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Report

Apricot anatomy

Measures of pinbones in fish fillets using CT

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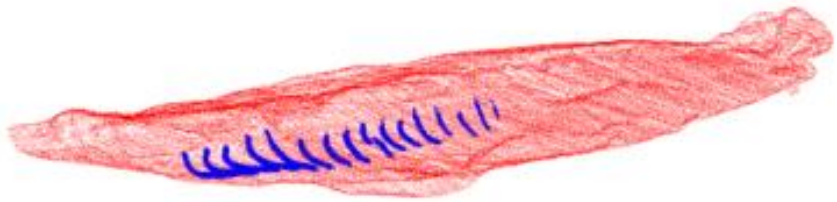

SINTEF ICT
Optical Measurements and Data Analysis
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ABSTRACT
The objectives of this project have been to provide detailed information about the size, orientation and location of pinbones in fillets of cod, haddock, saithe and salmon. For each spices 16 fillets were CT scanned and analyzed. The bones and fillet were segmented and length, thickness, position and orientation of the pinbones were estimated.

Comparison with manual control measurements for some of the fillets showed that all the bones were detected, but there were some deviations in the length and thickness measures. These deviations were mainly due to limitations in CT resolution.

In this study we found that all the spices have a mean pinbone thickness of 0.8-0.9mm, the mean number of bones is 7 for saithe and haddock, 13 for cod and 29 for salmon.

We present in this report initial analysis of the data. However, the goal of this project has primarily been to assemble a relevant dataset as a basis for further analysis. To enable independent analysis, all data is made available electronically for download.

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Table of contents

1 Objectives

The objectives of this project have been to provide detailed information about the size, orientation and location of pin bones in selected species of filleted fish. This will provide new, detailed knowledge about the bone anatomy of fish after they have been filleted. The information should be of a quality that enables:

- Sensor selection and placement for precise 3D bone positioning.
- Being used as guidance or starting point for bone removal methods.
- Being used as guidance or starting point for bone detection algorithms

The goal of this project has been to assemble a relevant dataset as a basis for further analysis.

2 Equipment and setup

We used Toshiba Aquilion One CT machine at Rikshospitalet for image acquisition. The following parameters were used:

- CT scan parameters:
  - KVP: 80 kV
  - Slice thickness: 0.50 mm
  - Field of view:
    - Data collection diameter: 240
  - X-ray tube current: 580 mA
  - Scan option: Helical CT
  - Exposure time 1 s
- CT reconstruction parameters:
  - Overlap 0.4
  - Reconstruction diameter: varies from fish to fish
- Data format
  - Format: Dicom
  - Width: 512
  - Height: 512
  - Bit depth: 16

The resolution of the CT scans is:

- X direction (along the fish): 0.4 mm. Results from slice thickness of 0.5 mm with overlap.
- Z, Y direction: 0.24-0.52 mm. Varies from fish to fish, because the reconstruction diameter varies with the width of the fish fillets.

3 Fish data

Norway Seafoods (Melbu, Båtsfjord) has provided fillets of cod, haddock and saithe, while Marine Harvest (Ryfisk) has provided fillets of salmon.

The fish has been selected such that it spans a realistic size variation, equal number of left and right side fillets. The fish has been automatically filleted by a representative machine (Baader 184/185, Marel filleting machine MS 2730). Fillets with and without skin are included. The data of the measured fillets are shown in Appendices I.A.1.a)(1)A.2. For each species 16 fillets have been CT scanned. In addition 8 cod and 8 haddock were x-ray imaged at SINTEF with an AJAT sensor (100 um resolution).

The following data are recorded for each fillet:

- Machine used for filleting
- Time spent from catch to processing (pre/post rigor)
- Method of catching the fish
- Original size of the fish
- Date, time and place for catching the fish
- Plant where the fish was processed
- Weight of fillet

In order to ensure correct handling of the fish including related information, the following protocol was developed in collaboration with NOFIMA:

> Each fish is placed in a plastic bag and marked with ink with a unique identification tag. The tag is constructed by: The Species_Place_Number (e.g. C_B_ 1 for cod number 1 from Båtsfjord). The fillets are placed lying flat in the plastic bag, so it could be CT scanned directly in the bag. In addition, each fillet was marked with the unique tag using needles, so the tag was visualized in the CT scan.

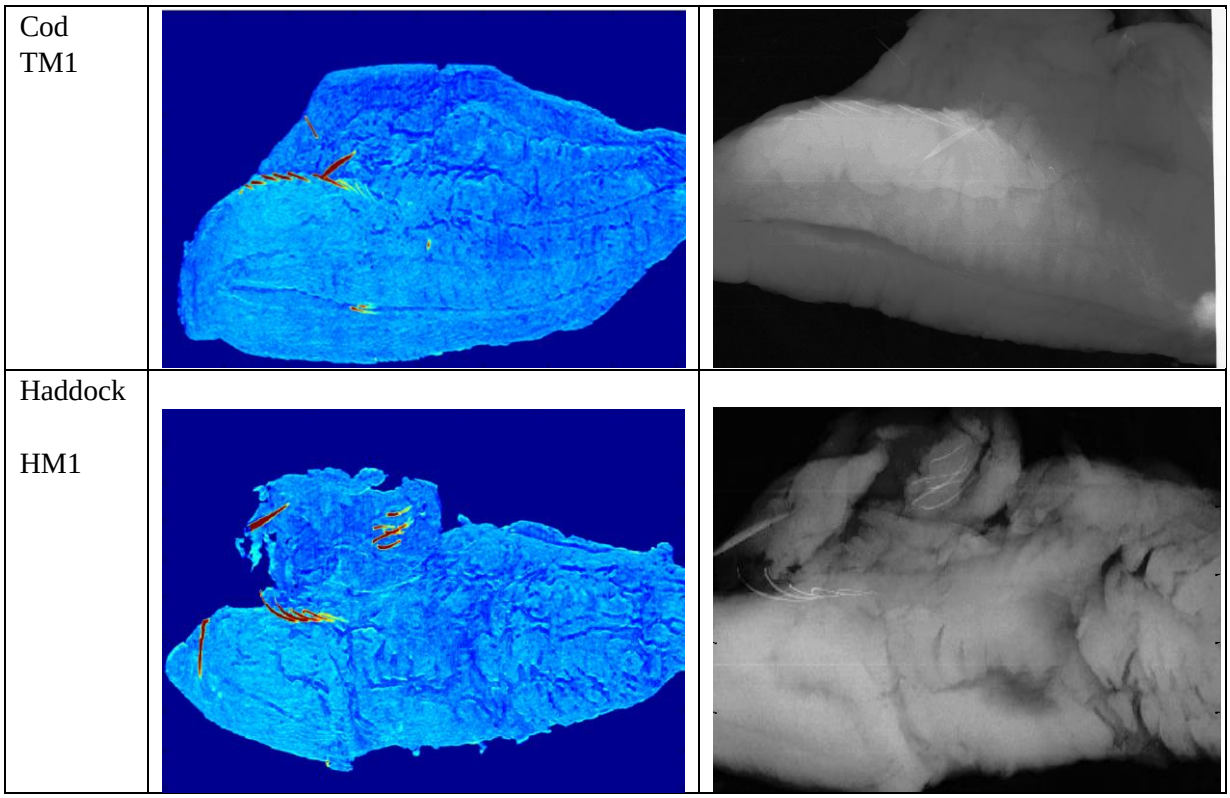


Figure 1. CT images (left) and X-ray image (right) of cod and haddock.

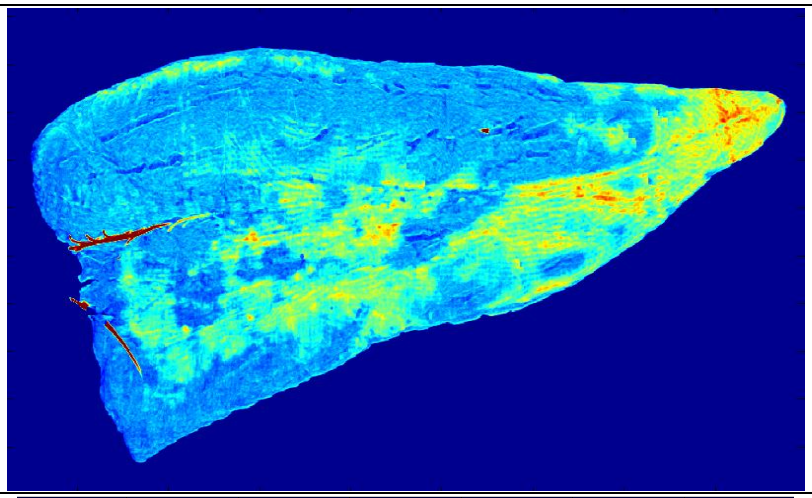
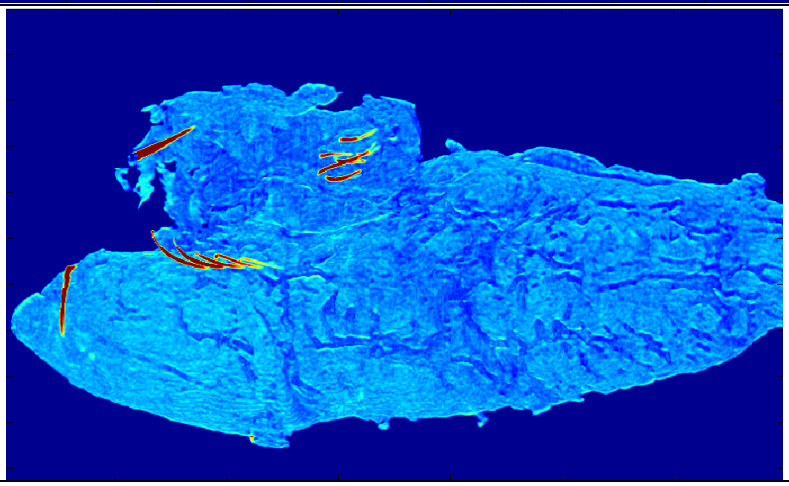
Saithe S1	
Salmon RL1	

Figure 2. CT images of saithe and salmon.

3.1 Fishbone measurement

In addition to CT measurements of the bone sizes, some bones were manually measured. For 3 cod, 1 salmon, 1 saithe and 1 haddock fillet, the bones were removed after CT scanning and measured manually by slide caliper. The bone thickness was measured at the center of the bone and the length of the bones was measured in a straight line between the ends. The shape of the fish bone is not always round, but have a more elliptic shape. This results in that the bones often have one thick and one thinner side. We have therefore measured the thickness in both directions and used the highest value.

4 Method

4.1 Scanner accuracy verification

Prior to data acquisition, initial tests were performed to verify that the CT scanner had sufficient resolution for further analysis. Two cod fillet were CT scanned, and for one of the fillets the bones were removed and measured by slide caliper. The fillets were placed on a plate, in order to provide a planar surface similar to a conveyor belt. During the initial test scanning, several recordings were performed with different settings in order to find the best parameter setting for the experiment, as given in section 4. The fillets were first scanned on a plastic plate and then a glass plate, to find the one with the minimum influence on the image.

4.2 Data acquisition

CT scans were performed at Oslo University Hospital in three rounds. The fillets were placed on a planar plastic plate and marked with a unique tag number. The following fillets were scanned:

1. 8 cod and 8 haddock
2. 16 salmon
3. 16 saithe, 8, cod and 8 haddock

The CT scans were saved as images in DICOM format.

4.3 Data segmentation

The DICOM images were analyzed in MATLAB. The bones and fillet were segmented out in order to provide data suited for further analysis and extraction of high-level information. The segmentation was done through the following procedure:

1. Segment the fillet out from the background, by means of simple intensity thresholding combined with dilation and sorting of regions by volume. Manually mark the region of interest and disturbing objects.
2. Segment the bones from the fillet, by similar means as for the fillet. The surface of the fillet is removed in order to detect the thinnest bones. Some adjustments are required to handle the different species.
3. Manually mark the pinbones in the thresholded image, in order to remove other bones and noise.

Due to high variations in bone sizes and properties of the fillet between the species, as well as variations in the background between the recordings, the segmentation was performed semi-automatically with manual guidance.

4.4 Fish bone information

We have extracted high level information from the data (per species) on the orientation, position, length and size of the pinbones.

4.4.1 Fish bone length and thickness

The length of each bone has been measured through the following procedure:

1. The XYZ position of all the voxels within the bone has been extracted, and put into a 3xN matrix
2. Principal component analysis has been used to rotate the bone such that its primary direction is parallel to the X-axis
3. The points have been sorted according to position along X-axis, and the 0-5% leftmost and 95-100% rightmost have been extracted, and the average XYZ of these two clusters have been extracted.
4. The length of the bone is defined as the Euclidean distance between these two clusters.

The thickness of each bone has been measured through the following procedure:

1. Steps 1 & 2 have been repeated
2. The points have been sorted according to position along X-axis, and the points on the middle (40-60 percentile) have been extracted. The average YZ position of these points

have been calculated, and the distance of each point to this average point has been calculated. The thickness has been calculated as the 98 percentile of these distances.

4.4.2 Extraction of fish bone position and orientation

The fish bone position is calculated through the following procedure:

1. The fish itself has been first positioned and aligned by calculating a linear transforms that:
    a. Orients the Z-axis such that it is normal to the planar surface the fish is laying on, and such that Z=0 is equal to this planar surface, and such the fish is primarily in the space Z > 0.
    b. Aligns the X-axis such that is aligned with the dominating direction of the fish (the longest direction)
    c. Positions X=0 such that it is at the start of the fish, and Y=0 such that it is in the middle of the fish.

    This transform has been calculated through primarily principal component analysis.
2. Steps 1-3 in section have been used to establish start and end point for the bone. These points are transformed back into the axis system defined in point 1 above, and are reported according to this coordinate system. The start position is defined as the point closest to Z=0.
3. After this, these points are transformed such that they are in the coordinate system defined in point 1 above
4. The start and end position (according to the coordinate system defined in 1) is reported as the fish bone's position. Similarly, the vector between start and end is reported as the fish bone's normal.

To calculate the fish bone's orientation, we map the fish bone's normal into each of the planes XY, YZ and XZ. We then measure (in degrees) the angle between the fish bone's normal and respectively the X, Z and Z axis.

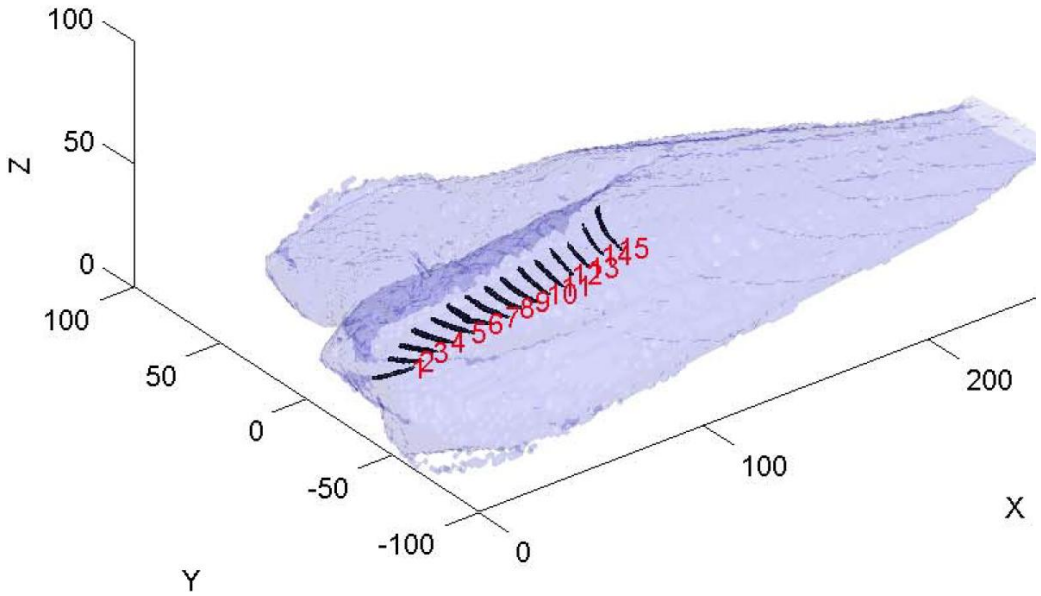


Figure 3. Processed CT image of a cod fillet (TM4) with x, y, z axis and detected bones highlighted in black and numbered. The red numbers are the number of the detected bones.

5 Results

5.1 Analysis of CT resolution

For the initial tests, two cod fillets (T1 and T2) were CT scanned and analysed. The plastic plate turned out to give less reflection than the glass plate, which made it easier to segment out the fillet, as shown in Figure 4. The plastic plate was therefore used in rest of the recordings.

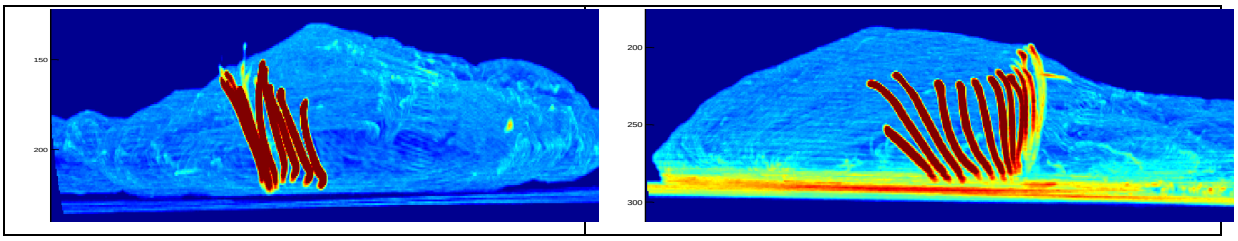


Figure 4. Cod fillet on plastic (left) and glass (right) plate

The fillets were analysed and the bones were segmented and automatically measured. Figure 5 shows the detected bones in the cod fillet (T1). The CT bone measures were compared with the manually measured bone length and thickness, see Table 1. All the 16 bones were detected in the CT image and manually measured. Even the thinnest bone with 0.2 mm centre thickness and 1 cm length were detected in the CT image. Furthermore, the CT image shows that bone number 9 was broken, and both parts are lying in the fillet. In the manual inspection only one part of bone no. 9 was detected and measured.

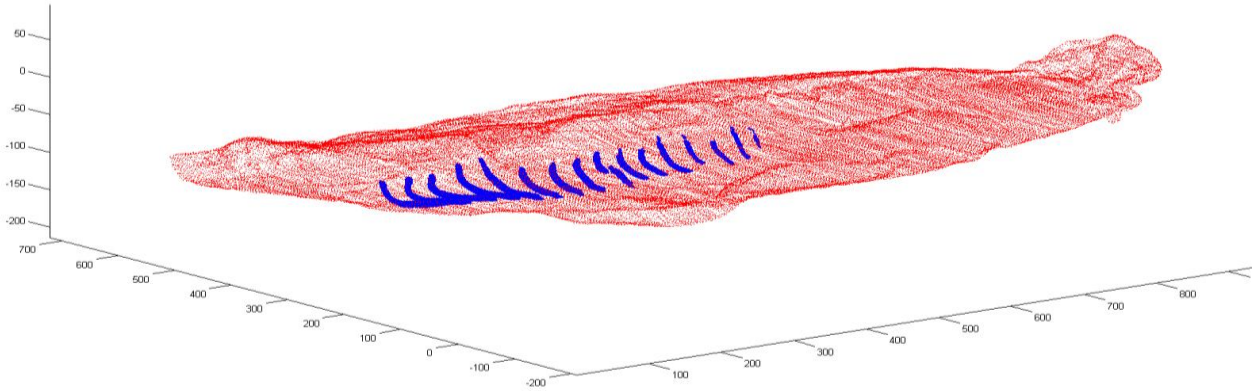


Figure 5. Processed CT scan of cod fillet T1, with the detected bones highlighted in blue.

No	Bone type	CT (Automatic)		Manual		
		Length (mm)	Centre width (mm)	Length (mm)	Centre width (mm)	Width thin end (mm)
1	Pinbone	24.8	1.0	29.2	1.0	0.4
2	Pinbone	25.9	1.0	30.4	1.0	0.4
3	Pinbone	26.2	1.0	30.7	1.0	0.4
4	Pinbone	25.1	0.9	29.2	0.9	0.3
5	Pinbone	25.0	0.9	28.9	1.0	0.3
6	Pinbone	21.1	0.8	24.2	1.0	0.4
7	Pinbone	20.3	0.9	23.0	1.0	0.5
8	Pinbone	19.5	0.9	22.0	0.8	0.4

9	Pinbone	9.9	0.9	10.9	0.6	0.5
10	Pinbone	21.2	0.8	24.0	0.7	0.3
11	Pinbone	19.4	0.8	21.9	0.5	0.2
12	Pinbone	20.0	0.7	22.6	0.4	0.2
13	Pinbone	14.5	0.6	16.2	0.3	0.15
14	Pinbone	15.8	0.7	17.8	0.3	0.15
15	Pinbone	14.8	0.6	16.3	0.2	0.1
16	Pinbone	8.6	0.6	9.5	0.2	0.05

Table 1. CT and manually measured sizes of pinbones from cod T1.

Table 2 shows the mean values and standard deviations of the differences between manual control measurements and CT measurements of pinbones for cod (T1, TM1), salmon (RL1), saithe (SB12) and haddock (HM8).

The mean difference between the measured thickness of the pinbones in the CT image and manually differs from 0.1mm to 0.3 mm for the four different spices. Figure 6 shows how this difference increases with decreasing pinbone thickness. Figure 6 Table 1 show that for bones with thickness less than 0.9mm, the CT measured pinbone width is too thick. This is probably due to an edge enhancement filter that is applied in the original DICOM images. Figure 7 shows how this deviation decreases with increasing bone thickness.

The mean difference between the measured lengths in the CT image and manual control was about 5mm for cod, saithe and haddock, while the difference for salmon was 11 mm. Figure 6 shows that for bones with thin ends, the estimated pinbone length in the CT image is too short. This is due to the limited resolution of the CT images.

As seen in Table 2, the largest deviation in length measures is for the salmon. This is mainly due to the long thin ends of the salmon pinbones. These thin ends are not imaged by the CT scanner because of the limitations in resolution. Since the salmon fillets were wide, the CT resolution was about 0.5mm, while for thinner fillet the resolution was 0.2mm. Figure 4 shows how the pinbones in cod are visual from the surface to the skin side of the fillet, while Figure 8 shows how the pinbones in salmon ends in the fillet, long before the skin.

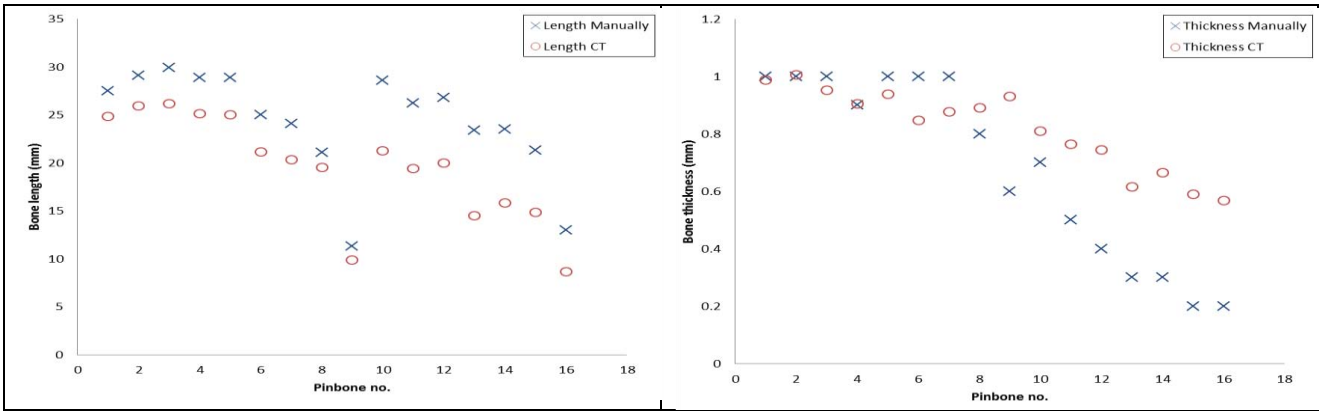


Figure 6. Differences in measured pinbone length (left) and thickness (right) between the CT image and manual control, for the cod fillet T1.

Fillet id	Mean difference thickness (mm)	Std of difference thickness (mm)	Mean difference length (mm)	Std difference length (mm)
T1	0.19	0.15	4.8	2.3
TM1	0.30	0.18	4.9	2.8
RL1	0.29	0.04	11.5	8.2
SB12	0.23	0.06	6.3	2.6
HB8	0.12	0.13	6.4	1.3

Table 2. Differences between manual control measures and CT measures of pinbone length and thickness for cod (T1, TM1), salmon (RL1), saithe (SB12) and haddock (HB8).

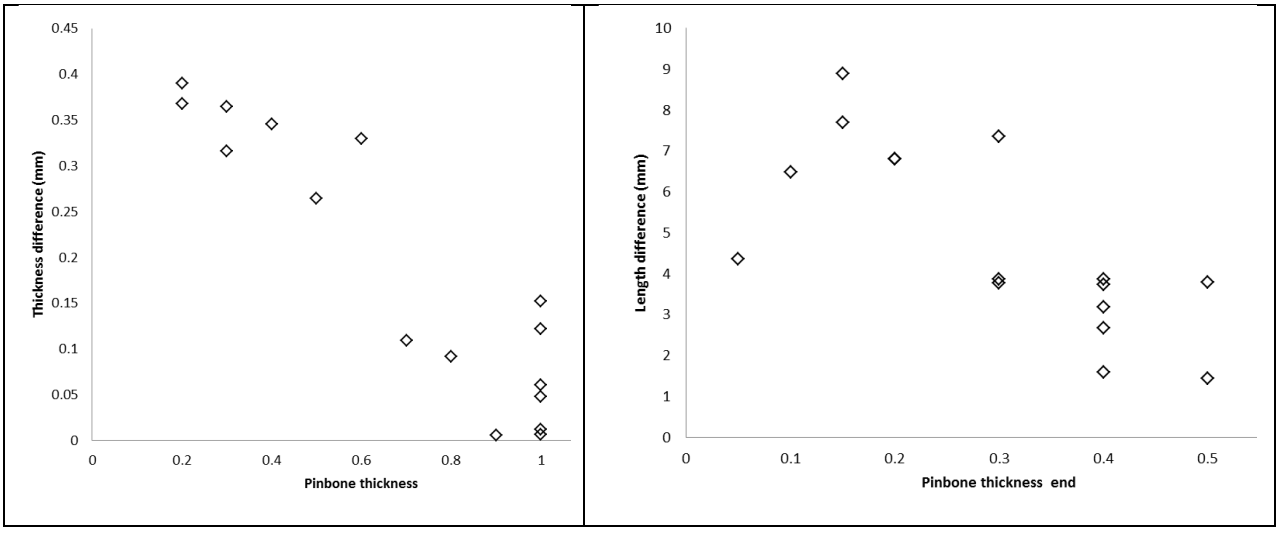


Figure 7. Differences between measured pinbone thickness (left) and length (right) in CT images and manual measures as a function of bone thickness.

