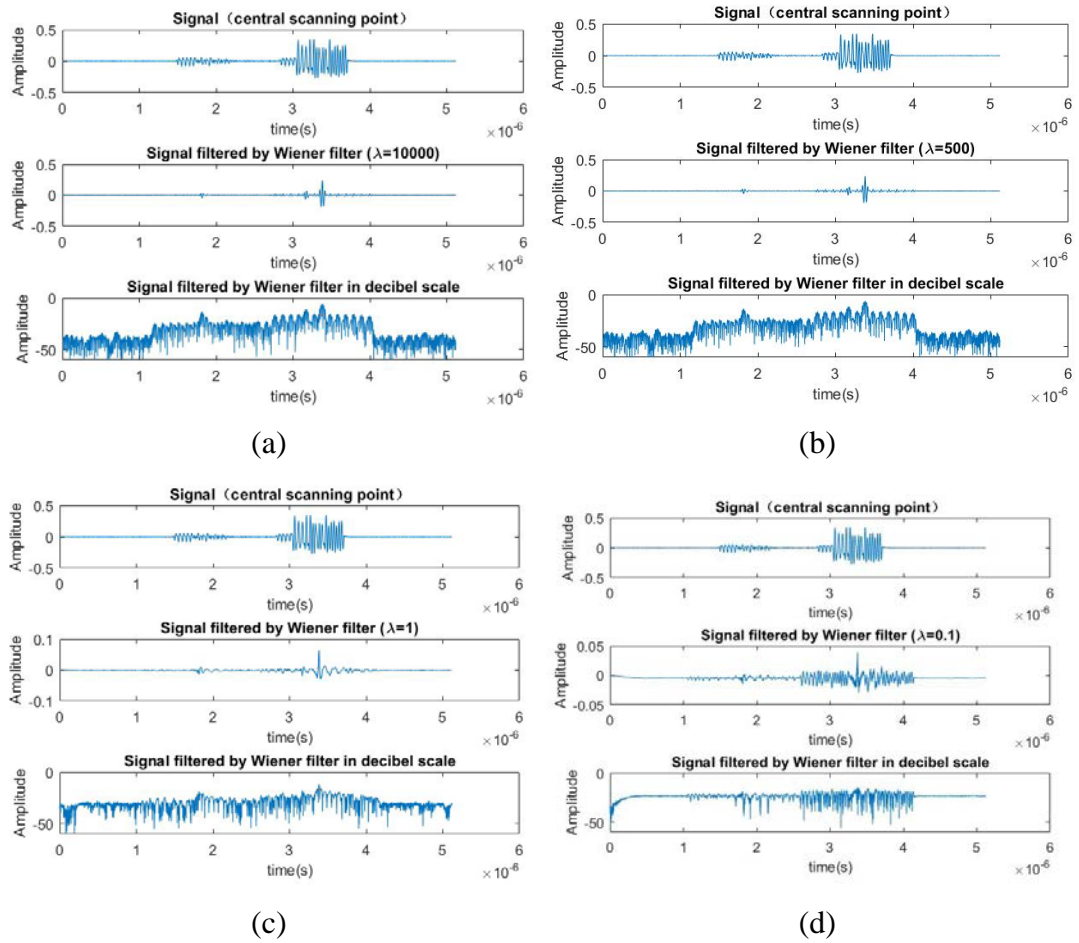


Figure 5.78: Filtered signals of central scanning point. (a)  $\lambda = 10000$ . (b)  $\lambda = 500$ . (c)  $\lambda = 1$ . (d)  $\lambda = 0.1$ .