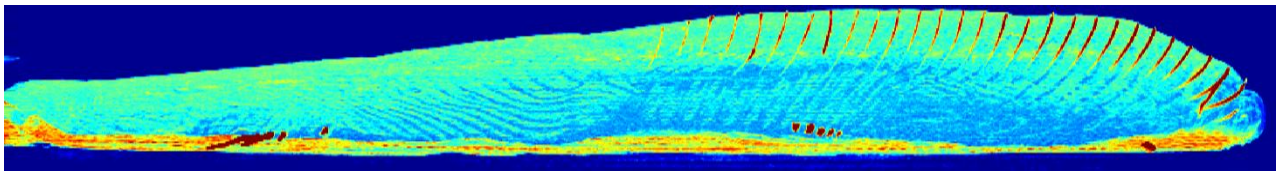


Figure 8. CT image of salmon (RL2)

5.2 Pinbone measures of cod fillets

The number of detected pinbones in cod varies between 9 and 17. The mean number of bones was 13. The length varied between 5mm to 38mm and the thickness varied between 0.4mm and 1.4mm. Table 3 shows the length, thickness, position and orientation of the pinbones. Figure 9 shows detected pinbones for the cod fillet TM1.

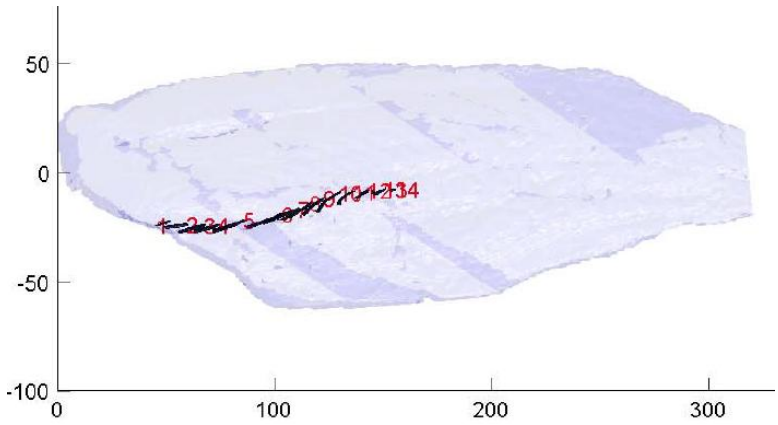


Figure 9. Detected pinbones in a cod fillet (TM1).

Fillet id	No. bones	Thickness (mm)			Length(mm)		
		Min	Max	Mean	Min	Max	Mean
TM1	14	0.48	0.88	0.74	5.08	18.46	13.67
TM2	11	0.41	0.76	0.66	5.39	14.92	9.66
TM3	13	0.74	0.97	0.85	14.70	23.71	17.19
TM4	15	0.62	1.42	0.85	12.31	19.55	16.52
TM5	14	0.62	0.92	0.79	11.05	22.05	16.97
TM6	16	0.77	1.02	0.90	6.22	30.67	17.64
TM7	13	0.65	1.01	0.85	5.40	38.28	21.85
TM8	10	0.50	1.05	0.72	8.43	26.67	16.55
TB1	14	0.63	0.85	0.75	8.15	23.36	18.44
TB2	14	0.40	1.03	0.68	5.51	18.37	11.94
TB3	9	0.48	0.87	0.66	7.76	22.63	16.96
TB4	14	0.55	0.85	0.68	4.98	19.60	12.40
TB5	15	0.50	0.85	0.70	4.75	29.98	16.77
TB6	11	0.49	0.84	0.71	5.49	32.45	19.71
TB7	12	0.50	0.78	0.64	6.26	24.08	15.92
TB8	12	0.63	0.85	0.76	10.66	32.11	21.89

Table 3. Extracted pinbone information for the cod fillets; Number of bones, bone thickness and bone length.

Fillet id	Orientation			Position (mm)	
	YZ mean	XZ mean	XY mean	X start	Length of bone area in x direction
TM1	29.92	50.88	147.10	45.70	110.15

TM2	30.22	51.13	154.56	55.74	94.94
TM3	21.17	58.85	154.49	31.16	106.59
TM4	12.08	48.59	167.44	25.81	116.42
TM5	24.36	58.24	164.46	34.60	113.50
TM6	20.99	46.27	158.82	53.00	114.50
TM7	40.41	59.68	154.41	102.17	184.66
TM8	27.03	51.17	156.43	129.48	102.64
TB1	24.47	58.78	166.38	54.95	102.55
TB2	17.60	64.19	159.81	49.90	113.23
TB3	12.51	47.59	167.78	66.94	77.56
TB4	32.44	55.52	158.71	47.73	118.73
TB5	26.30	60.32	158.68	21.64	136.86
TB6	23.42	59.51	164.30	41.43	106.06
TB7	24.86	57.92	165.09	27.40	140.87
TB8	22.66	59.12	165.67	39.56	131.72

Table 4. Extracted pinbone information for the cod fillets; Orientation and position

5.3 Pinbone measures of haddock fillets

The number of detected pinbones in haddock was between 2 and 16. The mean number of bones was 7. The length varied between 6mm to 31mm and the thickness varied between 0.5mm and 2.8mm. Table 5 shows the length, thickness, position and orientation of the pinbone. Figure 10 shows detected pinbones for the haddock fillet HM1.

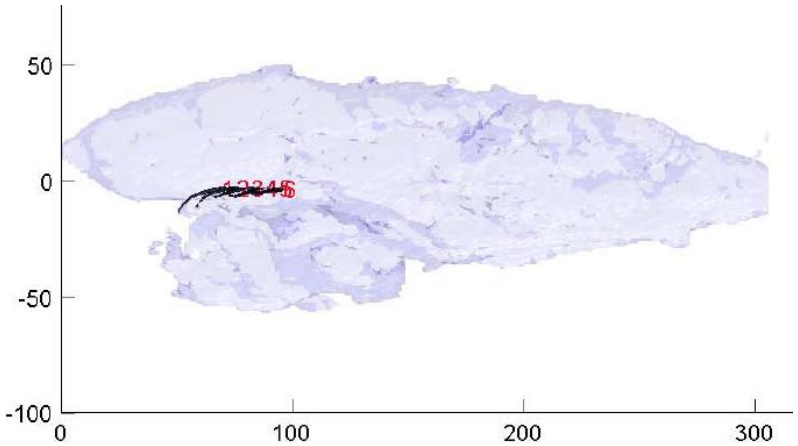


Figure 10. Detected pinbones in a haddock fillet (HM1).

Fillet id	No. bones	Thickness(mm)			Length(mm)		
		Min	Max	Mean	Min	Max	Mean
HM1	6	0.60	0.85	0.75	5.95	20.05	15.89
HM2	8	0.71	0.89	0.79	10.59	23.54	19.53
HM3	8	0.51	0.85	0.73	11.97	24.37	18.57
HM4	10	0.49	0.89	0.71	9.93	24.44	17.24
HM5	2	0.62	0.69	0.66	11.54	15.56	13.55
HM6	16	0.78	1.08	0.91	6.79	31.14	19.38
HM7	10	0.69	0.98	0.83	13.77	29.72	19.68
HM8	10	0.70	0.92	0.77	16.13	30.43	24.89
HB1	6	0.60	2.83	1.21	5.97	24.12	17.52
HB2	8	0.67	0.80	0.75	8.47	14.51	12.56
HB3	4	0.71	0.77	0.75	17.10	22.77	20.31
HB4	6	0.66	0.82	0.74	9.60	20.84	17.13
HB5	7	0.66	0.87	0.81	11.75	19.31	16.05
HB6	4	0.71	0.80	0.76	7.69	19.36	15.09
HB7	2	0.63	0.70	0.67	9.80	16.20	13.00
HB8	5	0.73	1.04	0.86	9.26	26.23	18.97

Table 5. Extracted pinbone information for the haddock fillets; Number of bones, bone thickness and bone length

Fillet id	Orientation			Position (mm)	
	YZ mean	XZ mean	XY mean	X start	Length of bone area in x direction
HM1	30.88	61.74	165.23	51.98	44.47
HM2	49.75	69.44	154.33	30.29	60.51
HM3	30.58	71.71	167.56	29.84	59.11
HM4	29.21	68.51	167.14	16.45	66.73
HM5	36.44	63.37	159.17	82.30	18.78
HM6	20.69	45.16	157.47	55.51	115.15
HM7	54.95	73.02	157.33	37.44	81.85
HM8	23.02	67.63	169.93	25.18	88.81
HB1	40.86	70.41	164.77	7.58	56.63
HB2	47.83	70.70	161.49	18.53	46.36
HB3	23.29	61.40	166.16	24.34	50.18

HB4	30.55	66.83	163.84	17.21	62.49
HB5	27.69	63.41	165.04	46.14	46.73
HB6	49.13	71.71	162.79	43.17	42.99
HB7	35.46	51.57	150.65	55.29	21.49
HB8	56.46	71.46	156.01	30.93	40.46

Table 6. Extracted pinbone information for the haddock fillets; Orientation and position

5.4 Pinbone measures of saithe fillets

The number of detected pinbones in saithe was between 5 and 10. The mean number of bones was 7. The length varied between 5mm to 34mm and the thickness varied between 0.5mm and 4.4mm. Table 7 shows the length, thickness, position and orientation of the pinbone. Figure 11 shows detected pinbones for the saithe fillet SB1.

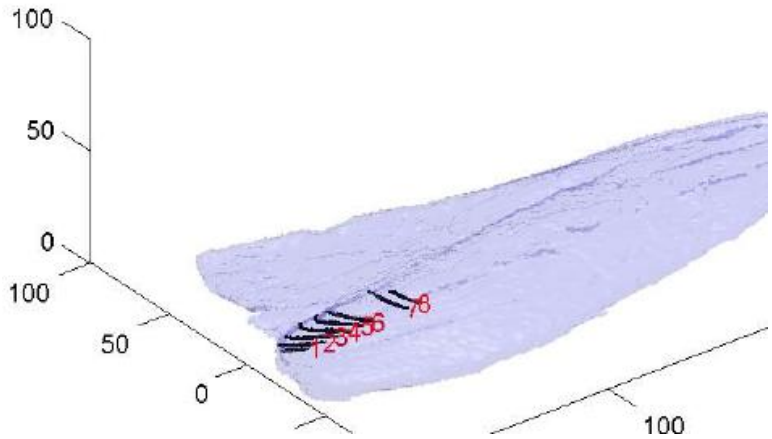


Figure 11. Detected pinbones in a saithe fillet (SB1).

Fillet id	No. bones	Thickness (mm)			Length (mm)		
		Min	Max	Mean	Min	Max	Mean
SB1	8	0.63	0.89	0.77	11.28	26.75	20.84
SB2	10	0.58	0.86	0.76	5.41	29.33	21.53
SB3	5	0.71	0.83	0.79	19.26	24.70	21.40
SB4	5	0.65	2.59	1.10	15.67	32.34	23.73
SB5	7	0.59	1.68	0.93	16.86	29.37	23.87
SB6	8	0.69	2.60	1.14	18.98	31.47	24.44
SB7	6	0.50	4.38	1.35	9.81	33.60	23.66
SB8	10	0.62	0.89	0.75	12.84	28.53	22.42
SB9	8	0.61	0.88	0.75	7.12	29.94	23.35

SB10	8	0.74	1.45	0.89	15.81	30.62	24.32
SB11	6	0.54	0.86	0.75	11.62	24.79	20.63
SB12	6	0.69	0.86	0.79	14.60	24.92	21.36
SB13	6	0.59	0.82	0.71	8.26	22.73	17.83
SB14	9	0.57	0.86	0.76	10.72	23.97	20.87
SB15	6	0.61	0.83	0.73	17.83	25.01	20.92
SB16	7	0.69	0.85	0.77	16.63	26.12	20.49

Table 7. Extracted pinbone information for the saithe fillets; Number of bones, bone thickness and bone length.

Fillet id	**Orientation**			**Position (mm)**	
	YZ mean	**XZ mean**	**XY mean**	**X start**	**Length of bone area in x direction**
SB1	16.92	65.80	173.86	13.53	65.62
SB2	10.68	64.63	176.18	16.04	65.41
SB3	6.99	57.73	177.22	2.80	61.80
SB4	12.98	66.18	175.47	8.53	47.28
SB5	22.74	64.02	168.65	3.67	54.64
SB6	12.66	61.77	173.34	8.09	68.75
SB7	11.05	64.74	176.01	12.46	62.90
SB8	9.77	60.09	174.83	6.89	72.17
SB9	10.65	63.04	175.51	11.87	56.10
SB10	22.01	68.14	170.96	7.17	70.00
SB11	29.47	65.51	164.24	-3.41	55.18
SB12	9.03	64.55	175.38	6.98	61.35
SB13	16.88	65.67	172.86	4.40	56.17
SB14	13.12	65.20	174.16	6.15	70.44
SB15	2.50	63.86	178.76	14.47	45.71
SB16	14.70	65.92	173.94	2.33	57.84

Table 8. Extracted pinbone information for the saithe fillets; Orientation and position

5.5 Pinbone measures of salmon fillets

The number of detected pinbones in salmon was between 28 and 31. The mean number of bones was 29. The length varied between 7mm to 37mm and the thickness varied between 0.5mm and 1.9mm. The estimated lengths are too short, as described in Section 5.1. Table 10 shows the length, thickness, position and orientation of the pinbones. Figure 12 shows detected pinbones for the salmon fillet RL1.

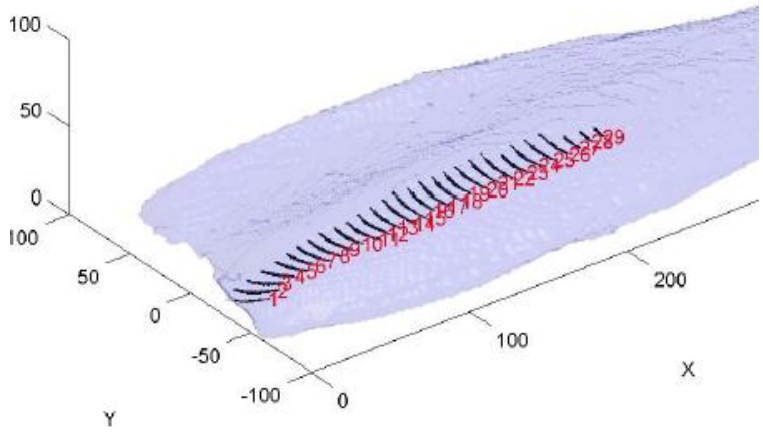


Figure 12. Detected pinbones in a salmon fillet (RL1).

Fillet id	No. bones	Thickness (mm)			Length (mm)		
		Min	Max	Mean	Min	Max	Mean
R_L_1	29	0.56	0.77	0.68	7.38	21.74	17.91
R_L_2	29	0.57	0.88	0.71	10.63	21.77	17.46
R_L_3	29	0.61	0.91	0.75	6.53	23.43	19.33
R_L_4	28	0.66	0.81	0.73	13.47	27.86	20.77
R_L_5	28	0.58	1.90	0.88	12.02	26.75	21.89
R_L_6	30	0.55	1.03	0.78	9.26	27.70	21.26
R_L_7	30	0.49	0.91	0.76	9.34	27.52	22.88
R_L_8	30	0.48	1.04	0.78	8.72	26.55	19.79
R_L_9	30	0.64	1.14	0.74	9.76	27.09	23.10
R_L_10	31	0.63	0.82	0.75	13.01	31.67	26.03
R_L_11	28	0.62	1.08	0.76	12.03	25.87	22.13
R_L_12	28	0.56	0.91	0.73	10.12	28.01	23.00
R_L_13	29	0.68	0.85	0.77	14.50	26.92	22.46
R_L_14	29	0.46	1.05	0.80	8.04	24.51	20.52
R_L_15	31	0.66	0.87	0.77	8.67	37.13	26.47
R_L_16	29	0.63	0.96	0.80	12.26	27.96	21.98

Table 9. Extracted pinbone information for the salmon fillets; Number of bones, bone thickness and bone length.

Fillet id	Orientation			Position (mm)	
	YZ mean	XZ mean	XY mean	X start	Length of bone area in x direction
R_L_1	31.21	51.86	156.40	5.09	233.57
R_L_2	24.57	40.47	152.58	5.06	211.63
R_L_3	31.98	40.41	144.31	2.42	220.93
R_L_4	22.97	46.46	158.52	1.46	228.53
R_L_5	32.94	46.98	149.27	3.21	221.35
R_L_6	30.52	49.31	153.43	3.26	236.22
R_L_7	28.09	48.77	155.13	3.72	235.29
R_L_8	24.46	46.37	157.08	-1.31	232.25
R_L_9	31.82	57.28	158.00	1.66	269.14
R_L_10	39.77	58.81	150.54	2.17	302.64
R_L_11	27.85	46.56	154.33	1.45	243.77
R_L_12	31.99	43.06	146.23	2.18	244.74
R_L_13	28.20	53.01	158.38	1.77	258.04
R_L_14	24.35	43.93	155.01	0.58	234.72
R_L_15	41.16	57.69	148.12	1.74	300.18
R_L_16	30.24	41.34	146.69	1.65	251.11

Table 10. Extracted pinbone information for the salmon fillets; Orientation and position

A summery of the statistic for each spices are given in

Table 11.

Spices	Mean no of bones	Min no of bones	Max no of bones	Mean bone Thickness (mm)	Min bone Thickness (mm)	Max bone Thickness (mm)	Mean bone Length (mm)	Min bone Length (mm)	Max bone Length (mm)
Cod	13	9	17	0.8	0.4	1.4	17	5	38
Haddock	7	2	16	0.8	0.5	2.8	18	6	31
Saithe	7	5	10	0.9	0.5	4.4	22	5	34
Salmon	29	28	31	0.8	0.5	1.9	22	7	37

Table 11. Statistics on number of bones, thickness and length for different species

6 Summary

The objectives of this project have been to provide detailed information about the size, orientation and location of pinbones in fillets of cod, haddock, saithe and salmon. For each spices 16 fillets were CT scanned and analyzed. The bones and fillet were segmented and length, thickness, position and orientation of the pinbones were estimated.

Comparison with manual control measurements for some of the fillets showed that all the bones were detected, but there were some differences in the length and thickness measures. The mean thickness difference was 0.2 mm while the mean length difference was 6.8 mm. This is mainly due to limitations in resolution of the CT scanner. The thin ends of the bones are below the resolution of the CT images.

The resolution depends on the width of the fillet, and all large fillets (> 1 kg) with high width is scanned with lower resolution which results in to short estimates of the pinbone length.

In this study we found that all the spices have a mean pinbone thickness of 0.8-0.9mm, the mean number of bones is 7 for saithe and haddock, 13 for cod and 29 for salmon.

We present in this report initial analysis of the data. However, the goal of this project has primarily been to assemble a relevant dataset as a basis for further analysis. To enable independent analysis, all data is made available electronically for download. All images and analyzed data are available at an eroom, see Appendice I.A.1.a)(1)A.1 for more details.

A Fish fillet data

A.1 Fish fillet data at eroom

All the CT images in Matlab format, detected bones and fillet in PLY format together with statistics of estimated features of the pinbones are available for downloading from the eroom Apricot anatomy (https://project.sintef.no/eRoom/ikt2/Apricotanatomy).

Anyone who is interested will be invited into this eroom by contacting Jens Thielemann (email: jtt@sintef.no) or Helene Schulerud (email: hsc@sintef.no)

Overview of data at the eroom

- Rawdata.mat: Raw CTscanner data (int16) in Matlab format.

- ApricotData.zip: contains one folder for each fillet with the following files
  - bone.ply: Shell of pinbones in PLY format for import into CAD software
  - fish.ply: Shell of fillet in PLY format for import into CAD software
  - patches.mat: 3D surfaces of bone and fish in MAT format (suitable for later plotting and processing in Matlab through i.e. patch command)
  - stats.mat: Matlab file containing measured lengths, orientations etc per bone in the fillet, and overall statistics per fillet.
  - segmented.mat: Matlab file with the following variables:
    - info: Raw DICOM info for the captured data
    - resolution: Resolution in XYZ (in mm) for captured data

    - segmented: Segmented data. The following values are used:
        - 0: Background (non-fish)
        - 10: Fish meat
        - 101-150: Each bone is given an individual number in this range

- FishIllustrations.pdf: 3D rendering of fish.

- SpeciesStats.xls: Contains length, thickness, orientation, start, and stop position of each individual bone. Distances are measured in millimeters; angles in degrees.

- Allstats.xls: Minimum, maximum and mean of pinbone length, thickness, orientation and the start point of the first bone and the stop position of the last bone.

- Readme.txt: text file describing the content in the different files.

A.2 Fish fillet data

A.2.1 Cod

Navn på anlegg: Norway Seafoods AS avd Melbu												
Navn på fileteringsmaskin: Baader 184												
Fillet kode	**Størrelse**	**H/V fillet side**	**Skinn**	**Fillet vekt**	**Fillet lengde**	**Filet maks høyde**	**Fangst dato**	**Fangst sted**	**Fangst metode**	**Tid fra fangst til prosessering**	**Spalting**	**Bløthet**
TM1	Liten	L	-	396g	38 cm	25	24.08.12	Vesterålen	Garn	3 døgn	Lite	Normal
TM2	Liten	R	with	469g	40 cm	23	24.08.12	Vesterålen	Garn	3 døgn	Lite	Normal
TM3	Liten	R	-	664g	43 cm	36	24.08.12	Vesterålen	Garn	3 døgn	Lite	Normal
TM4	Medium	L	with	764g	45,5 cm	38	24.08.12	Vesterålen	Garn	3 døgn	Lite	Normal
TM5	Medium	R	-	706g	44 cm	35	24.08.12	Vesterålen	Garn	3 døgn	Lite	Normal
TM6	Medium	L	with	783g	48 cm	39	24.08.12	Vesterålen	Garn	3 døgn	Lite	Normal
TM7	Stor	L	with	1339g	57 cm	45	24.08.12	Vesterålen	Garn	3 døgn	Lite	Normal
TM8	Stor	R	-	1224g	56 cm	50	24.08.12	Vesterålen	Garn	3 døgn	Lite	Normal

Navn på anlegg: Norway Seafoods AS avd Båtsfjord												
Navn på fileteringsmaskin: Baader 184 (1-4) 185 (5-8)												
Fillet kode	**Størrelse**	**H/V fillet side**	**Skinn**	**Fillet vekt**	**Fillet lengde**	**Fangst dato**	**Fangst kl.**	**Fangst sted**	**Fangst metode**	**Tid fra fangst til prosessering**	**Spalting**	**Bløthet**
TB1	Liten	L	Med	425g	44 cm	12.09.12	?	Makkaur/Båtsfjord	Line	1 døgn	Ingen	Normal
TB2	Liten	R	Uten	395g	44 cm	12.09.12		Makkaur/Båtsfjord	Line	1 døgn	Lite	Normal
TB3	Medium	L	Med	450g	44 cm	12.09.12		Makkaur/Båtsfjord	Line	1 døgn	Ingen	Fast
TB4	Liten	R	Uten	425g	42 cm	12.09.12		Makkaur/Båtsfjord	Line	1 døgn	Ingen	Fast
TB5	Medium	L	Med	675g	51 cm	12.09.12		Makkaur/Båtsfjord	Line	1 døgn	Ingen	Fast
TB6	Medium	R	Uten	660g	49 cm	12.09.12		Makkaur/Båtsfjord	Line	1 døgn	Ingen	Fast
TB7	Stor	L	Med	690g	51 cm	12.09.12		Makkaur/Båtsfjord	Line	1 døgn	Ingen	Fast
TB8	Stor	R	Uten	690g	50,5 cm	12.09.12		Makkaur/Båtsfjord	Line	1 døgn	Lite	Normal

Navn på anlegg: Norway Seafoods AS avd Melbu												
Navn på fileteringsmaskin: Baader 184												
Fillet kode	**Størrelse**	**H/V fillet side**	**Skin**	**Fillet vekt**	**Fillet lengde**	**Max height (mm)**	**Fangst dato**	**Fangst sted**	**Fangst metode**	**Tid fra fangst til prosessering**	**Spalting**	**Bløthet**
HM1	Liten	L	-	220g	35 cm	21	23.08.12	Vesterålen	Line	4 døgn	Mye	Bløt
HM2	Liten	R	With	256g	35 cm	17	23.08.12	Vesterålen	Line	4 døgn	Mye	Bløt
HM3	Liten	L	-	216g	32,5 cm	12	23.08.12	Vesterålen	Line	4 døgn	Middels	Normal
HM4	Medium	R	With	228g	33 cm	15	23.08.12	Vesterålen	Line	4 døgn	Middels	Normal
HM5	Medium	L	-	298g	39 cm	15	23.08.12	Vesterålen	Line	4 døgn	Middels	Normal
HM6	Medium	R	With	335g	40 cm	14	23.08.12	Vesterålen	Line	4 døgn	Middels	Normal
HM7	Stor	L	-	374g	41 cm	20	23.08.12	Vesterålen	Line	4 døgn	Middels	Normal
HM8	Stor	R	With	420g	44 cm	19	23.08.12	Vesterålen	Line	4 døgn	Middels	Normal

Navn på anlegg: Norway Seafoods AS avd Båtsfjord												
Navn på fileteringsmaskin: Baader 184 (1-4) 185 (5-8)												
Fillet kode	**Størrelse**	**H/V fillet side**	**Skinn**	**Fillet vekt**	**Fillet lengde**	**Fangst dato**	**Fangst kl.**	**Fangst sted**	**Fangst metode**	**Tid fra fangst til prosessering**	**Spalting**	**Bløthet**
HB1	Liten	L	Med	235g	34 cm	12.09.12	?	Makkaur/Båtsfjord	Line	1 døgn	Lite	Normal
HB2	Liten	R	Uten	195g	32 cm	12.09.12		Makkaur/Båtsfjord	Line	1 døgn	Lite	Normal
HB3	Medium	L	Med	295g	35 cm	12.09.12		Makkaur/Båtsfjord	Line	1 døgn	Lite	Normal
HB4	Liten	R	Uten	260g	33 cm	12.09.12		Makkaur/Båtsfjord	Line	1 døgn	Mye	Bløt
HB5	Medium	L	Med	310g	37 cm	12.09.12		Makkaur/Båtsfjord	Line	1 døgn	Ingen	Fast
HB6	Medium	R	Uten	280g	35 cm	12.09.12		Makkaur/Båtsfjord	Line	1 døgn	Ingen	Fast
HB7	Stor	L	Med	365g	38 cm	12.09.12		Makkaur/Båtsfjord	Line	1 døgn	Ingen	Fast
HB8	Stor	R	Uten	315g	35 cm	12.09.12		Makkaur/Båtsfjord	Line	1 døgn	Ingen	Fast

A.2.3 Saithe

Navn på anlegg: Norway Seafoods AS avd Båtsfjord												
Navn på fileteringsmaskin: Baader 184												
Fillet kode	**Størrelse**	**H/V fillet side**	**Skinn**	**Fillet vekt**	**Fillet lengde**	**Fangst dato**	**Fangst kl.**	**Fangst sted**	**Fangst metode**	**Tid fra fangst til prosessering**	**Spalting**	**Bløthet**
SB1	Medium	L	Med	375g	35 cm	09.09.12		Makkaur/Båtsfjord	Snurrevad	3 døgn	Middels	Normal
SB2	Stor	L	Uten	385g	35 cm	09.09.12		Makkaur/Båtsfjord	Snurrevad	3 døgn	Middels	Normal
SB3	Stor	R	Med	390g	36 cm	09.09.12		Makkaur/Båtsfjord	Snurrevad	3 døgn	Lite	Normal
SB4	Medium	L	Uten	370g	35 cm	09.09.12		Makkaur/Båtsfjord	Snurrevad	3 døgn	Lite	Normal
SB5	Stor	R	Med	390g	36 cm	09.09.12		Makkaur/Båtsfjord	Snurrevad	3 døgn	Ingen	Normal
SB6	Medium	R	Uten	783g	35 cm	09.09.12		Makkaur/Båtsfjord	Snurrevad	3 døgn	Lite	Normal
SB7	Medium	L	Uten	380g	36 cm	09.09.12		Makkaur/Båtsfjord	Snurrevad	3 døgn	Lite	Normal
SB8	Stor	R	Med	405g	36 cm	09.09.12		Makkaur/Båtsfjord	Snurrevad	3 døgn	Lite	Normal

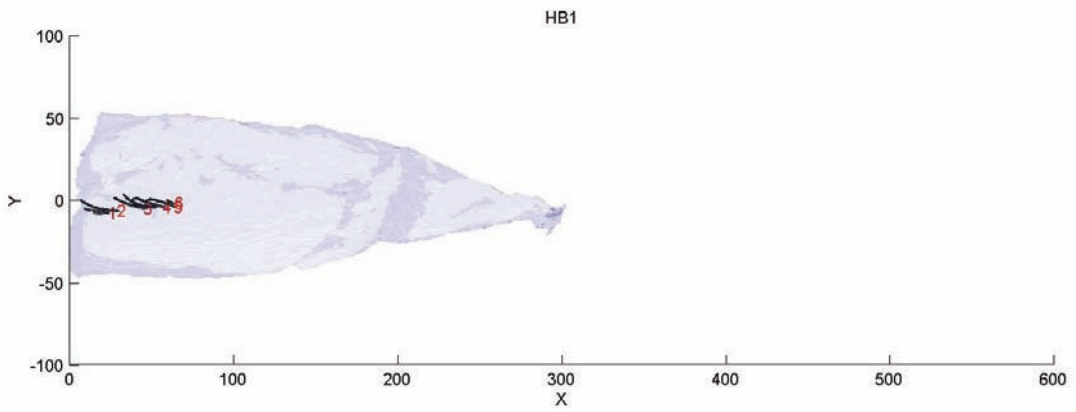
Navn på anlegg: Norway Seafoods AS avd Båtsfjord												
Navn på fileteringsmaskin: Baader 184												
Fillet kode	**Størrelse**	**H/V fillet side**	**Skinn**	**Fillet vekt**	**Fillet lengde**	**Fangst dato**	**Fangst kl.**	**Fangst sted**	**Fangst metode**	**Tid fra fangst til prosessering**	**Spalting**	**Bløthet**
SB9	Stor	L	Uten	450g	37 cm	09.09.12	?	Makkaur/Båtsfjord	Snurrevad	3 døgn	Middels	Normal
SB10	Stor	R	Med	475g	37 cm	09.09.12		Makkaur/Båtsfjord	Snurrevad	3 døgn	Ingen	Fast
SB11	Medium	R	Med	355g	34 cm	09.09.12		Makkaur/Båtsfjord	Snurrevad	3 døgn	Middels	Normal
SB12	Liten	L	Uten	335g	35 cm	09.09.12		Makkaur/Båtsfjord	Snurrevad	3 døgn	Noe	Normal
SB13	Medium	R	Med	360g	35 cm	09.09.12		Makkaur/Båtsfjord	Snurrevad	3 døgn	Lite	Normal
SB14	Liten	L	Uten	250g	29 cm	09.09.12		Makkaur/Båtsfjord	Snurrevad	3 døgn	Lite	Fast
SB15	Liten	R	Uten	315g	33 cm	09.09.12		Makkaur/Båtsfjord	Snurrevad	3 døgn	Lite	Fast
SB16	Liten	R	Med	315g	34 cm	09.09.12		Makkaur/Båtsfjord	Snurrevad	3 døgn	Ingen	Normal

A.2.4 Salmon

Filet kode	Størrelse	H/V filet side	Skinn	Filet vekt	Filet lengde	Fangst dato	Fangst kl.	Fangst sted	Fangst metode	Tid fra fangst til prosessering	Spalting	Bløthet
R_L_1	3-4	V	M	1,22	48	11/9	17.45	Bømlo	Brønnbåt	12 t	0	0
R_L_2	3-4	V	M	1,26	48	11/9	-	-	-	-	0	0
R_L_3	3-4	V	M	1,36	48,5	11/9	-	-	-	-	0	0
R_L_4	3-4	V	M	1,31	49	11/9	-	-	-	-	0	0
R_L_5	3-4	H	M	1,38	49	11/9	-	-	-	-	0	0
R_L_6	3-4	H	M	1,35	46	11/9	-	-	-	-	0	0
R_L_7	3-4	H	M	1,36	48,5	11/9	-	-	-	-	0	0
R_L_8	3-4	H	M	1,22	47,5	11/9	-	-	-	-	0	0
R_L_9	4-5	V	M	1,96	58	12/9	12.30	Sotra	-	17t	0	0
R_L_10	4-5	V	M	2,01	60	12/9	-	-	-	-	Middels	0
R_L_11	4-5	V	M	1,73	53	12/9	-	-	-	-	0	0
R_L_12	4-5	V	M	2,13	57	12/9	-	-	-	-	Lite	0
R_L_13	4-5	H	M	1,93	58	12/9	-	-	-	-	0	0
R_L_14	4-5	H	M	1,76	52	12/9	-	-	-	-	0	0
R_L_15	4-5	H	M	1,94	59	12/9	-	-	-	-	Lite	0
R_L_16	4-5	H	M	2,14	58	12/9	-	-	-	-	0	0

B 3D renderings of fish

In the following pages, we present a 3D rendering of all the fish captured, with the 3D bones plotted in. These illustrations can also be found in the PDF FishIllustrations.pdf on the eRoom.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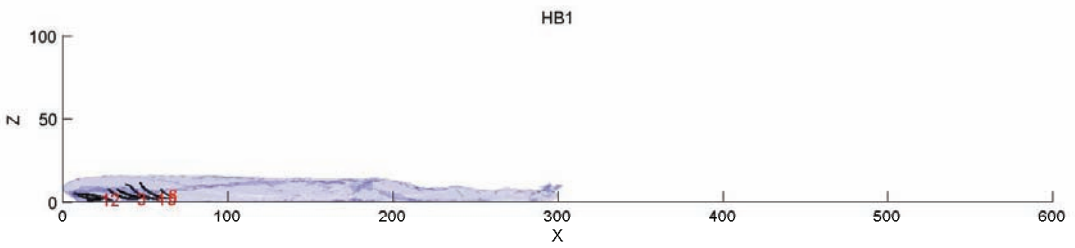
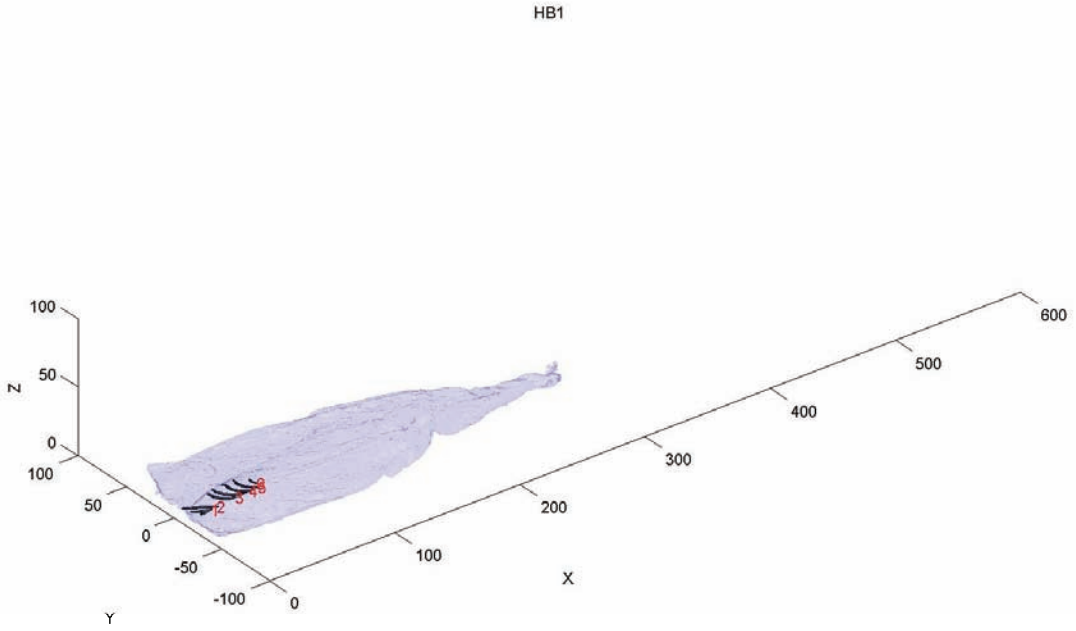
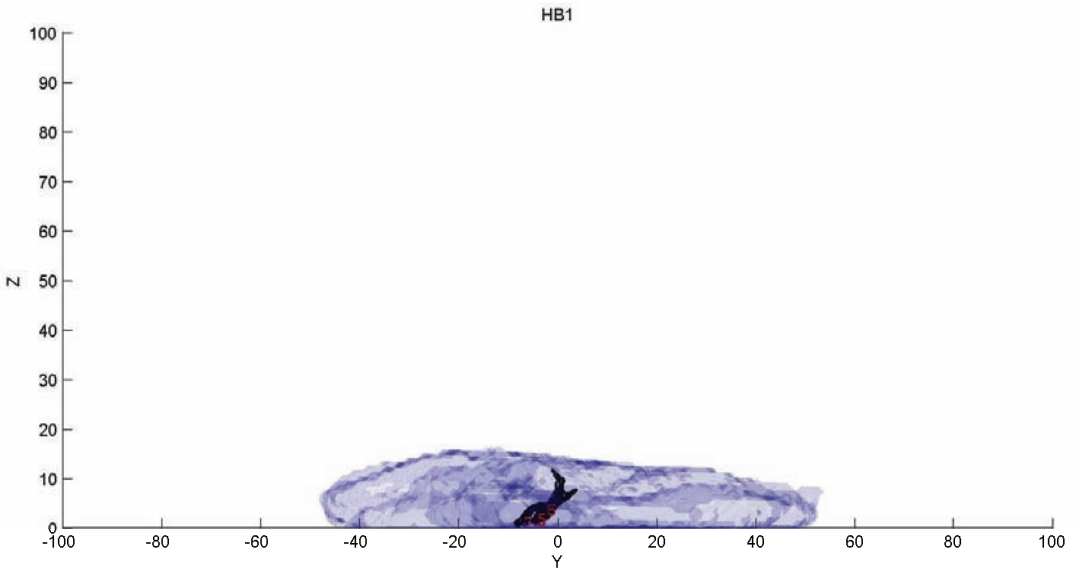
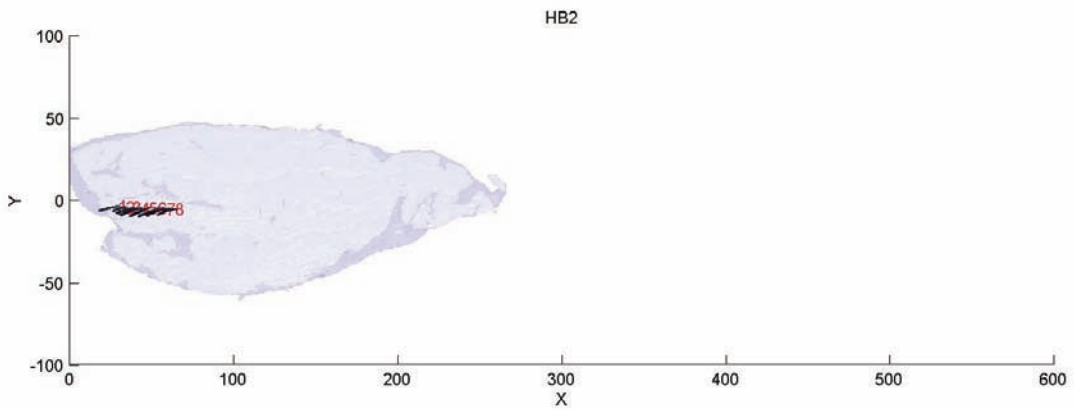
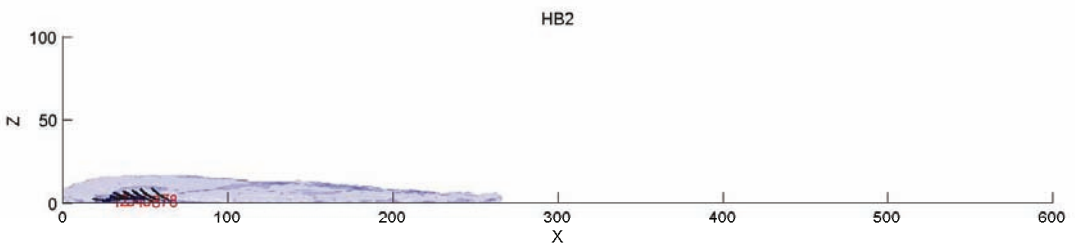
50
0
-50
-100
Y
0
100
200
300
400
500
600
X