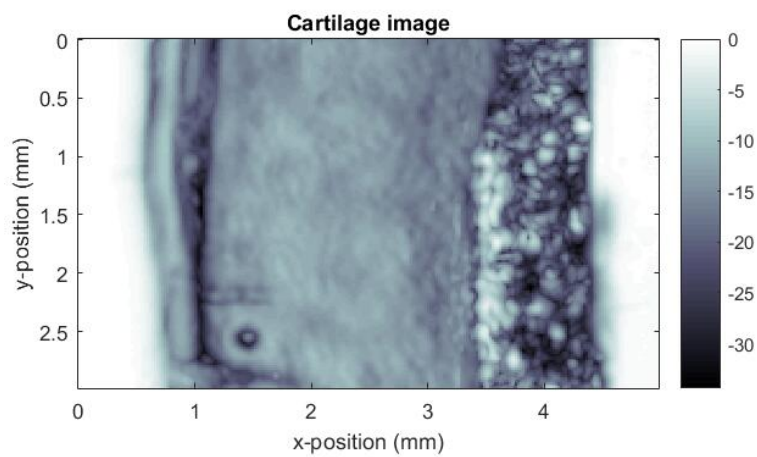


Figure 5.79: Cartilage image

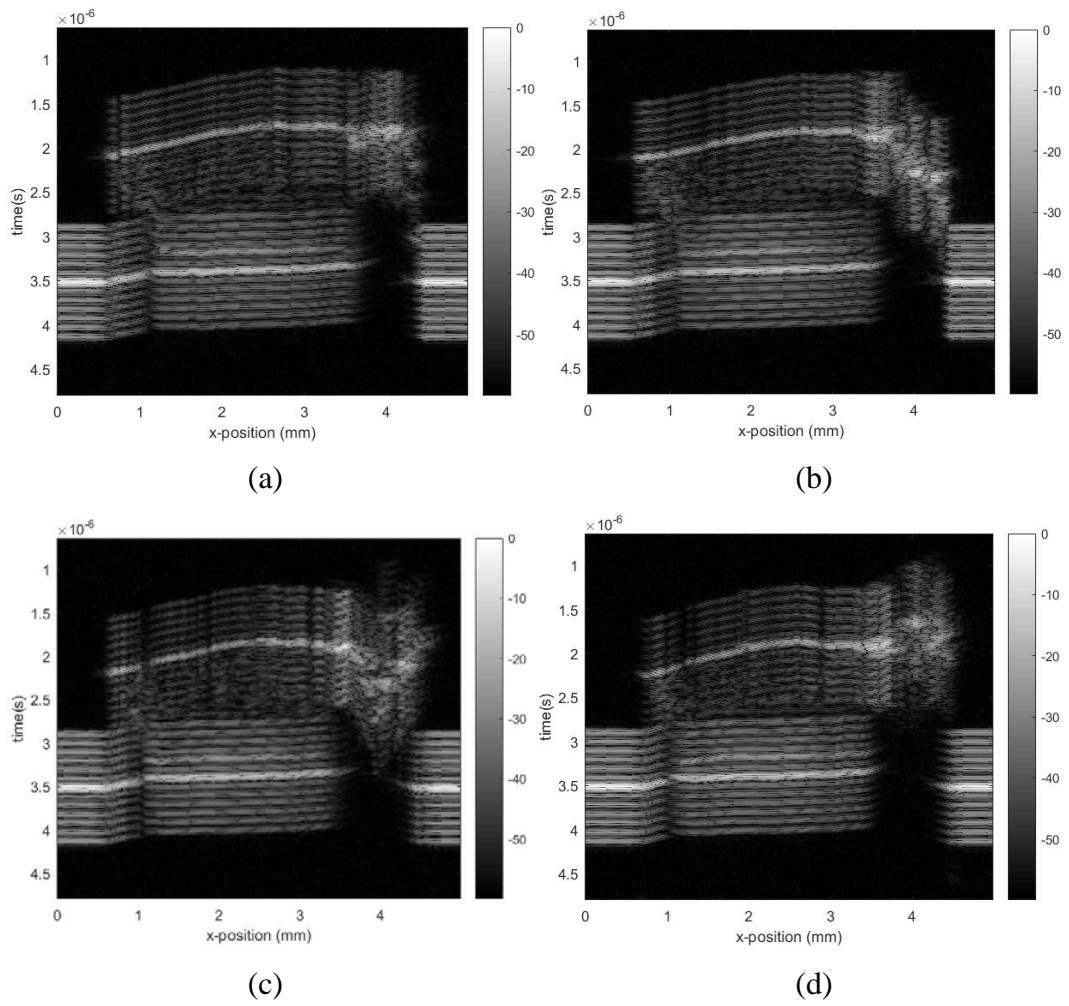


Figure 5.80: B scan. (a)  $y = 0.5 \text{ mm}$ . (b)  $y = 1 \text{ mm}$ . (c)  $y = 1.5 \text{ mm}$ . (d)  $y = 2 \text{ mm}$ .