HB1
100
50
0
Z
0
100
200
300
400
500
600
X


HB1
100
50
0
Z
100
50
0
-50
-100
Y
0
100
200
300
400
500
600
X


HB1
100
90
80
70
60
50
40
30
20
10
0
Z
-100
-80
-60
-40
-20
0
20
40
60
80
100
Y


HB2
Y
X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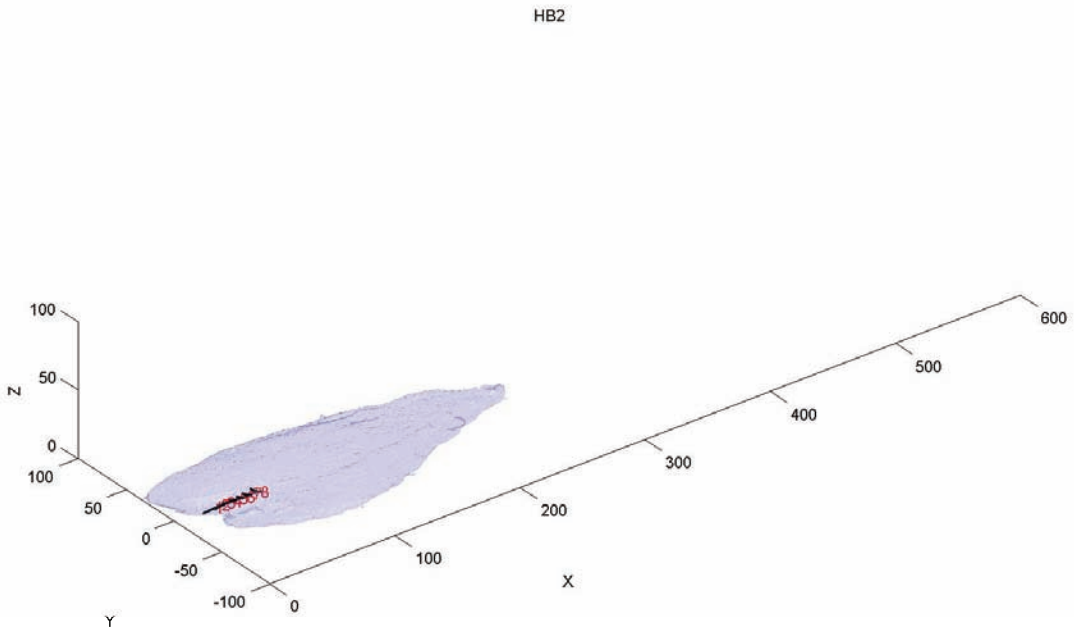
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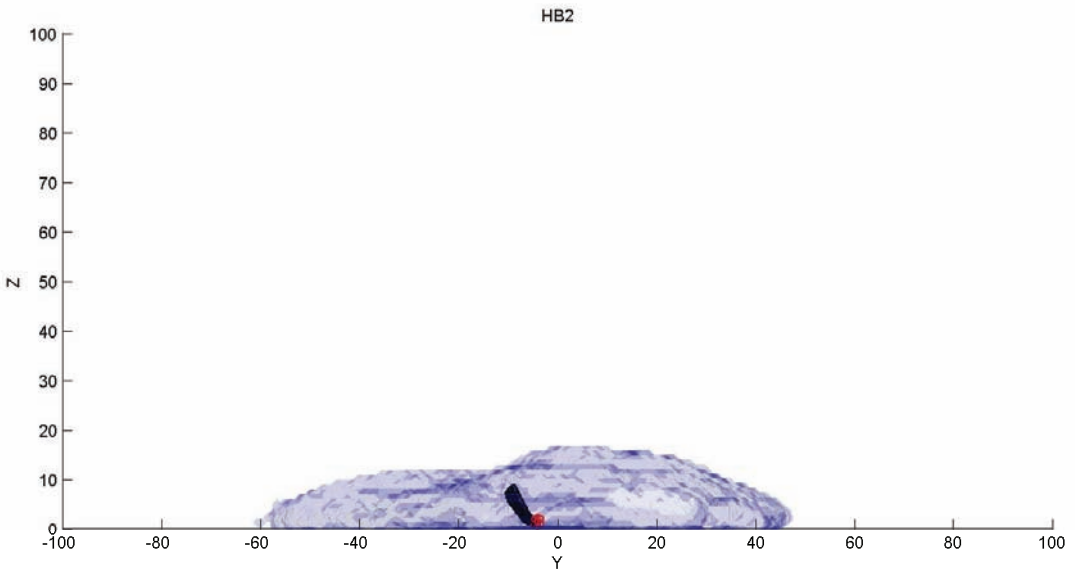
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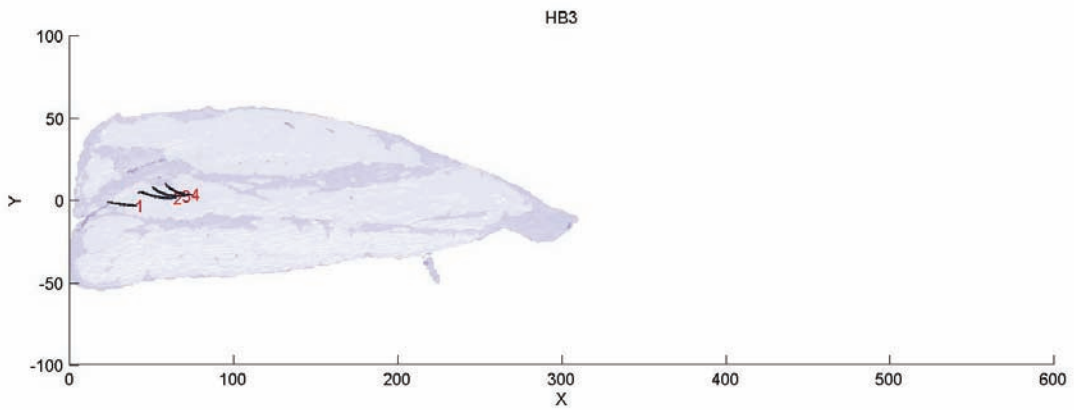
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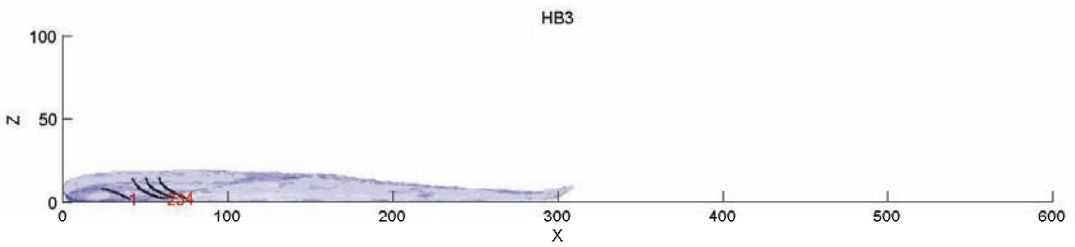
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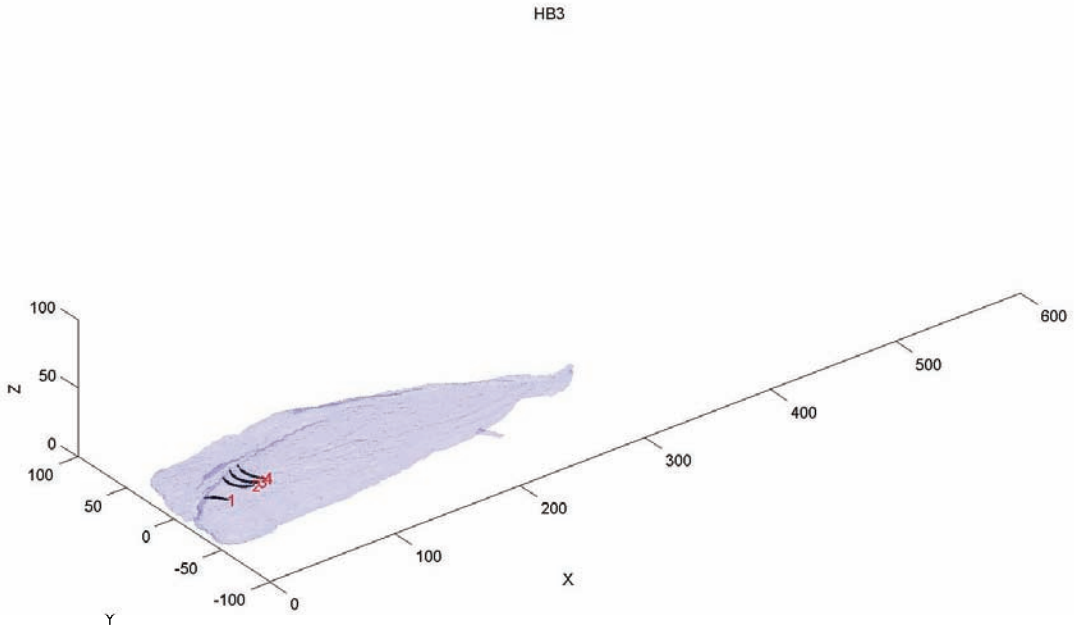
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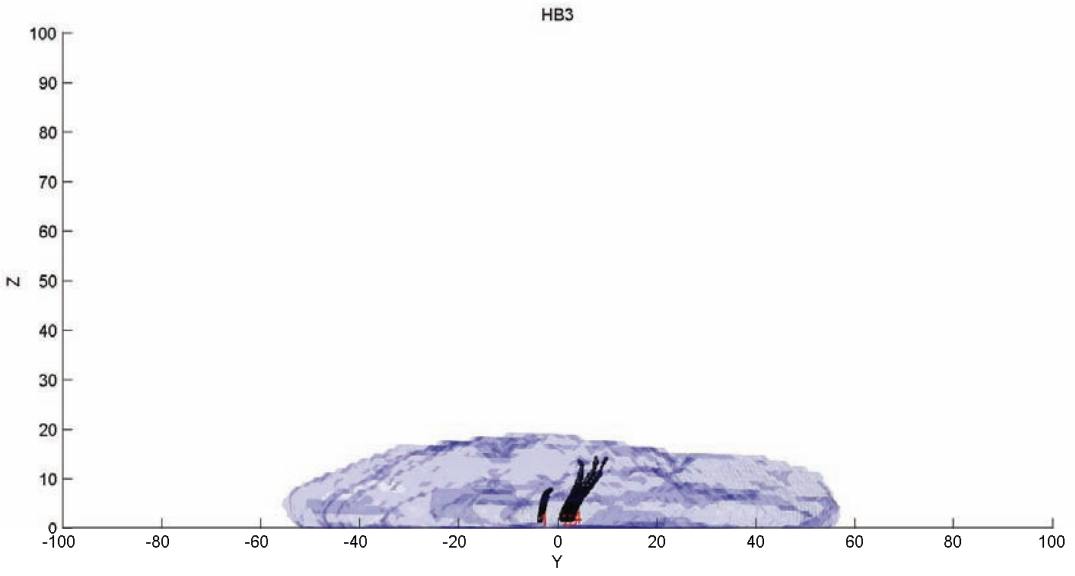
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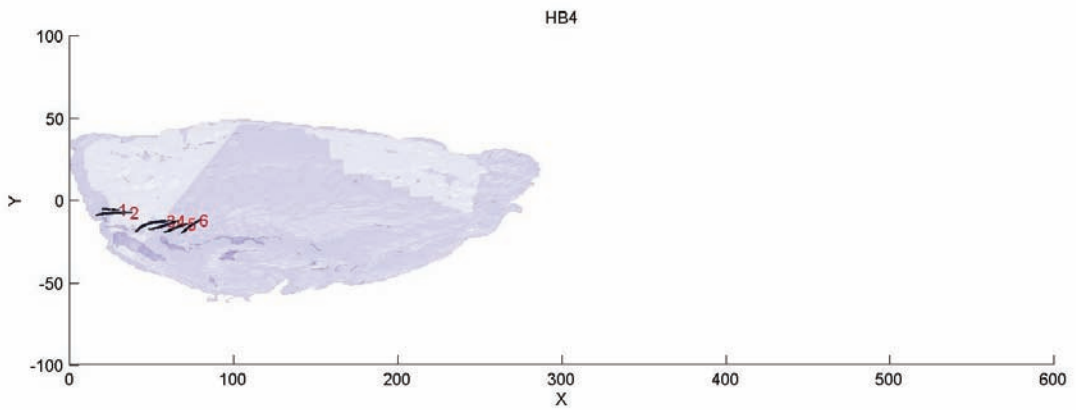
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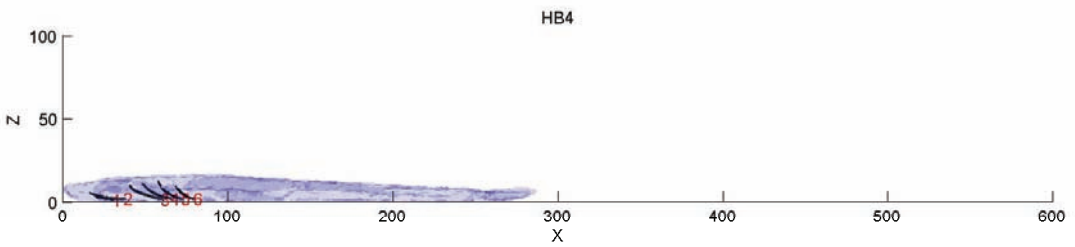
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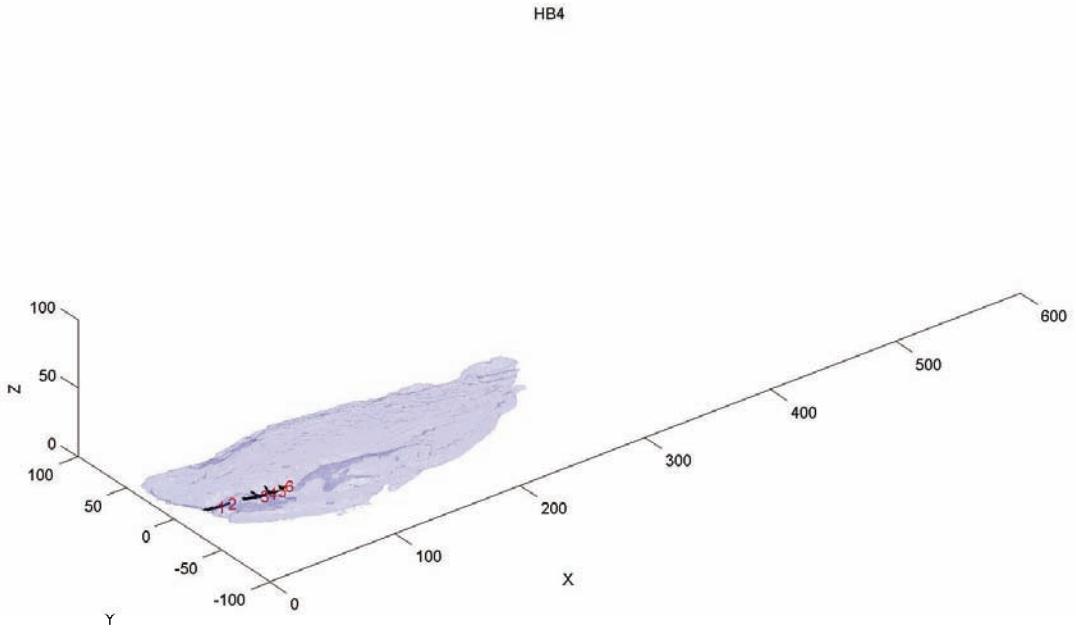
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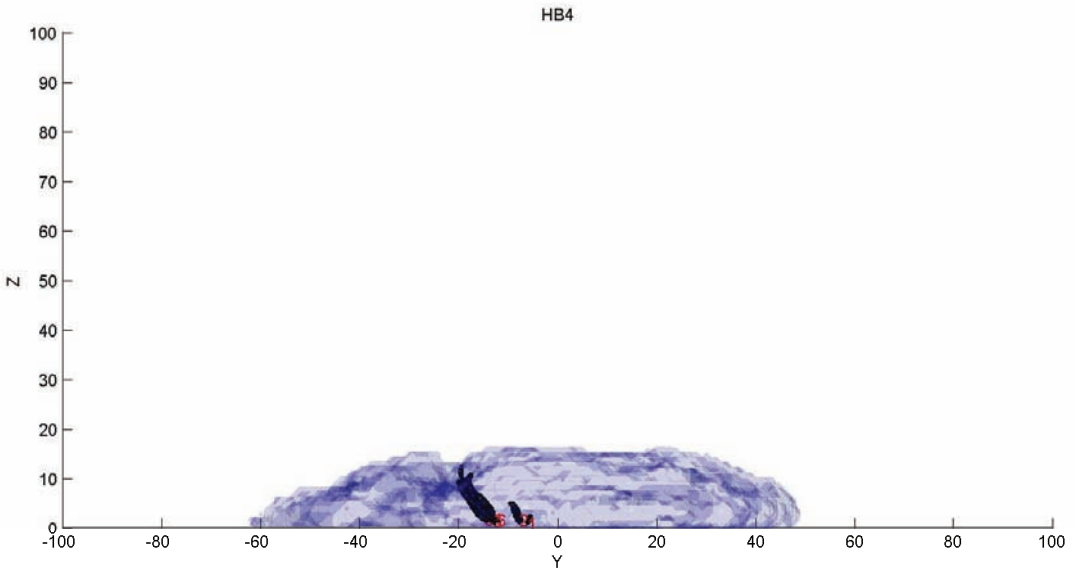
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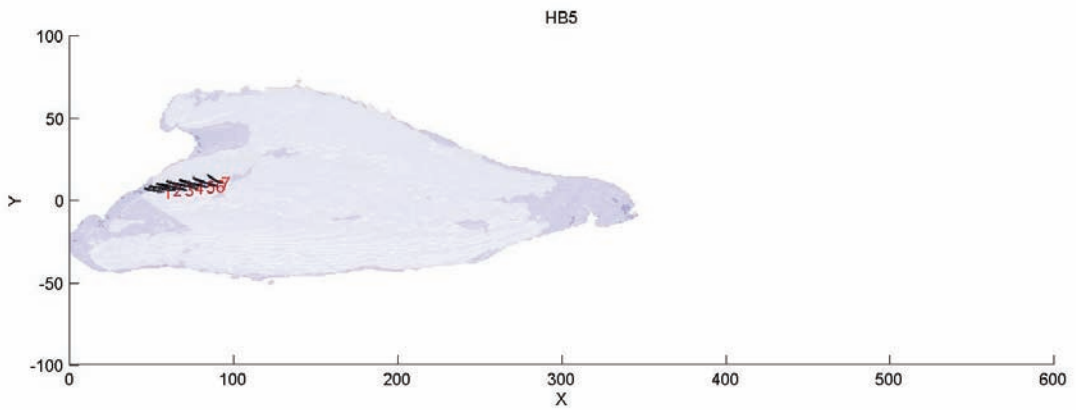
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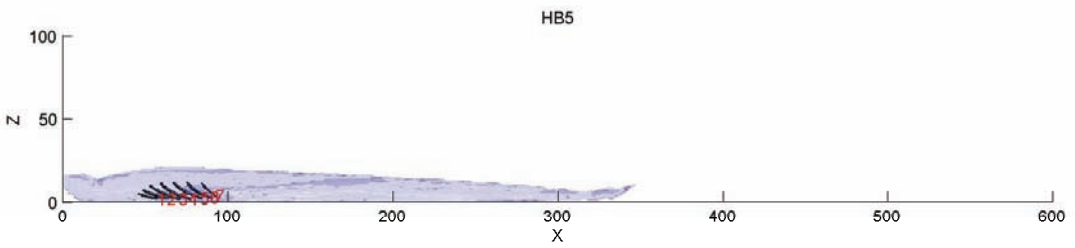
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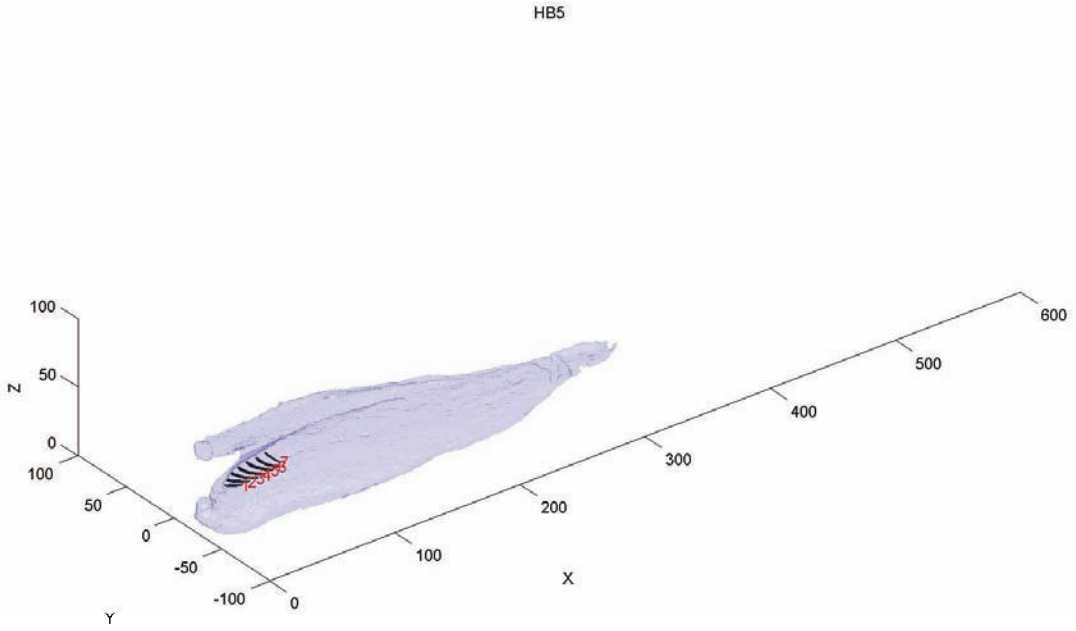
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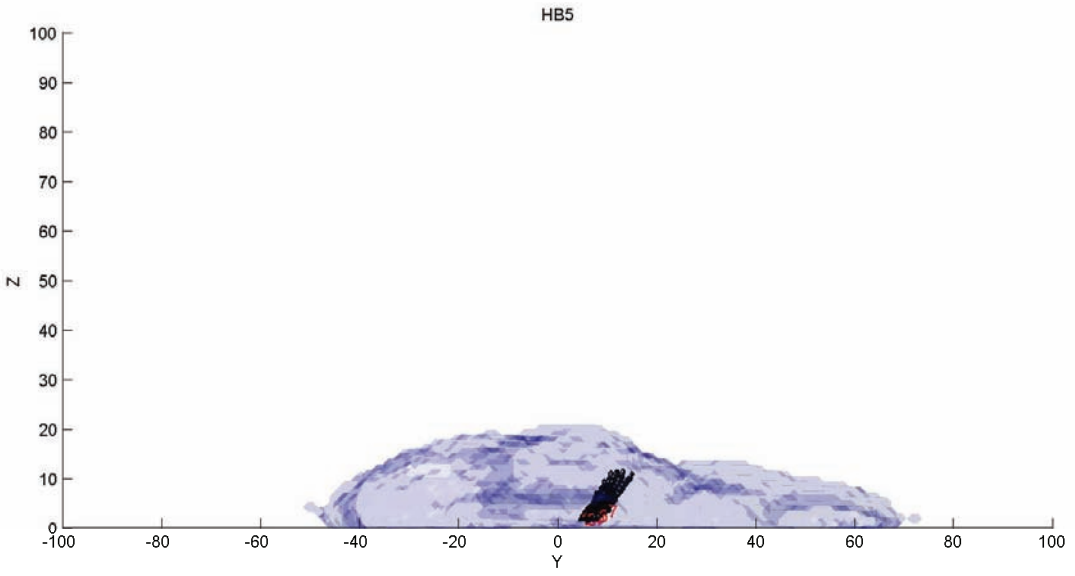
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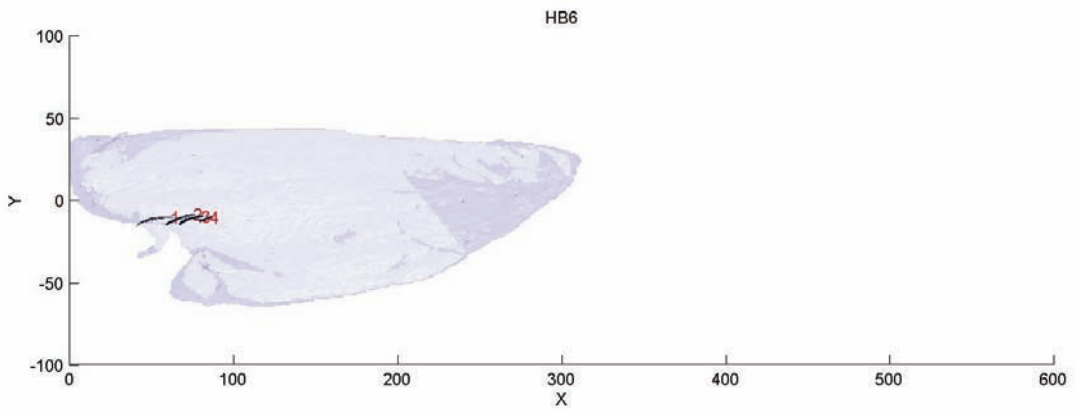
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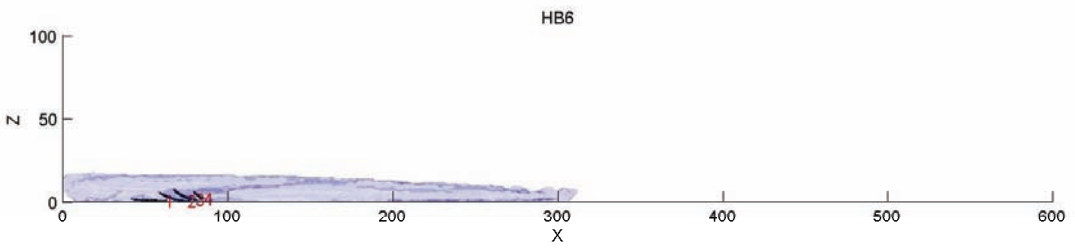
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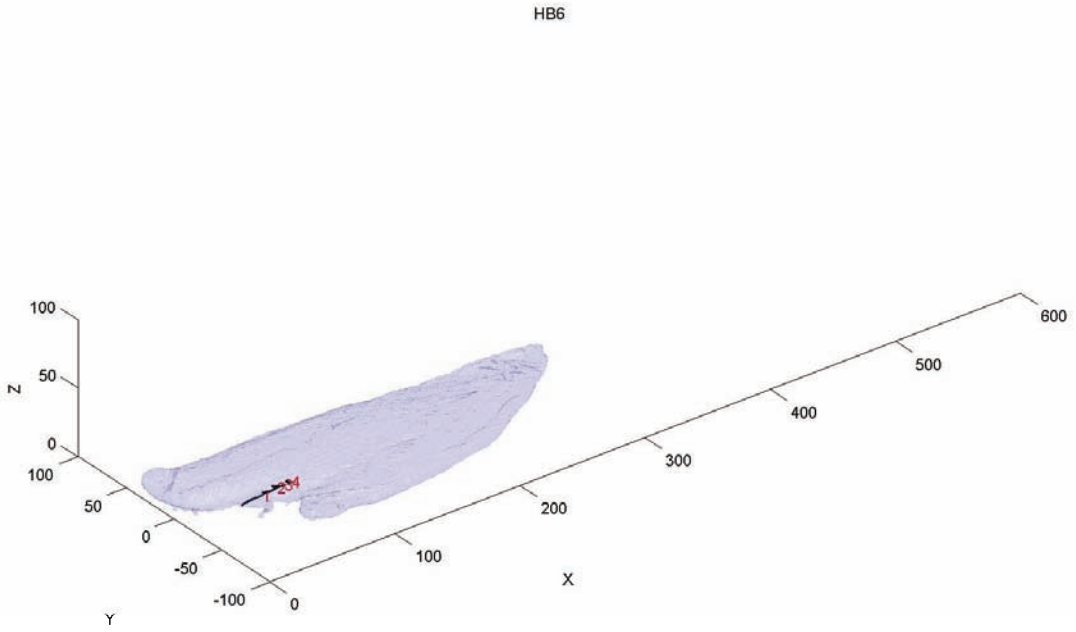
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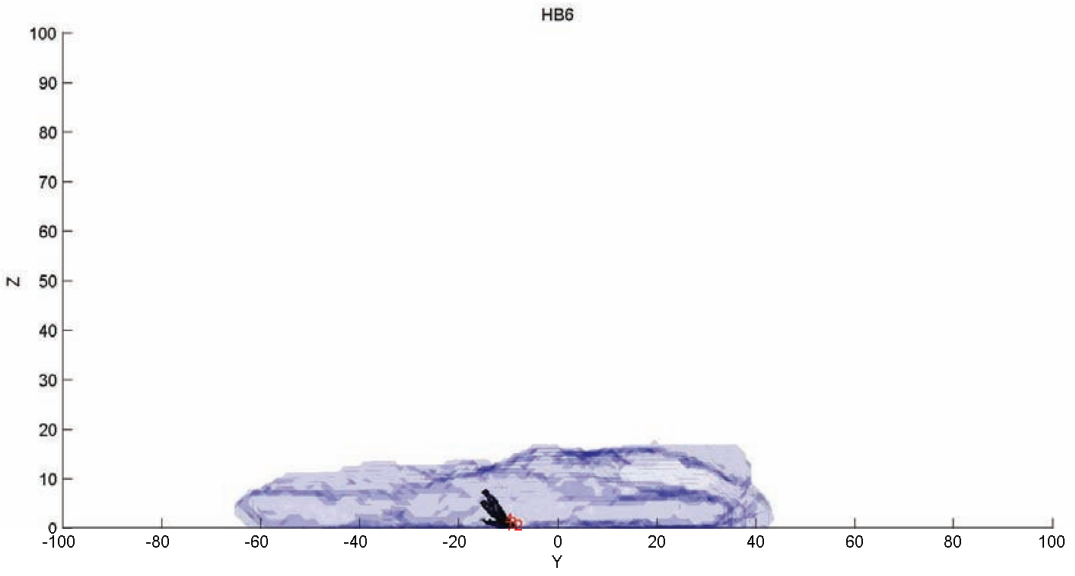
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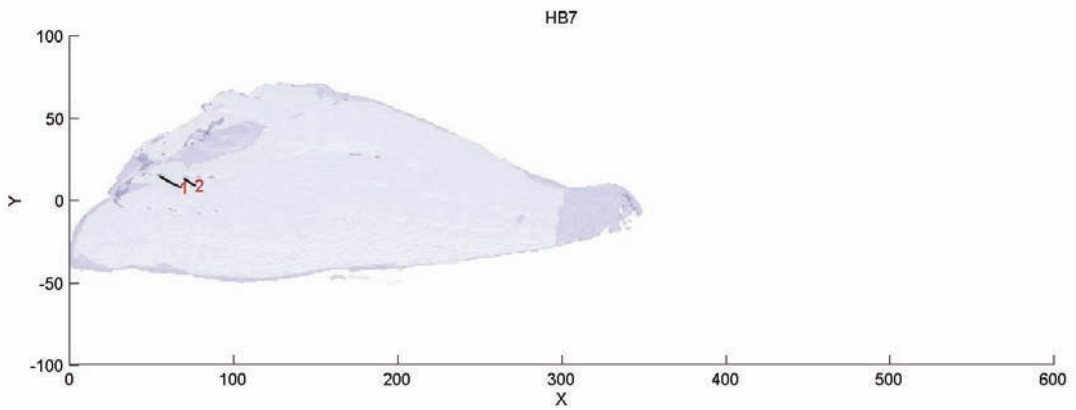
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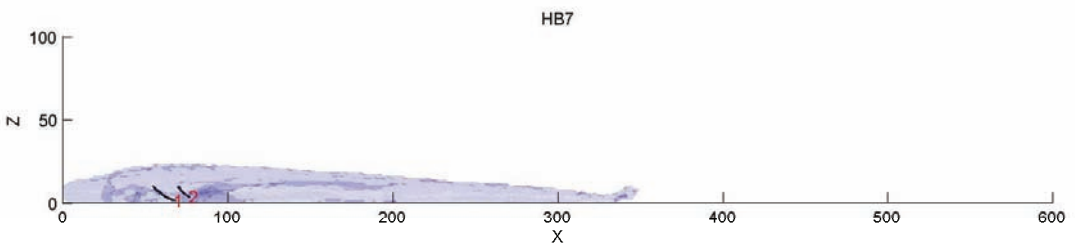
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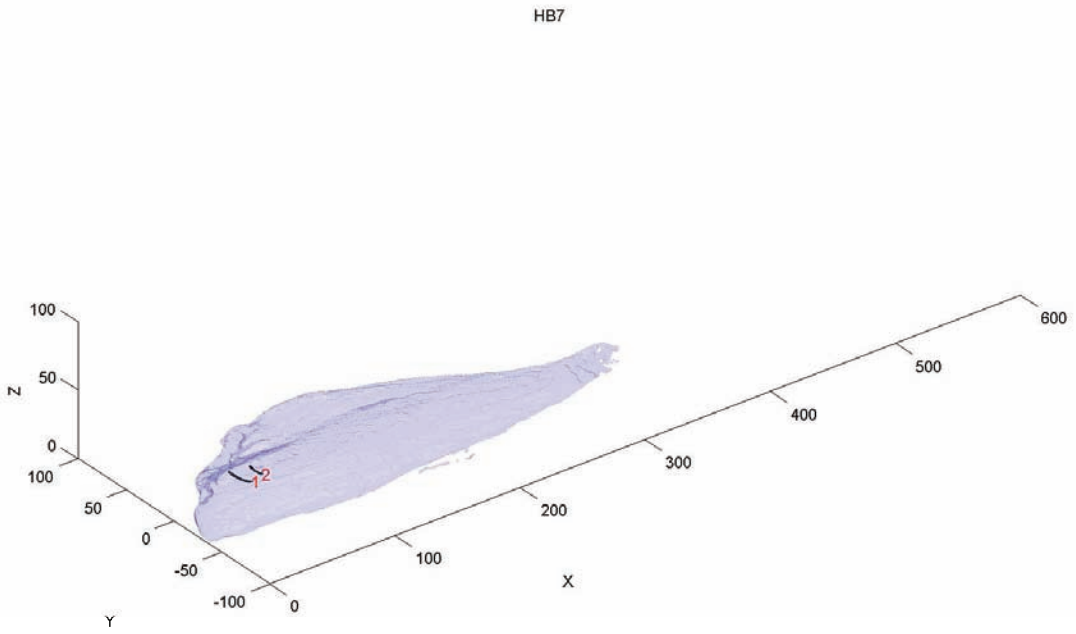
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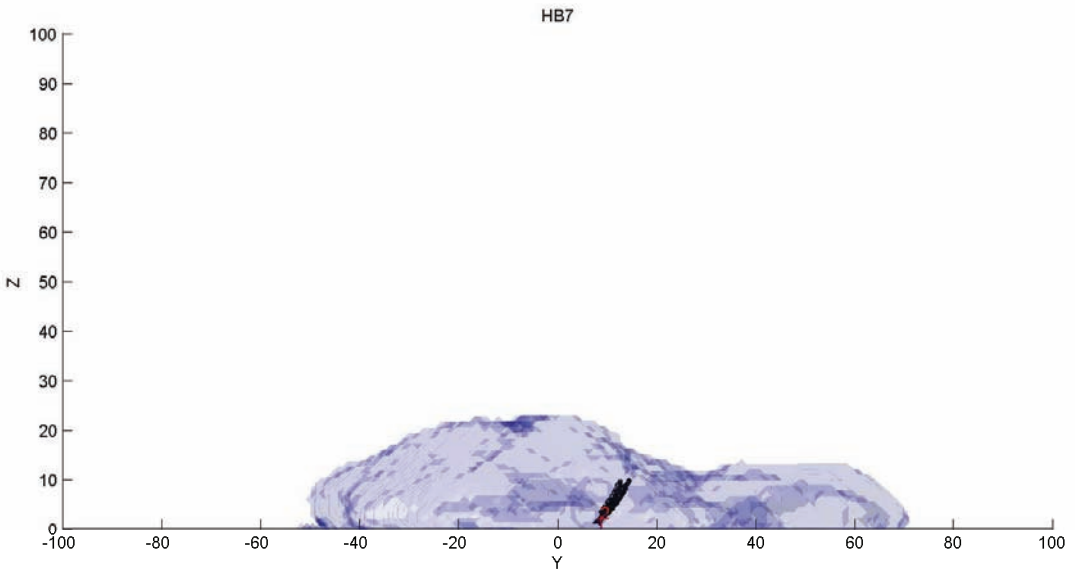
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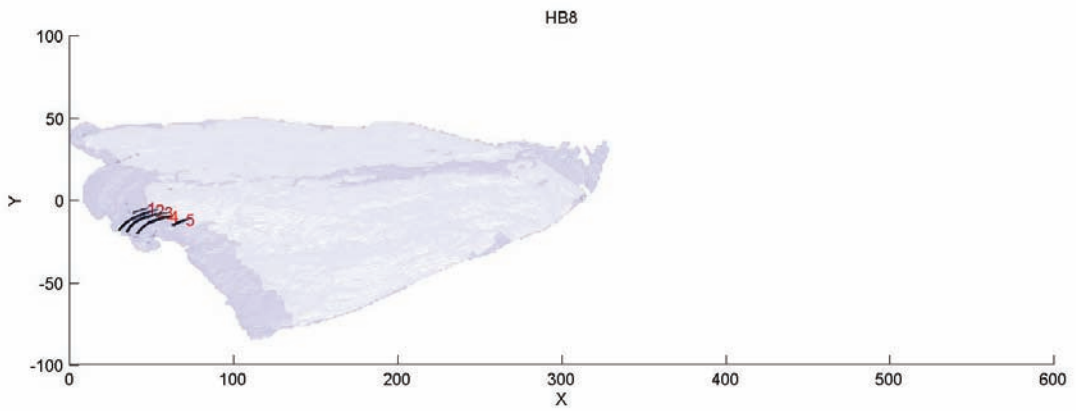
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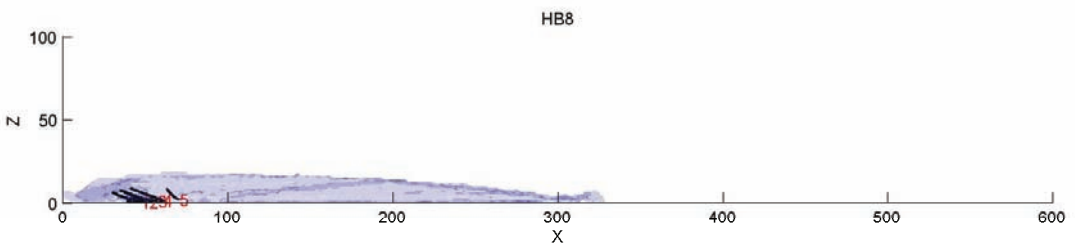
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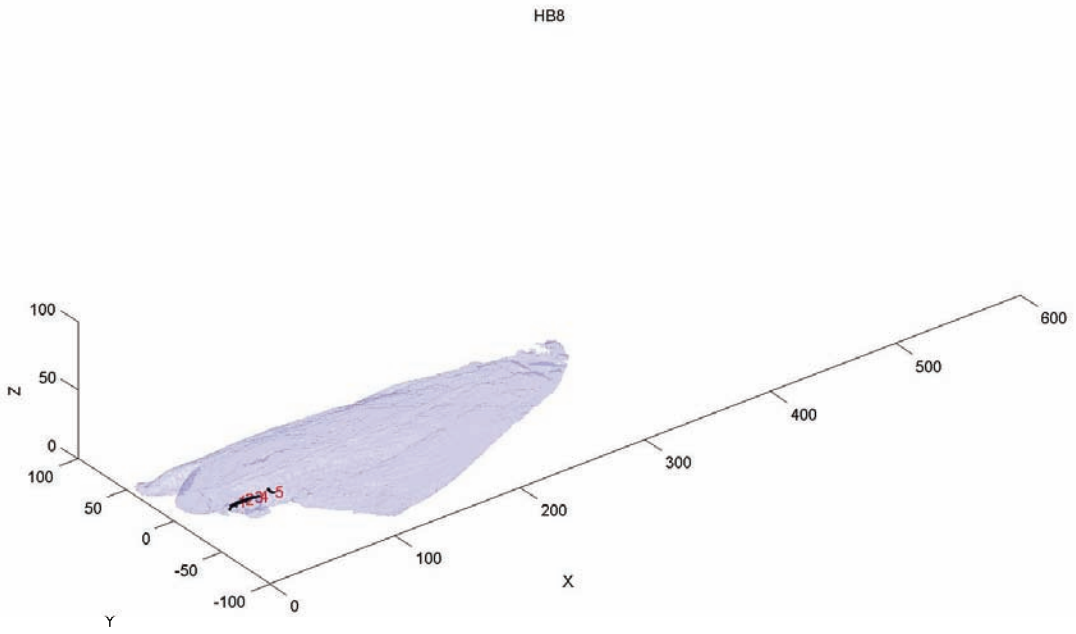
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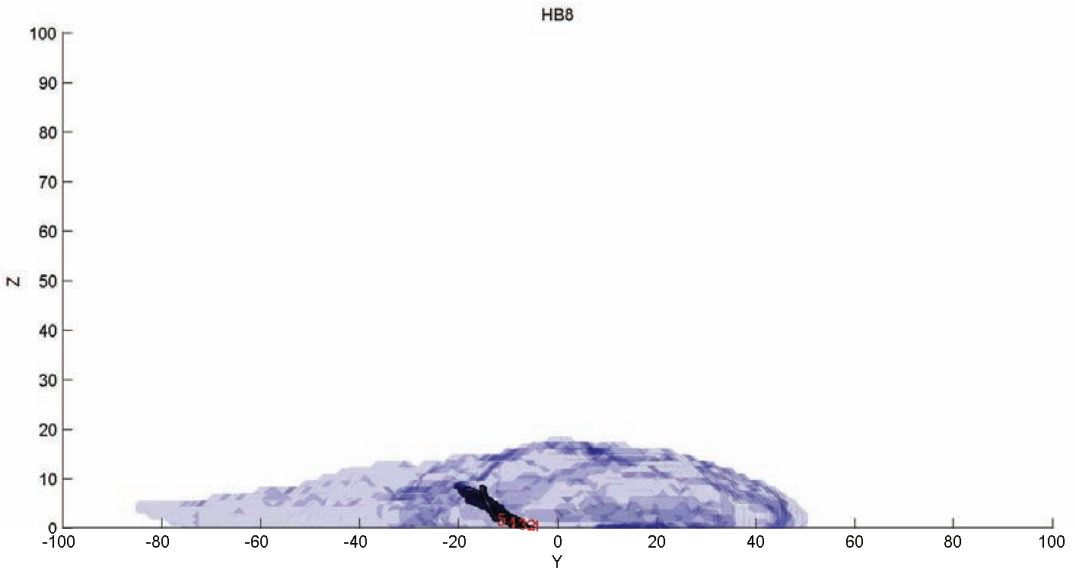
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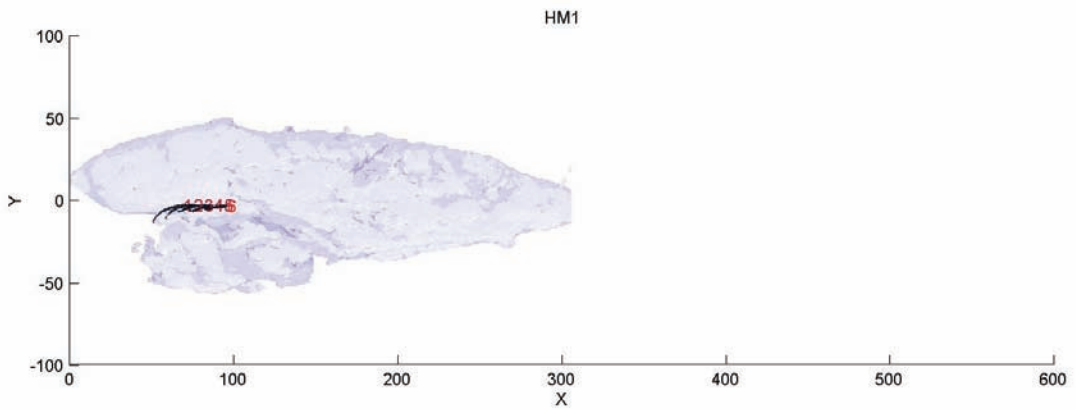
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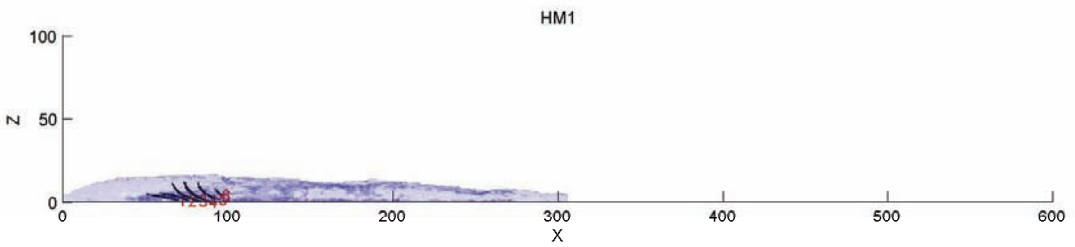
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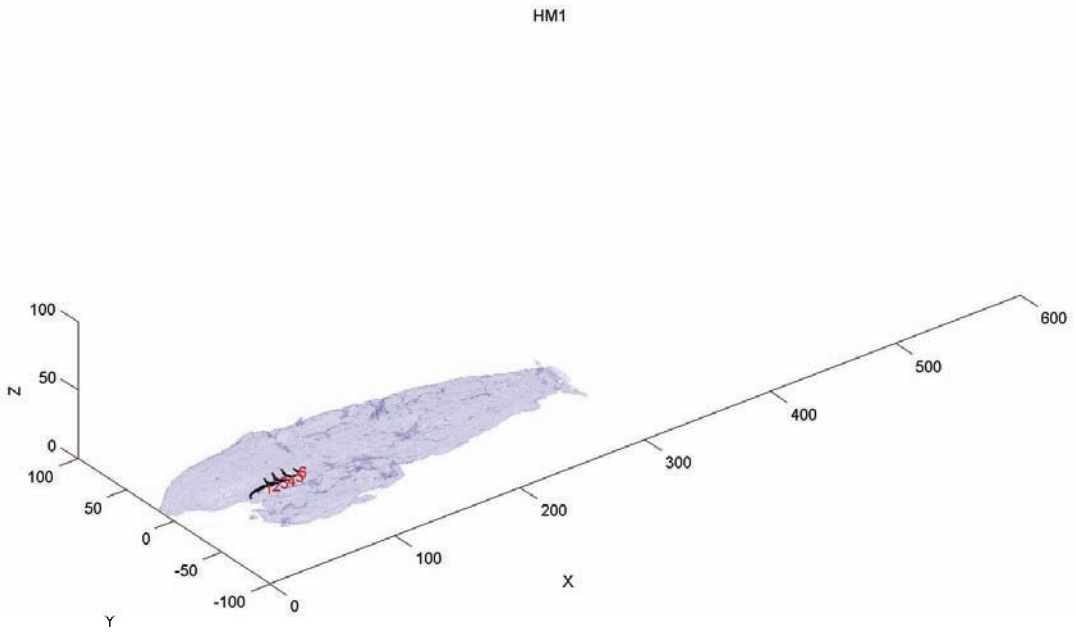
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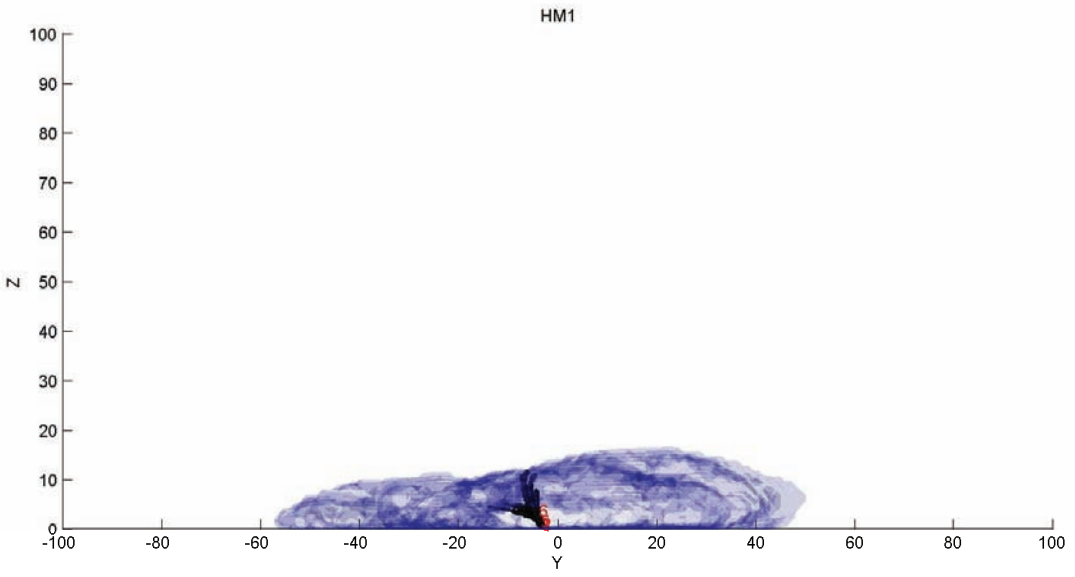
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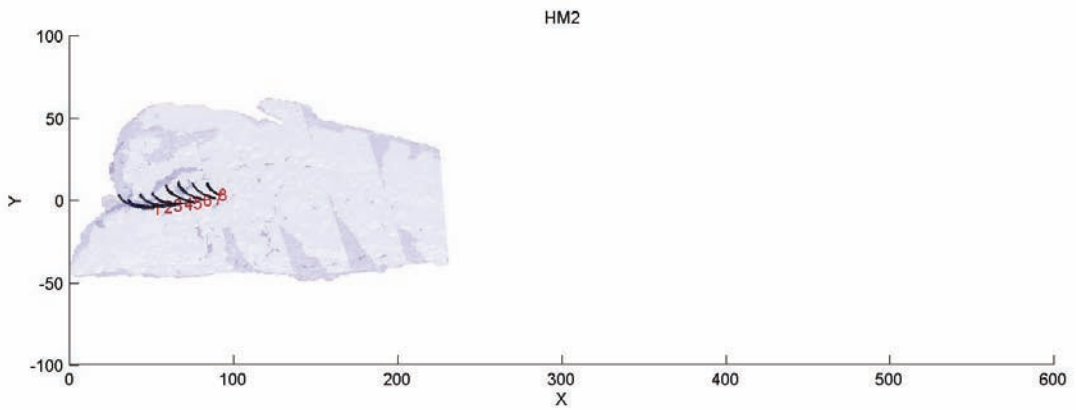
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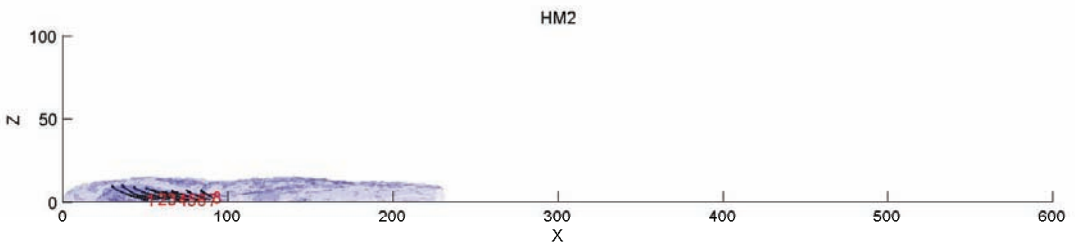
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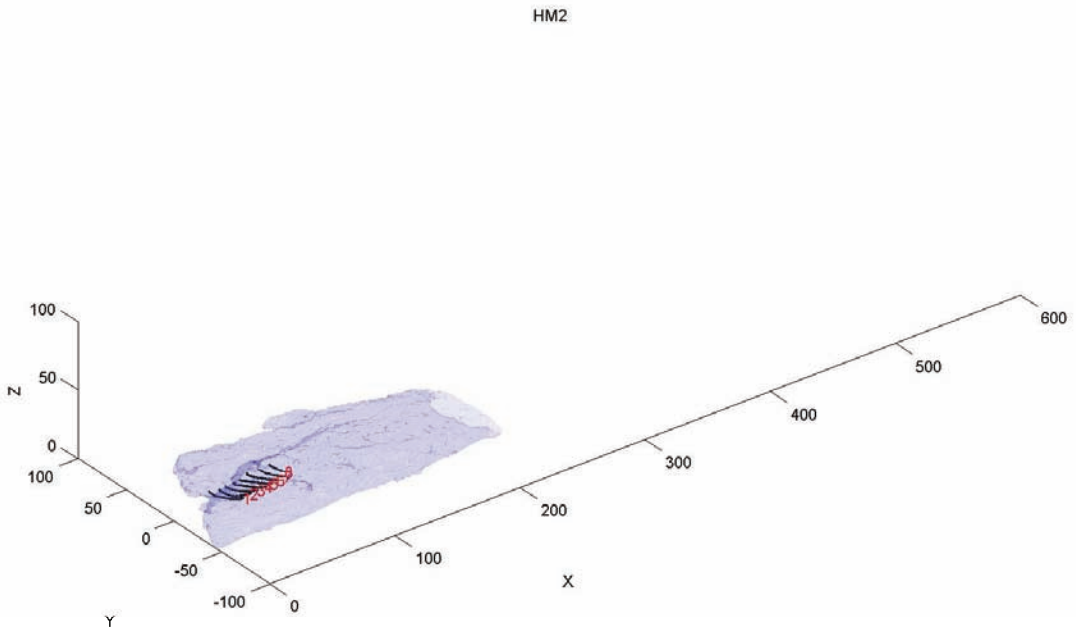
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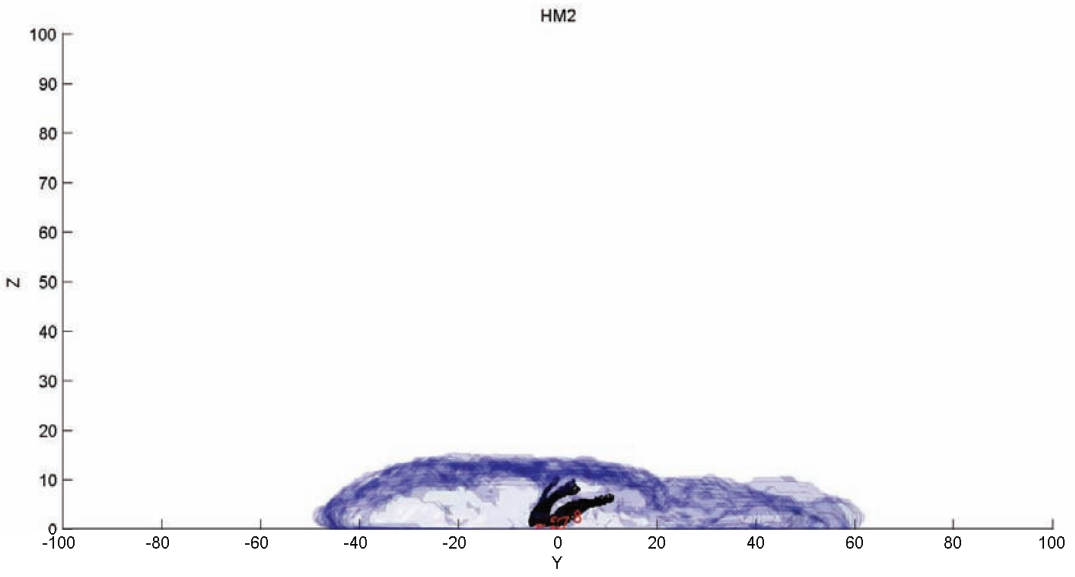
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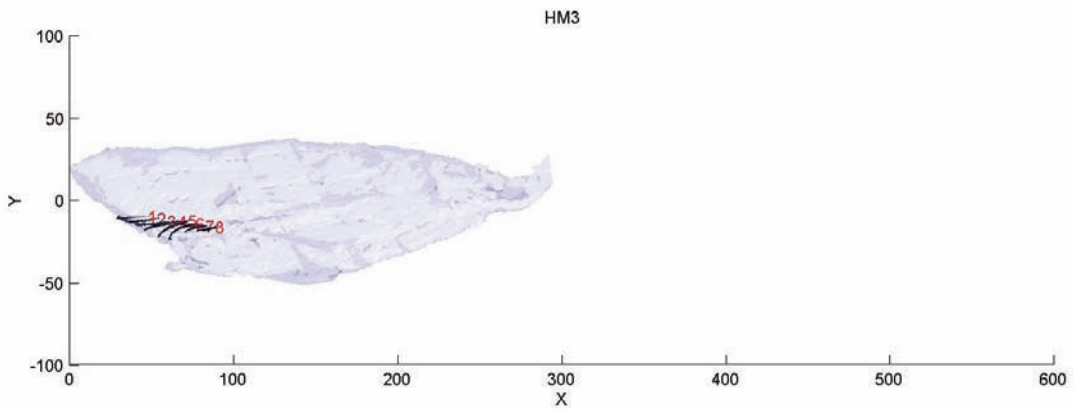
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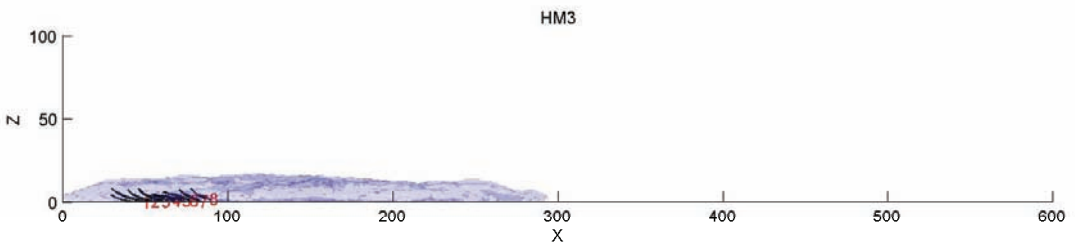
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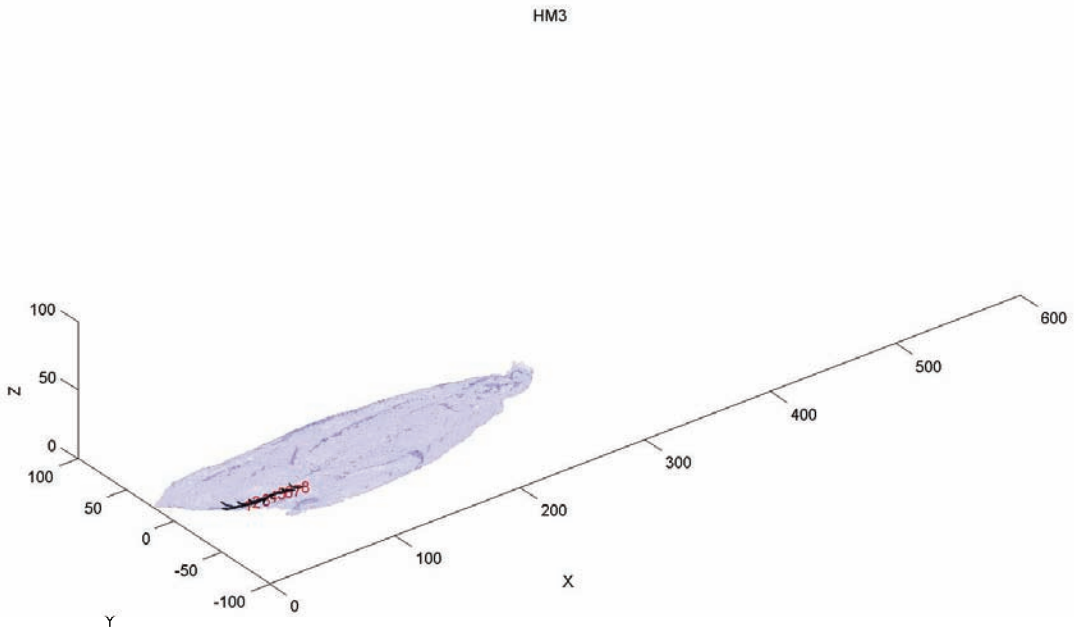
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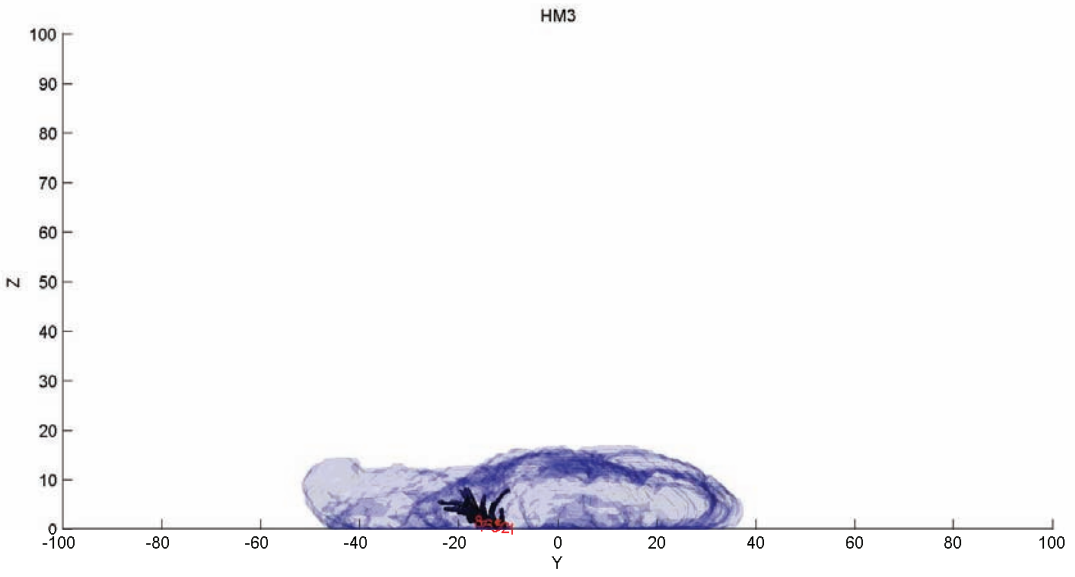
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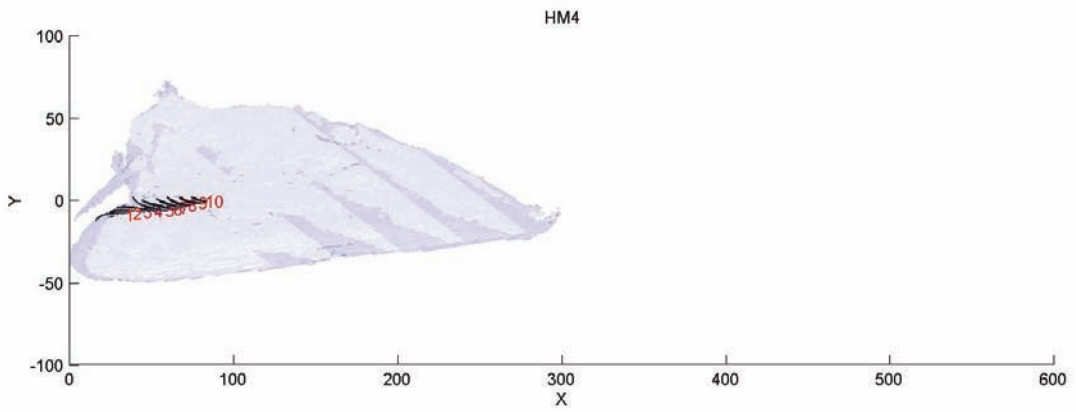
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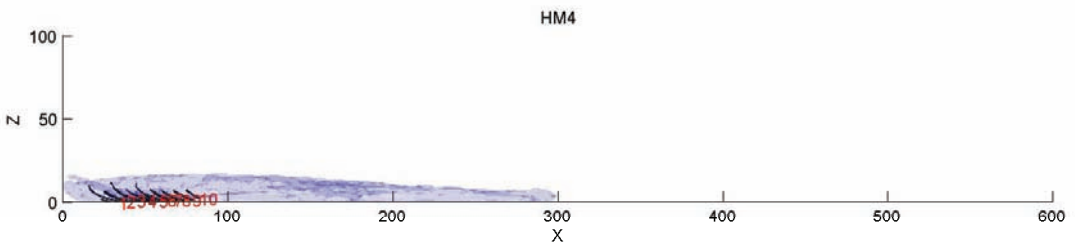
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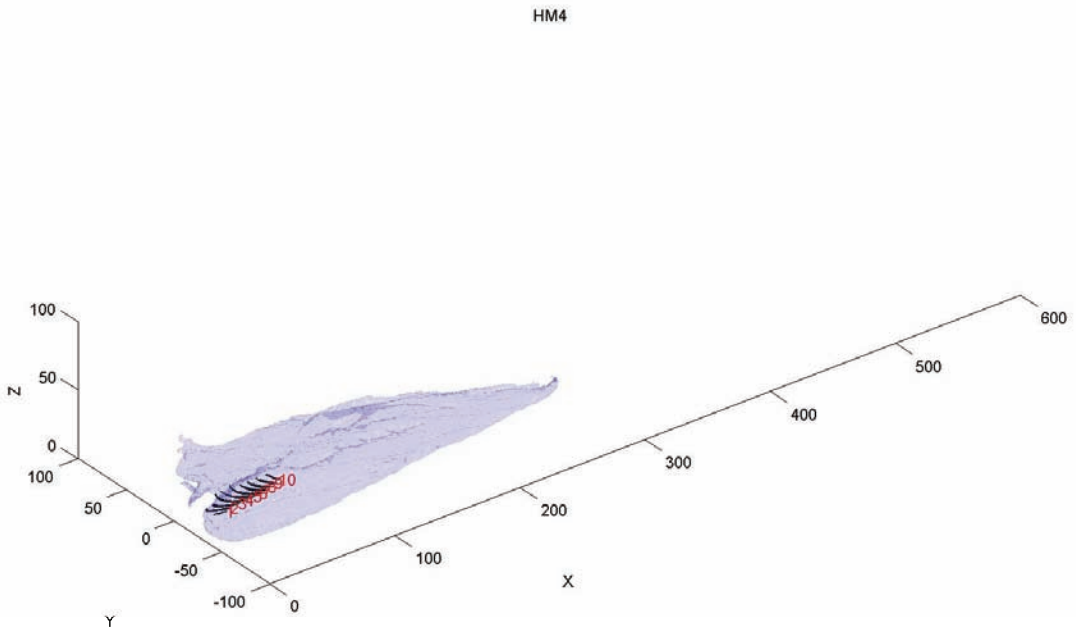
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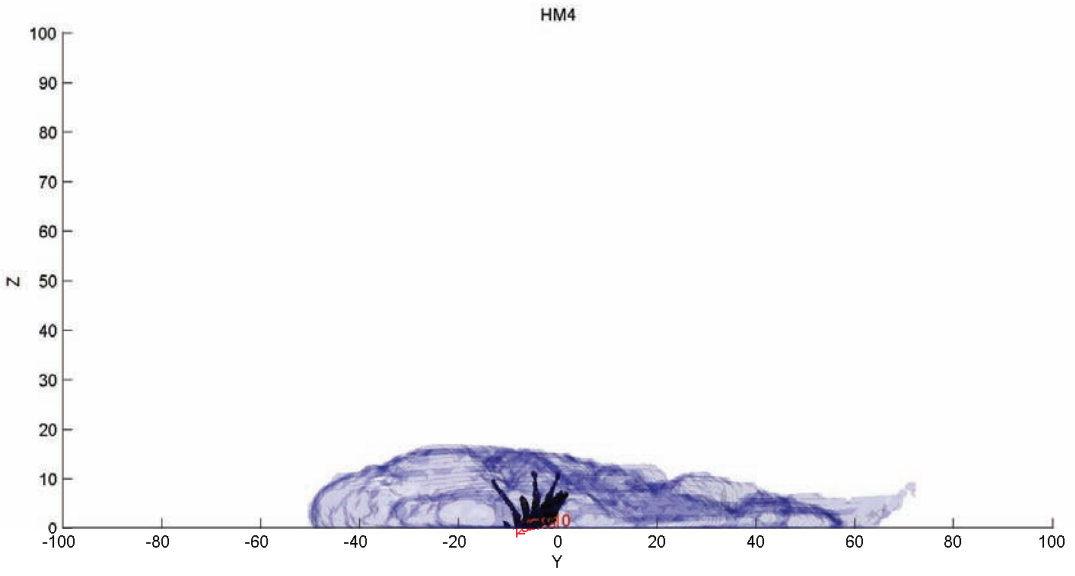
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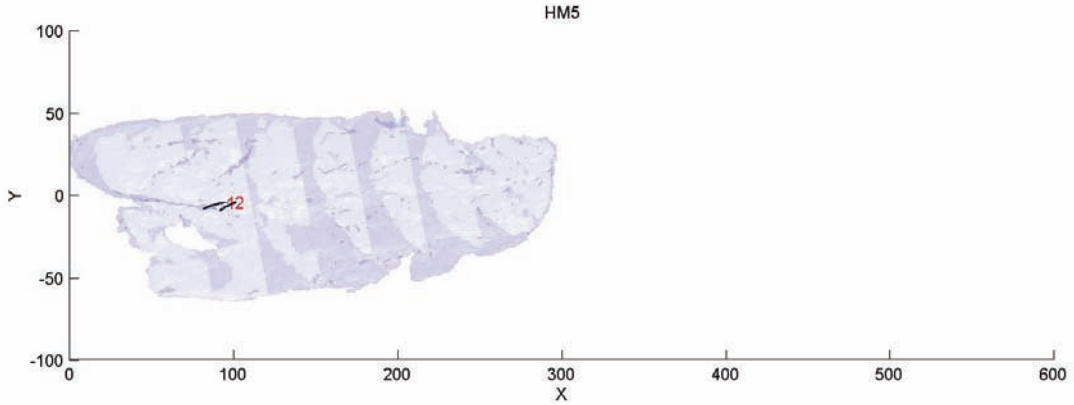
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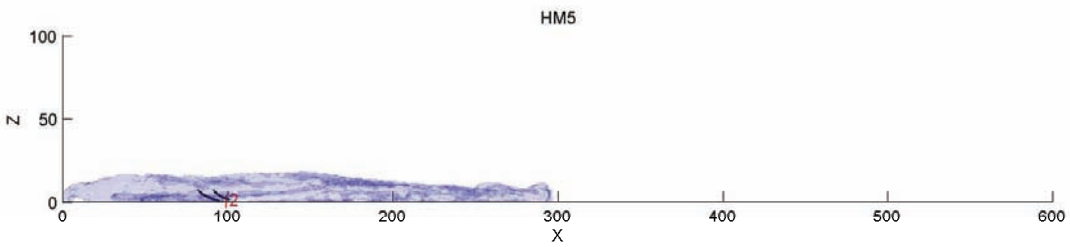
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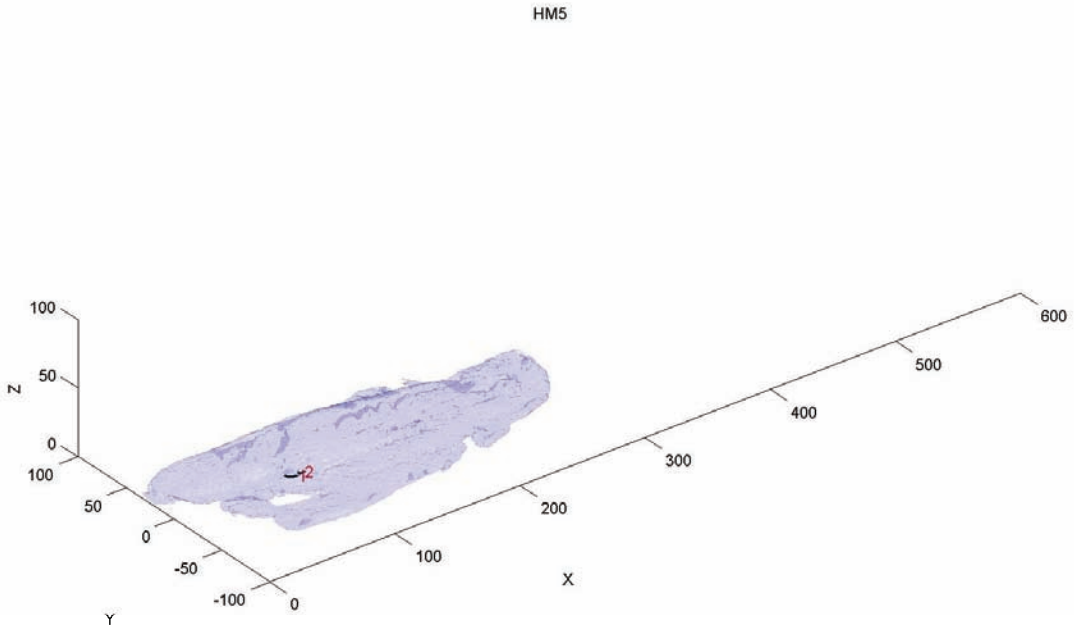
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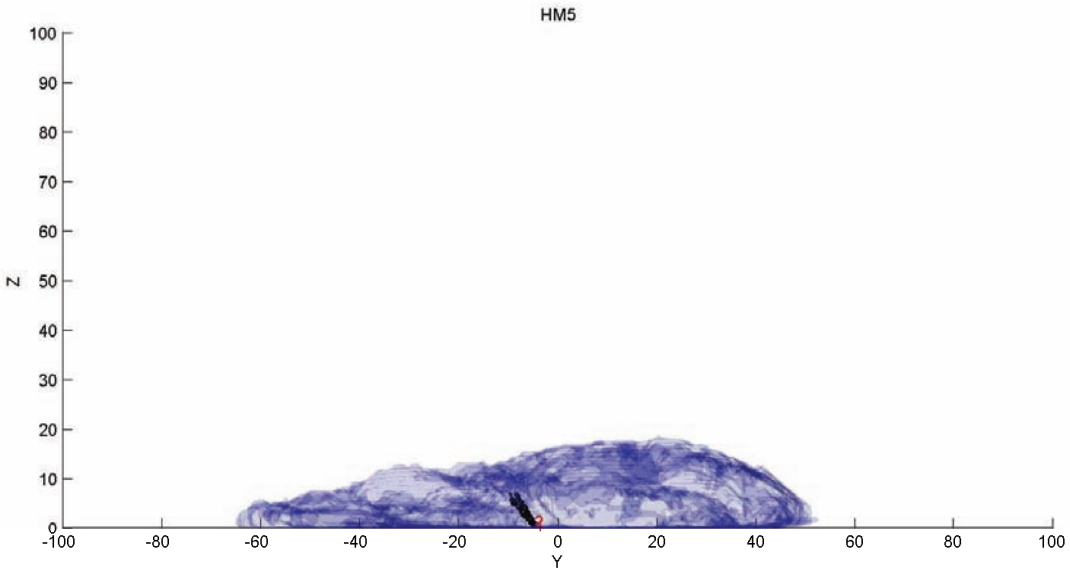
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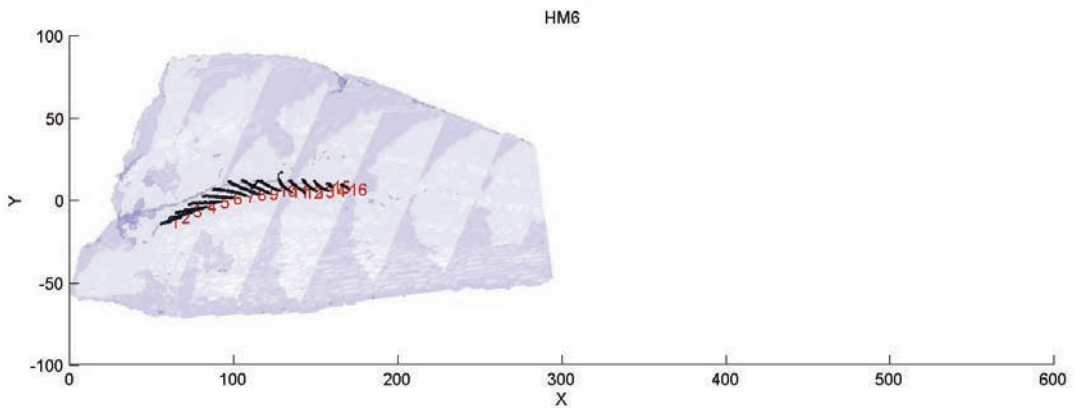
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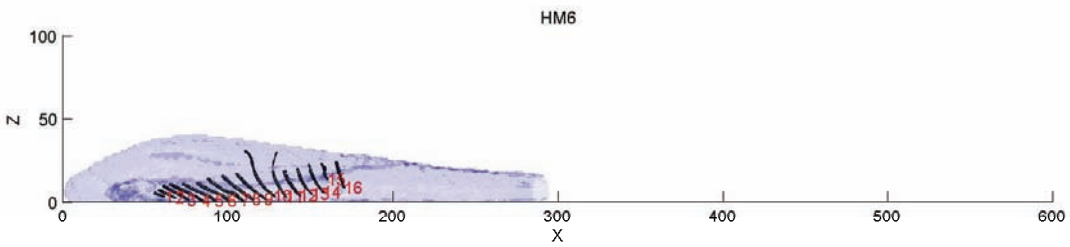
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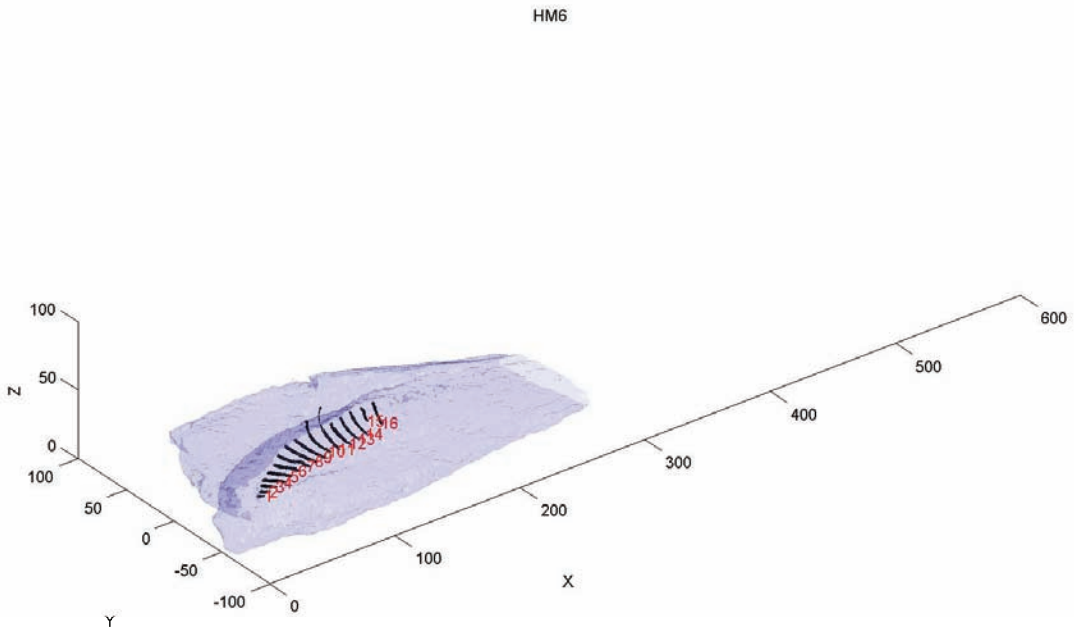
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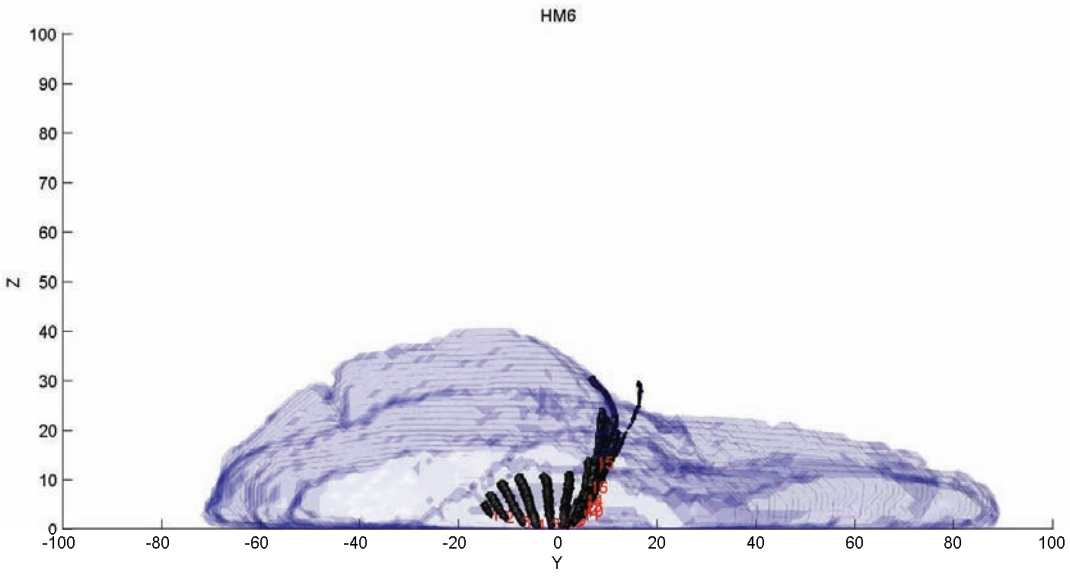
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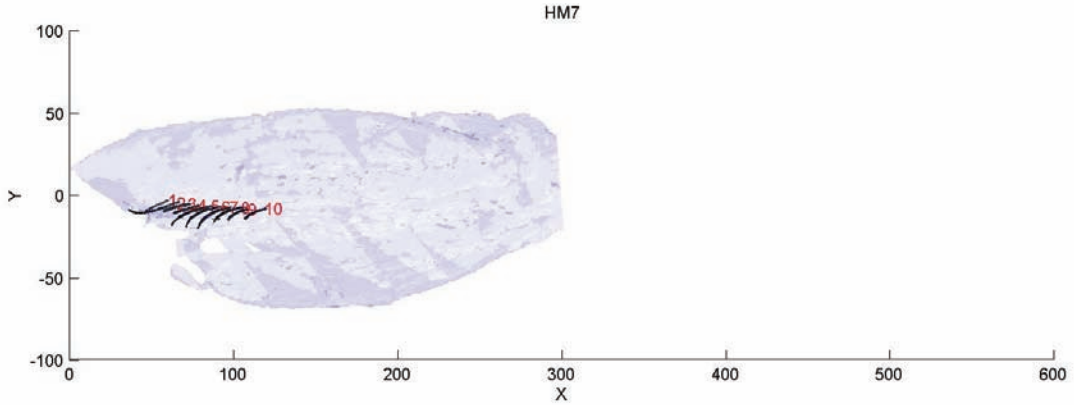
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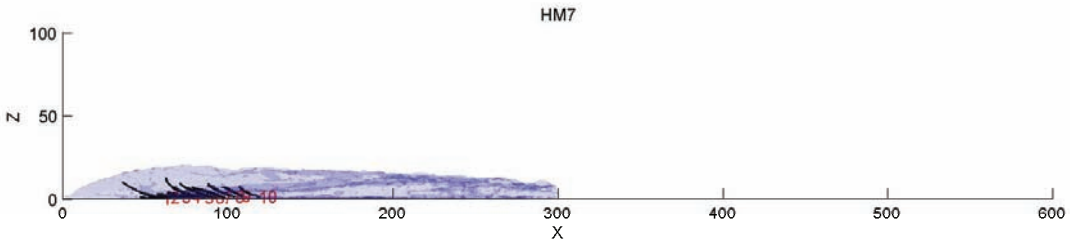
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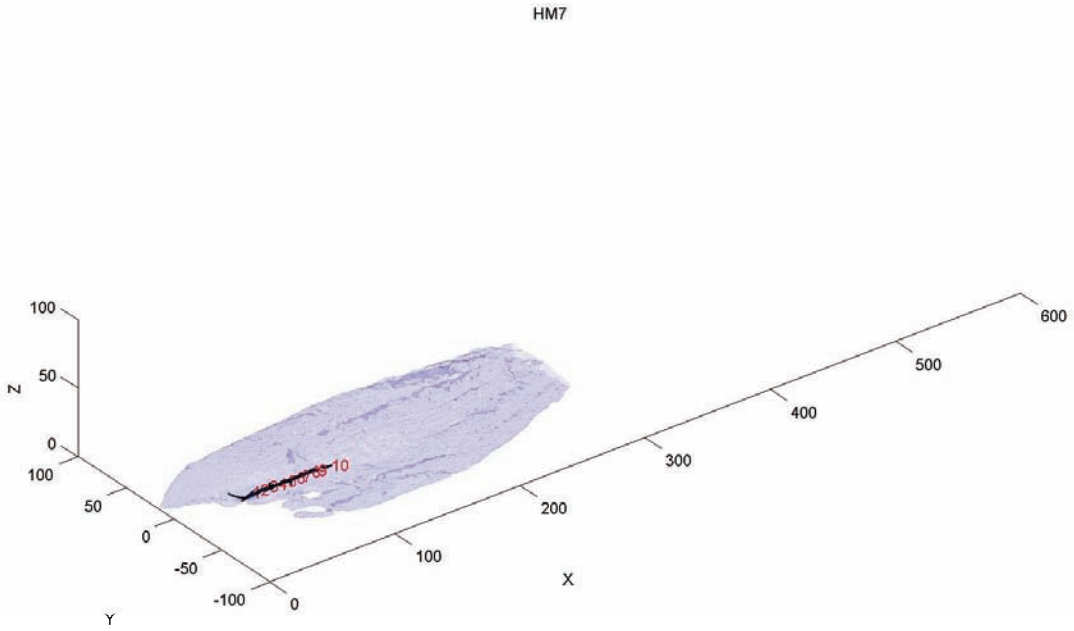
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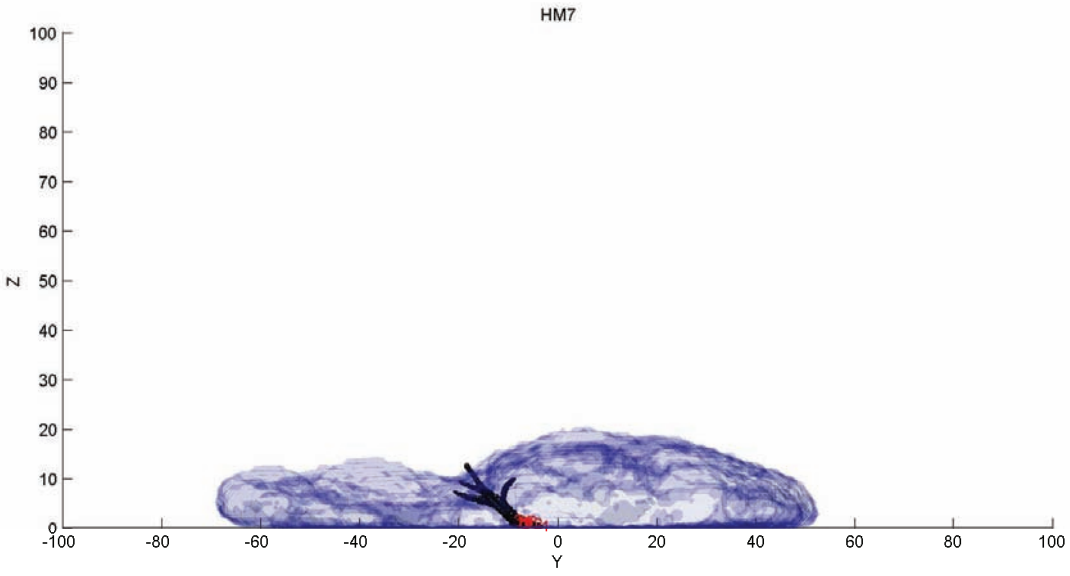
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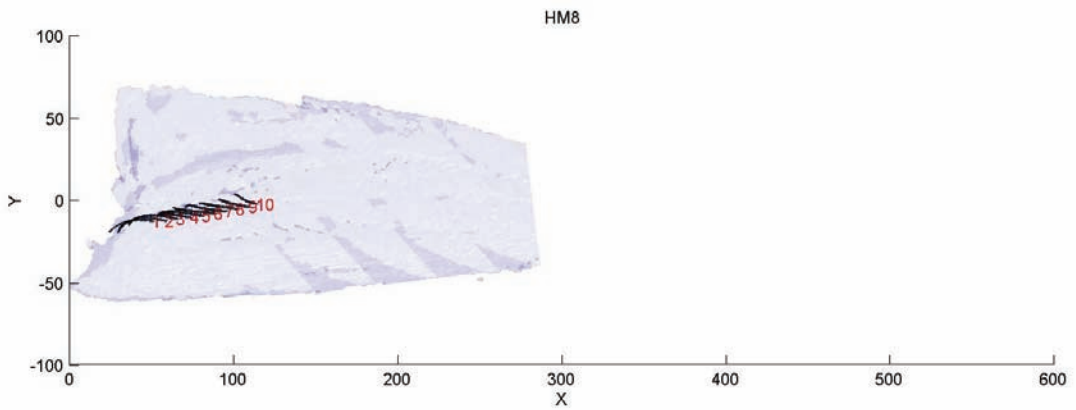
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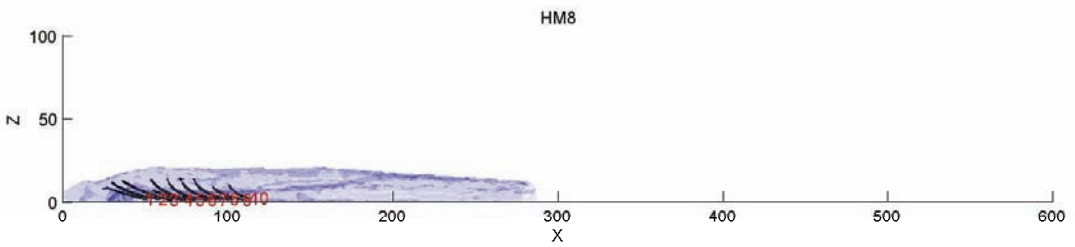
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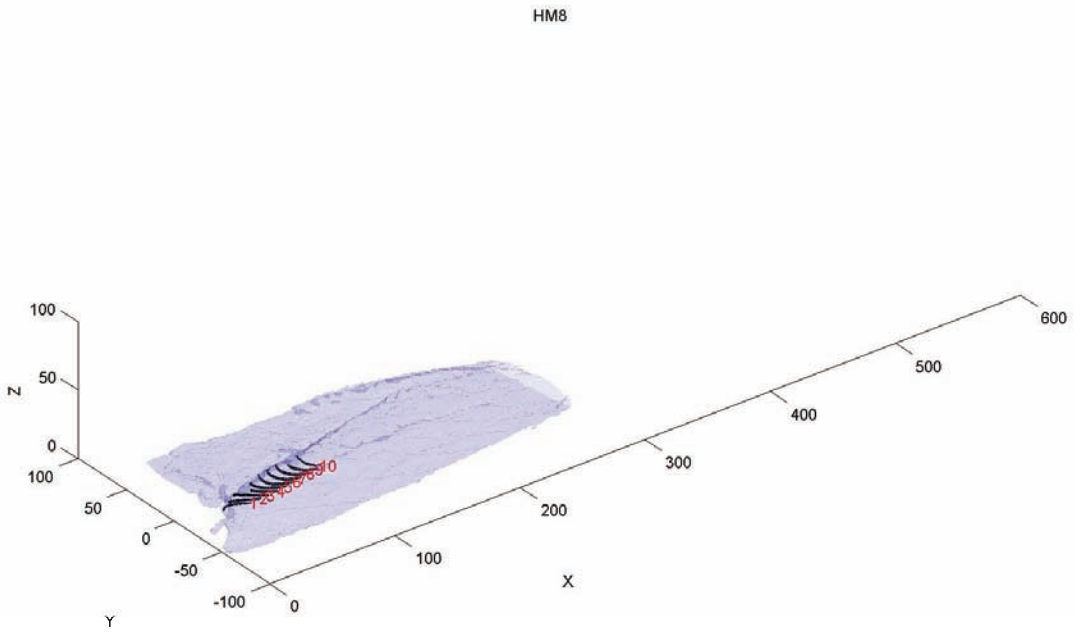
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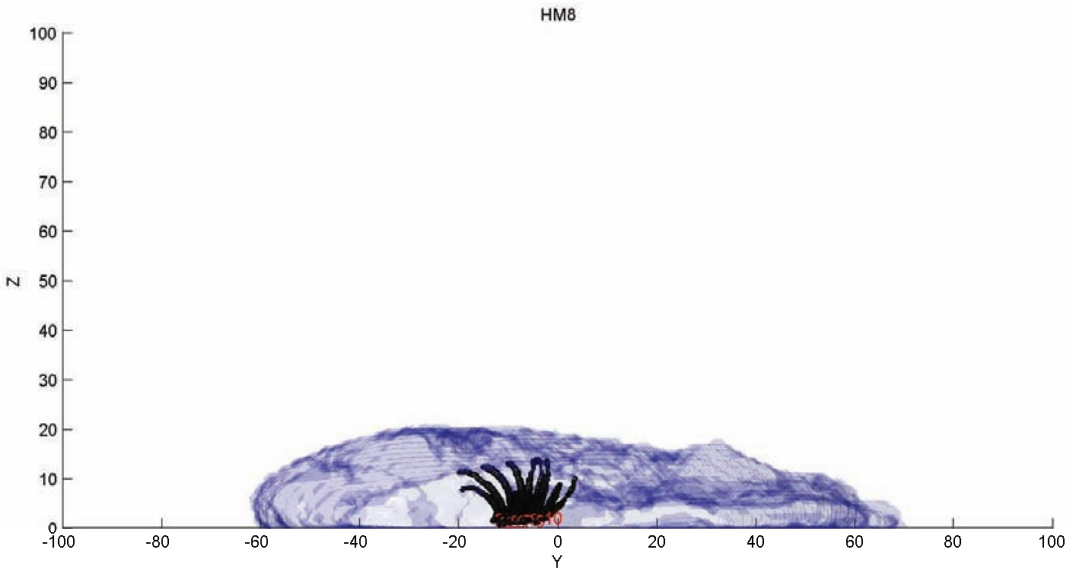
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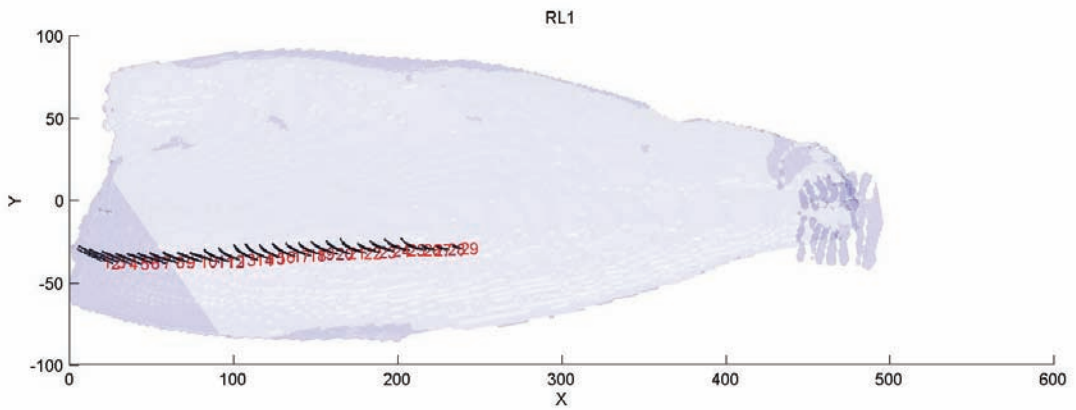
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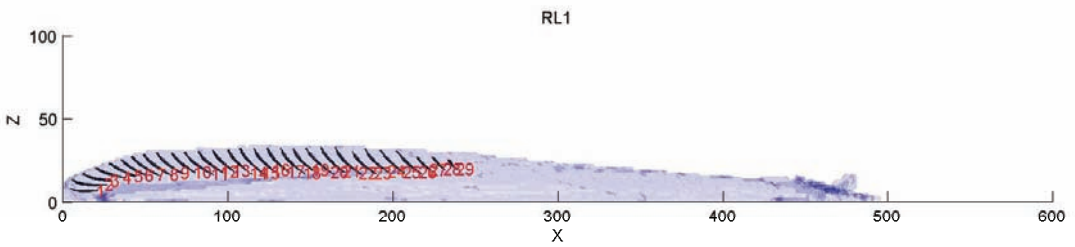
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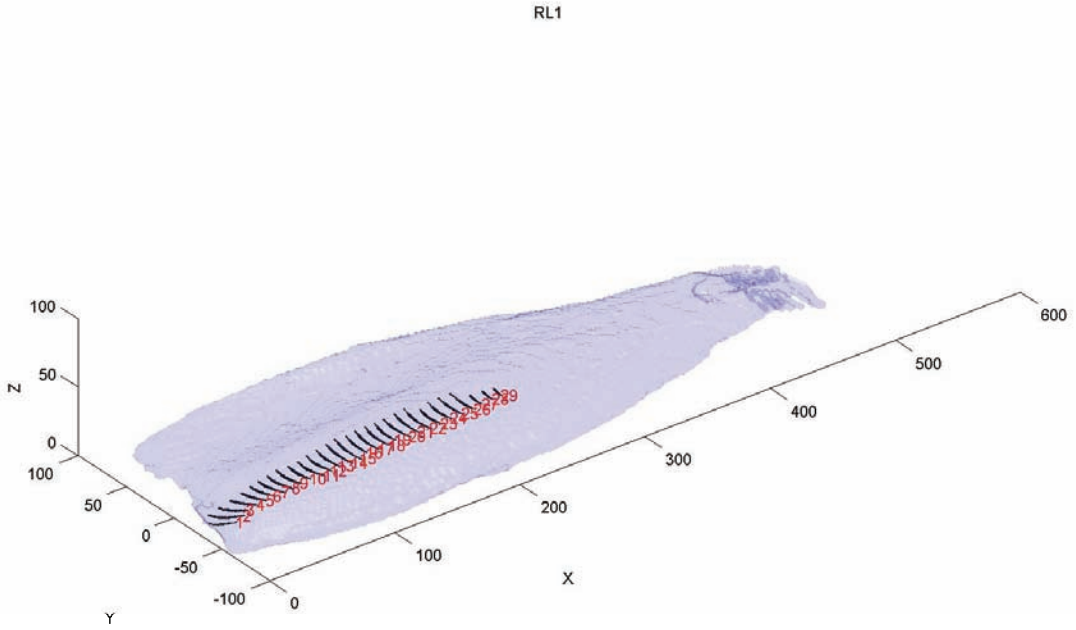
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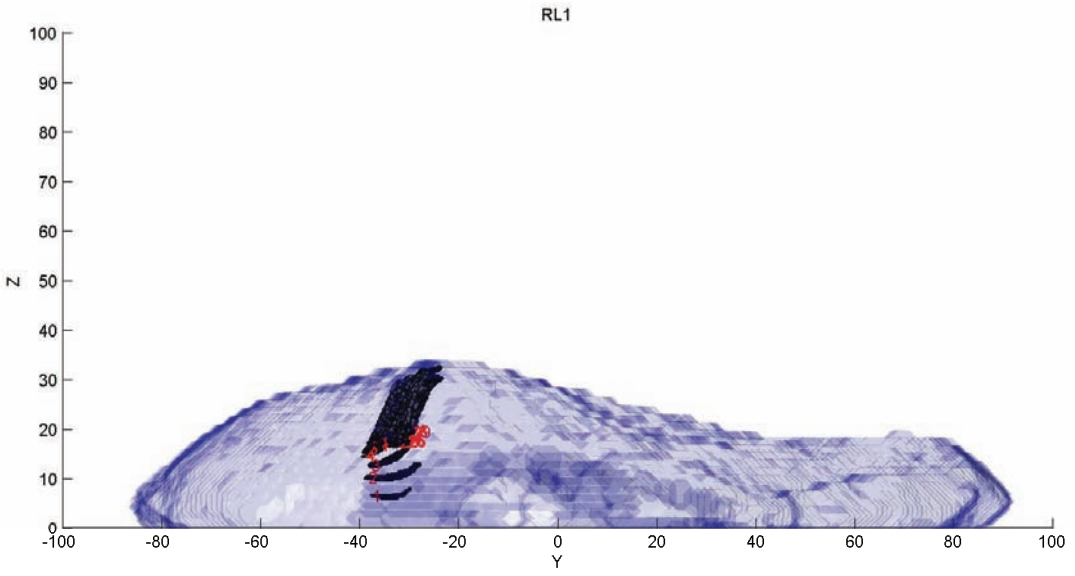
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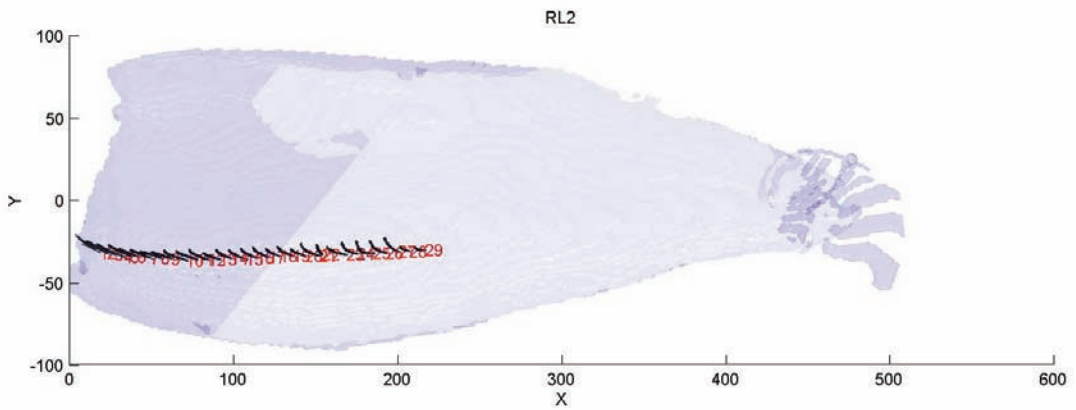
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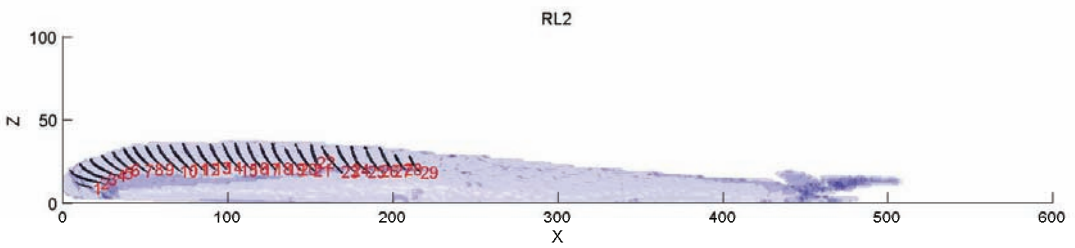
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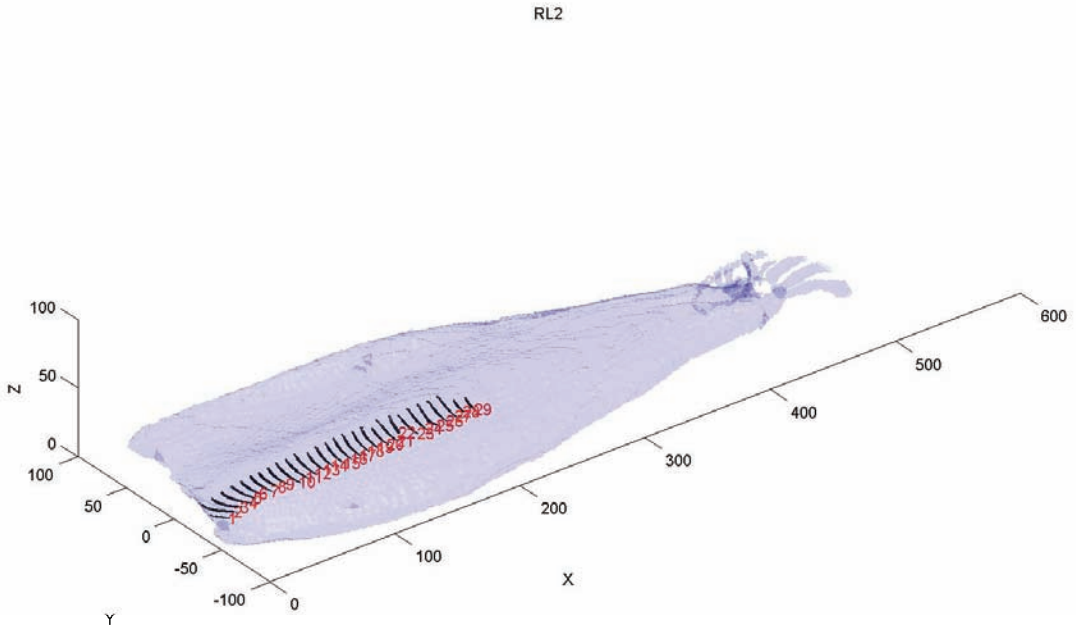
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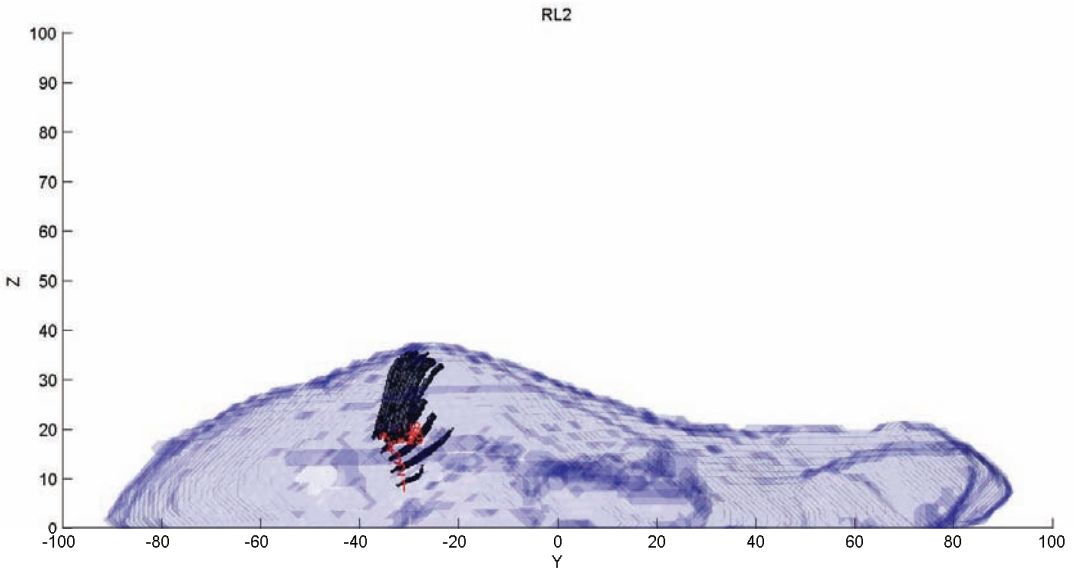
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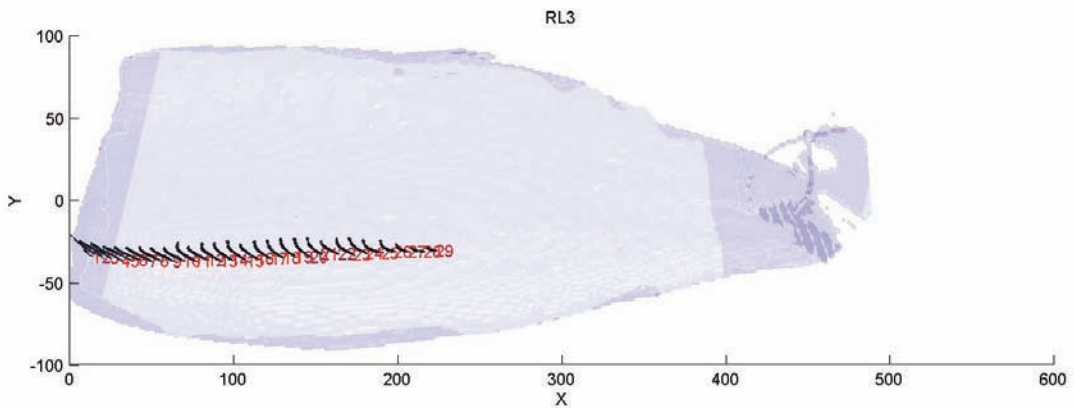
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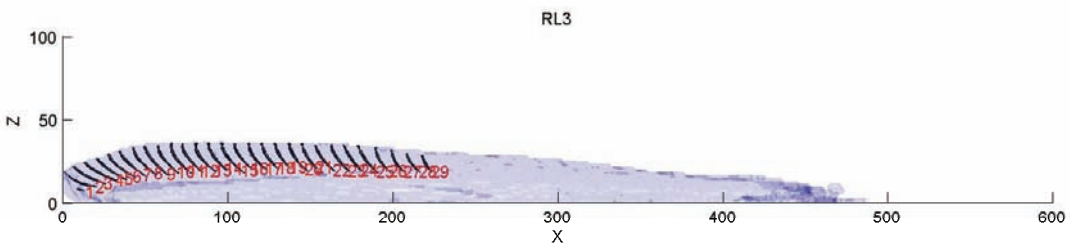
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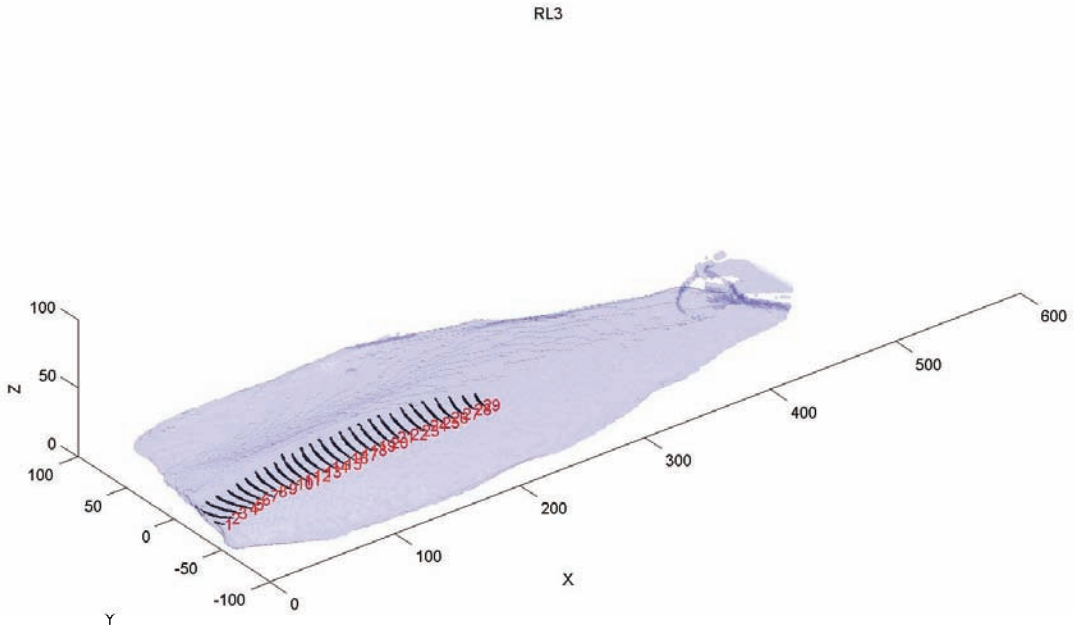
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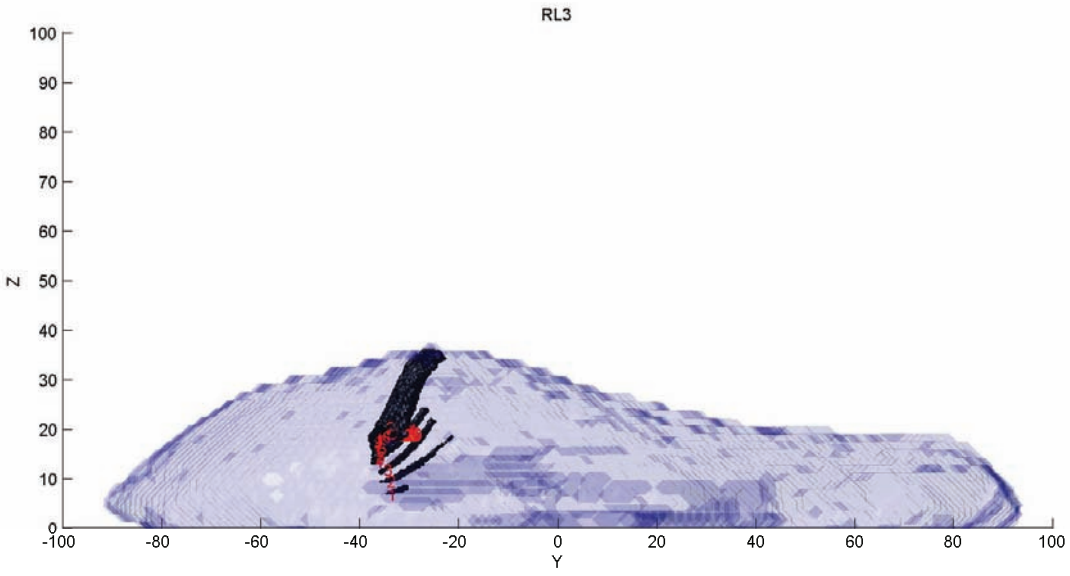
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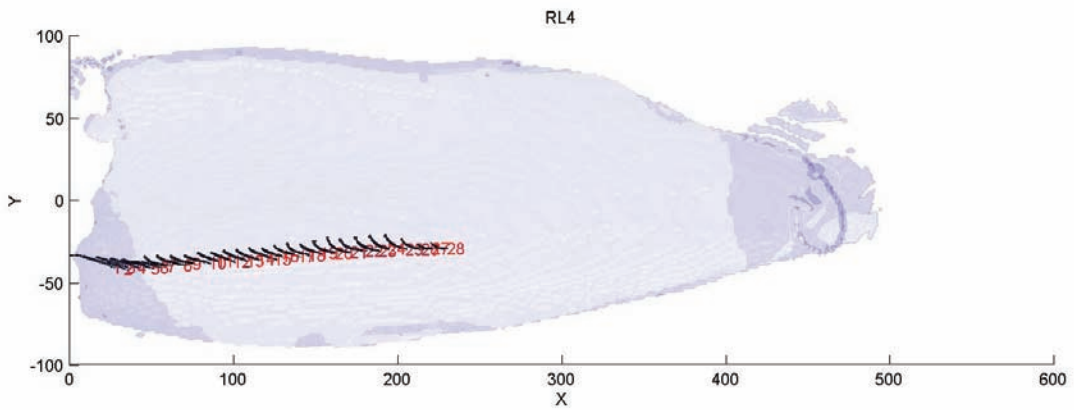
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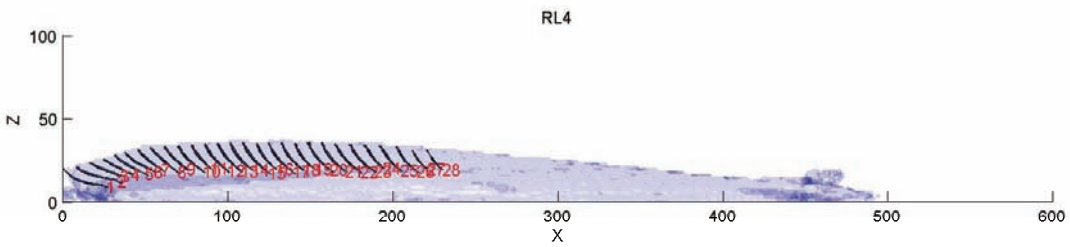
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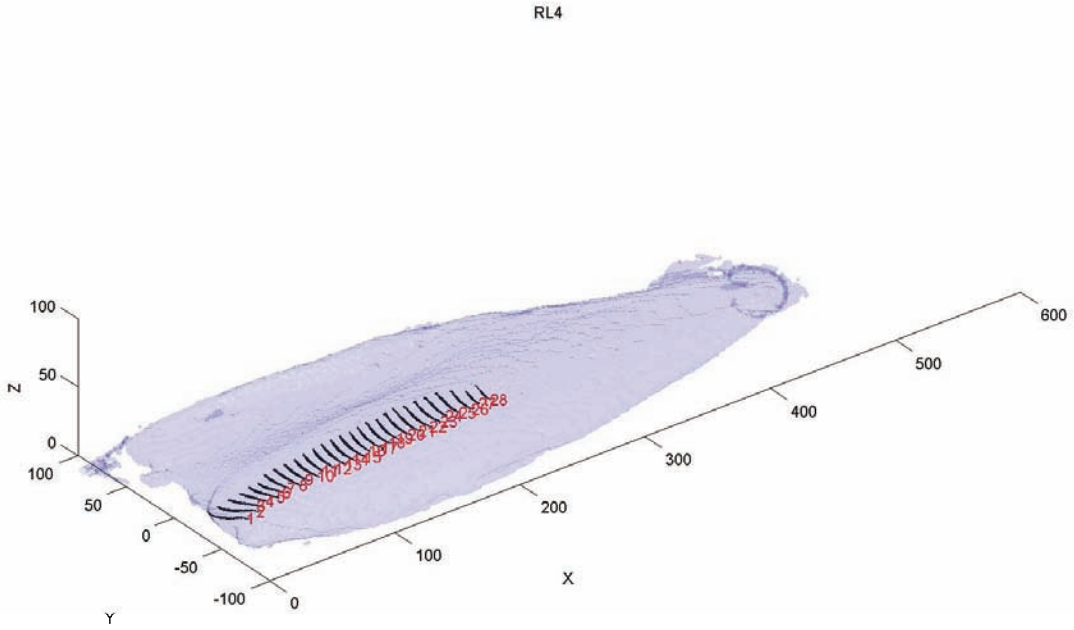
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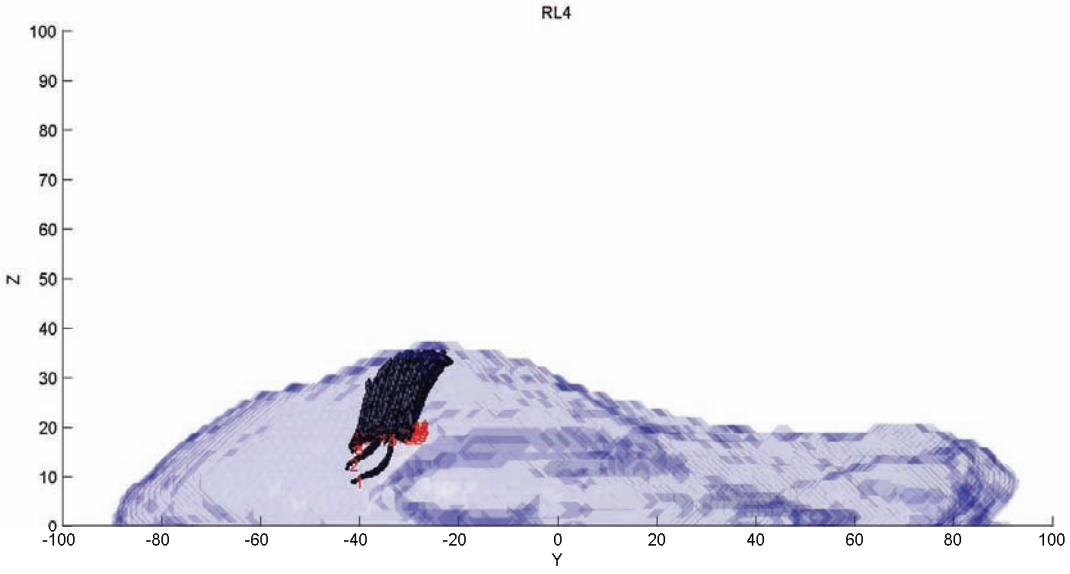
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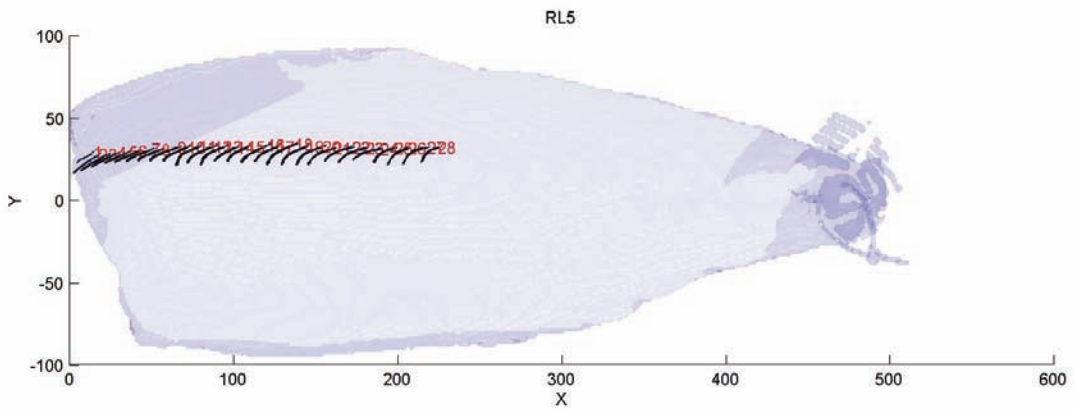
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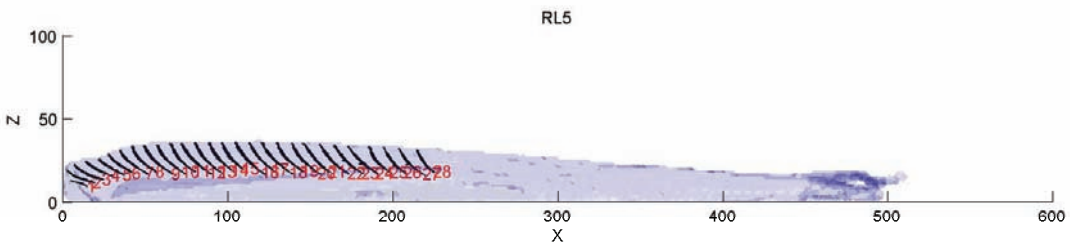
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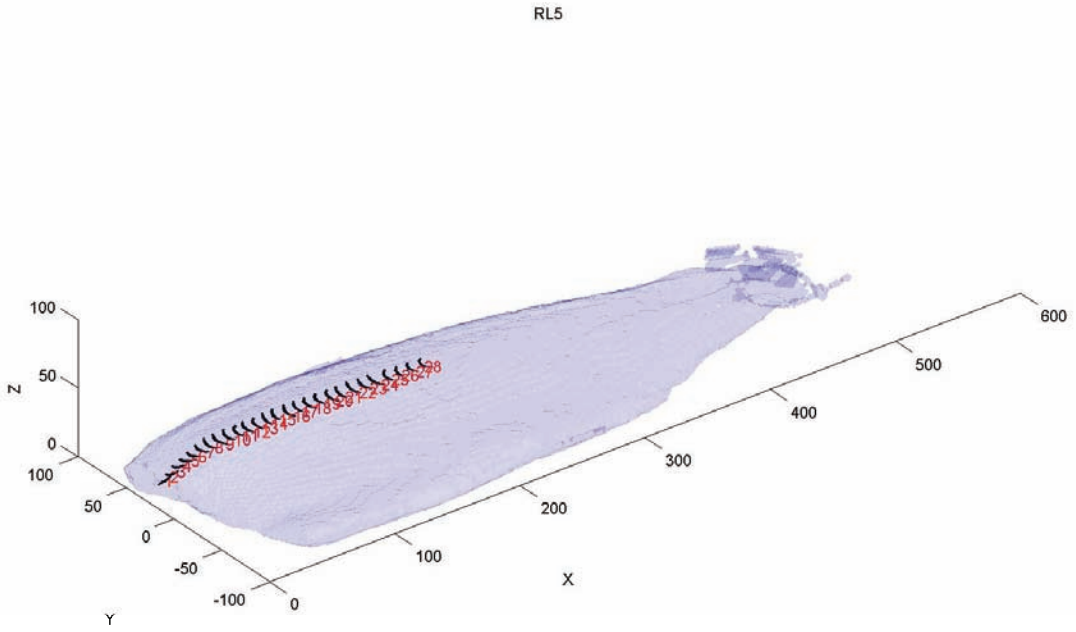
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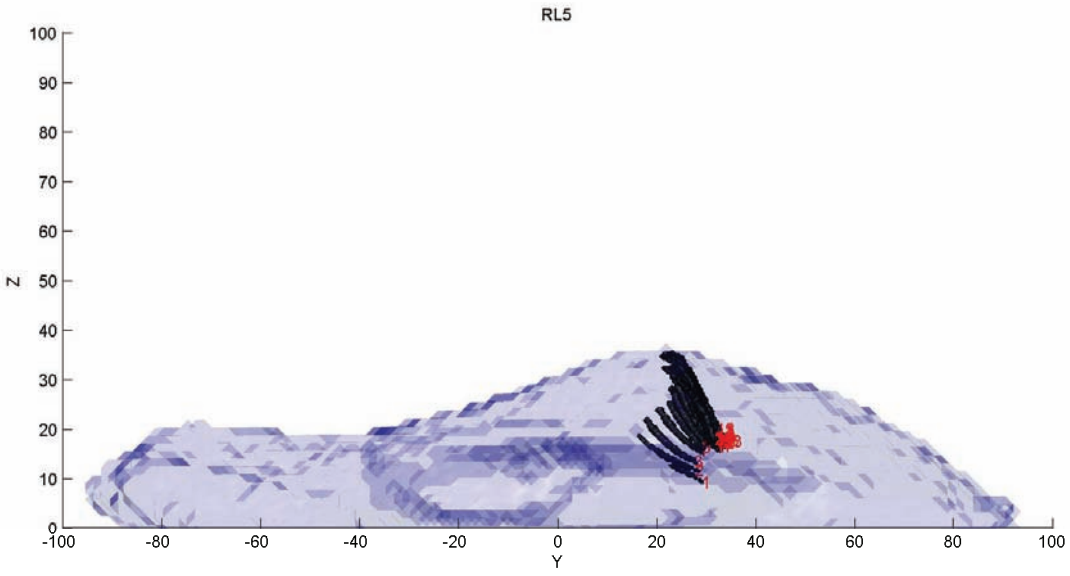
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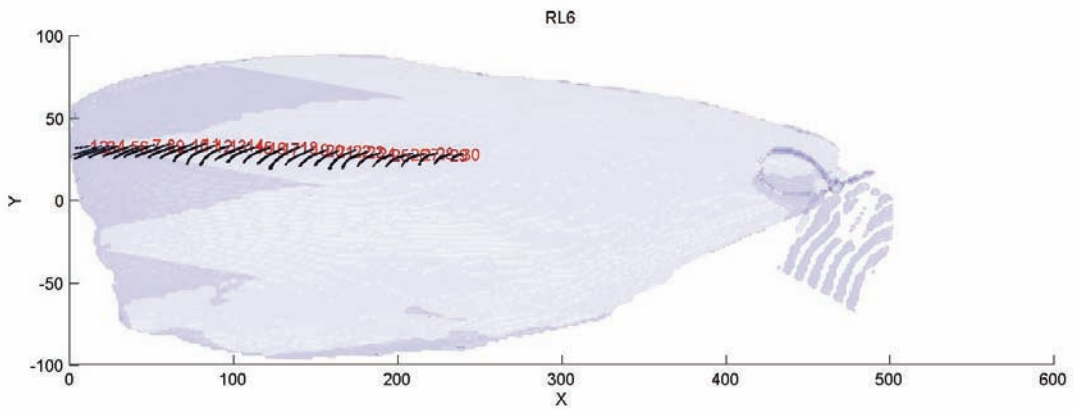
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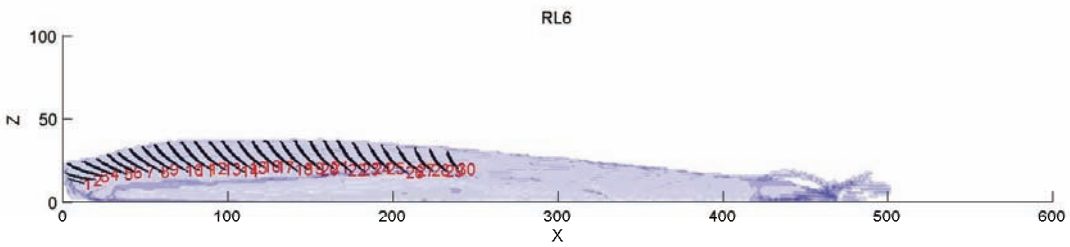
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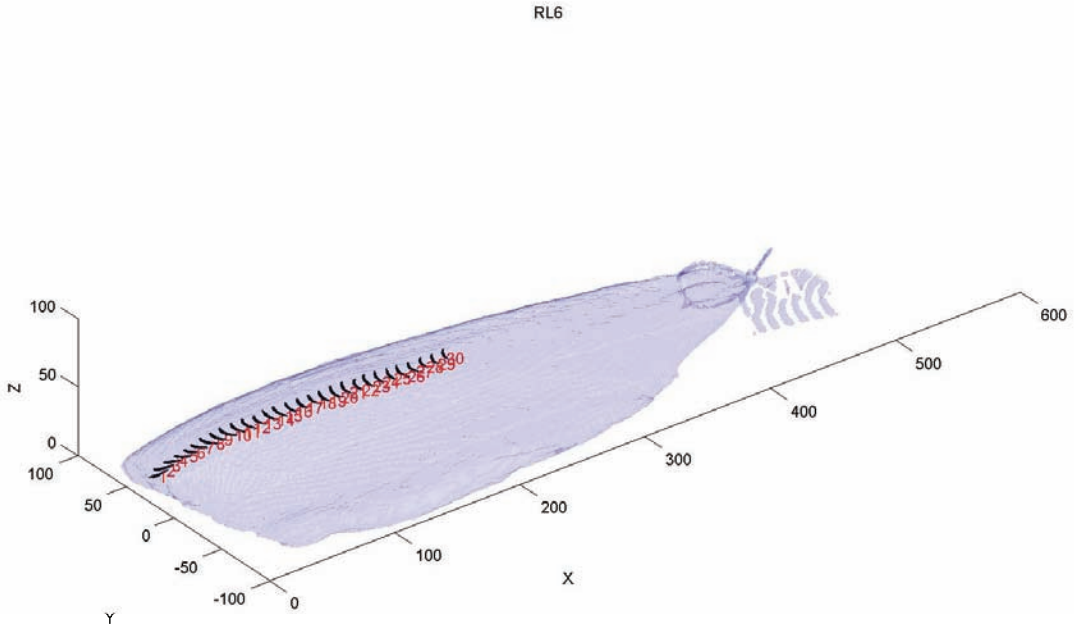
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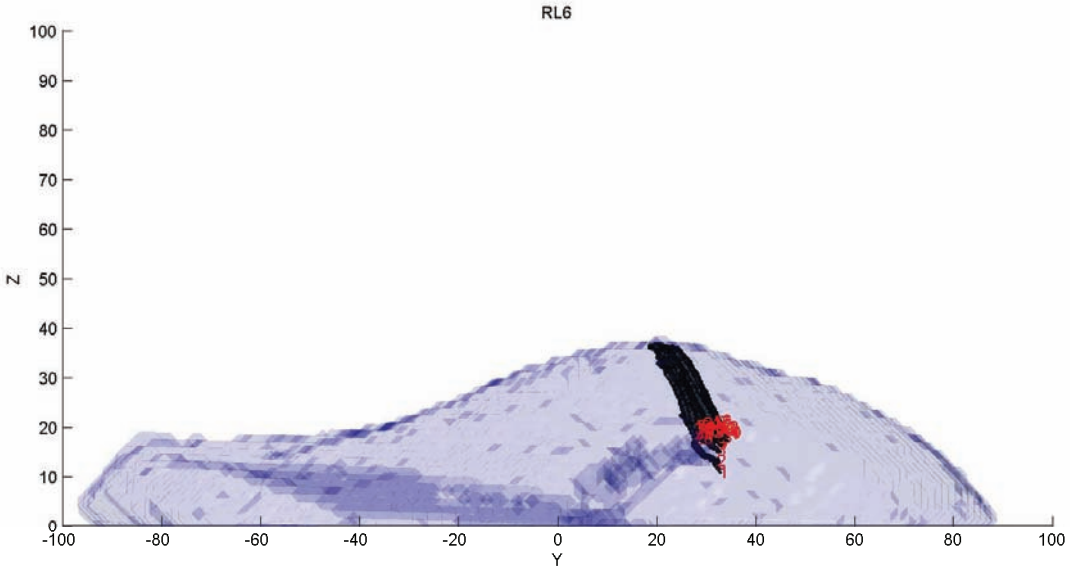
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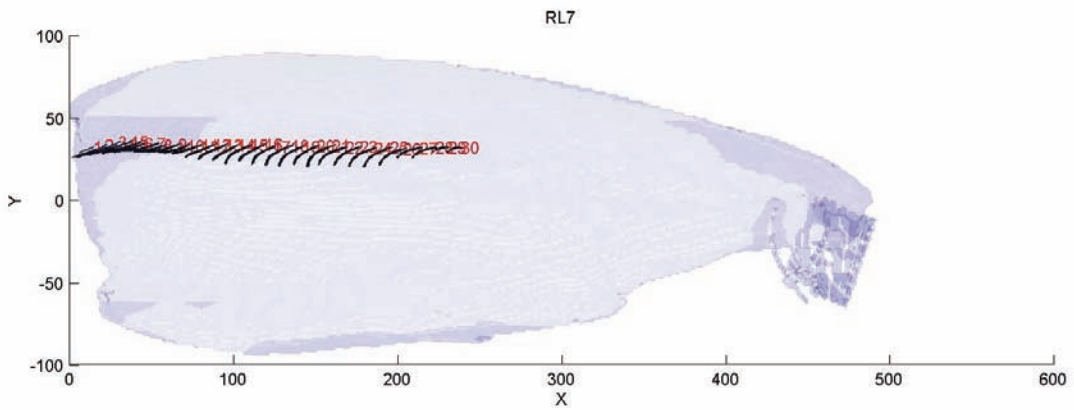
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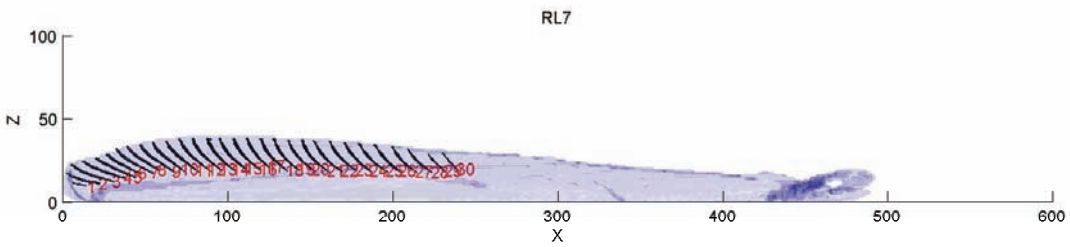
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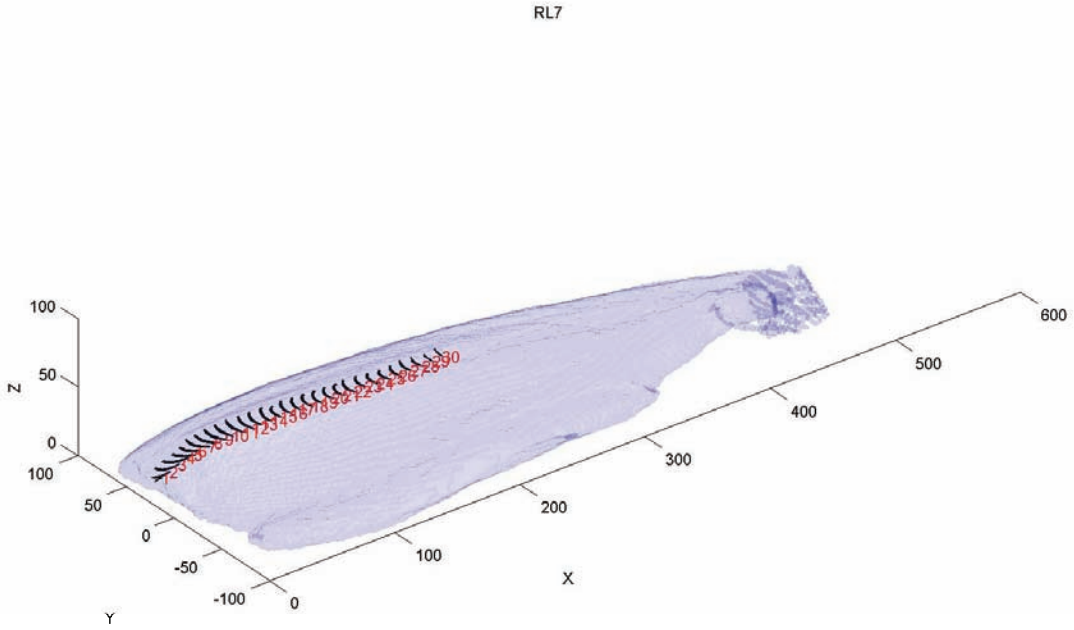
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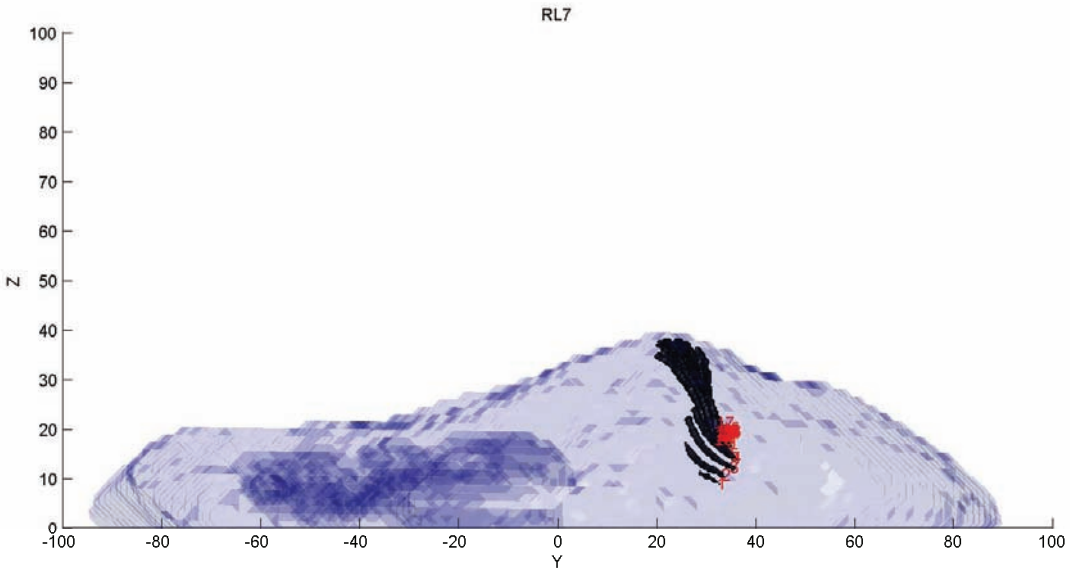
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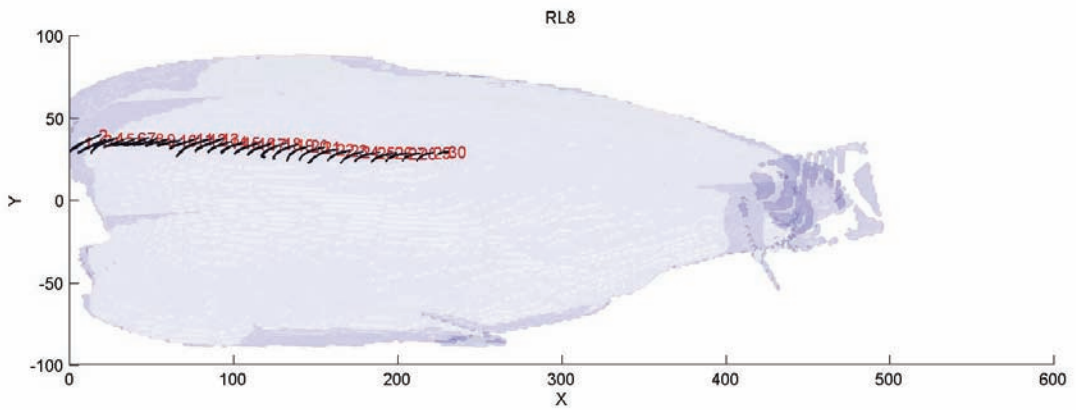
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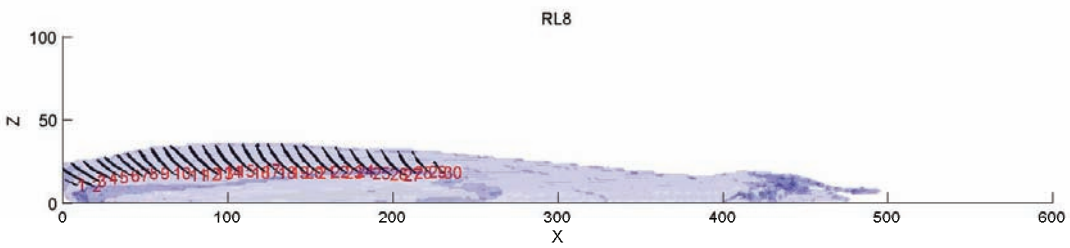
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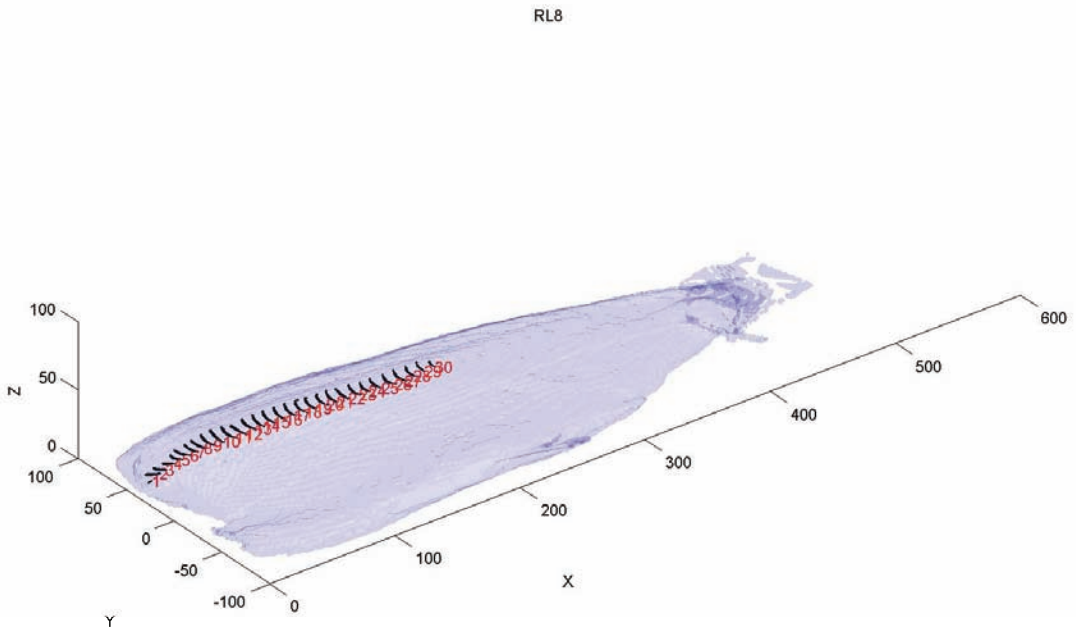
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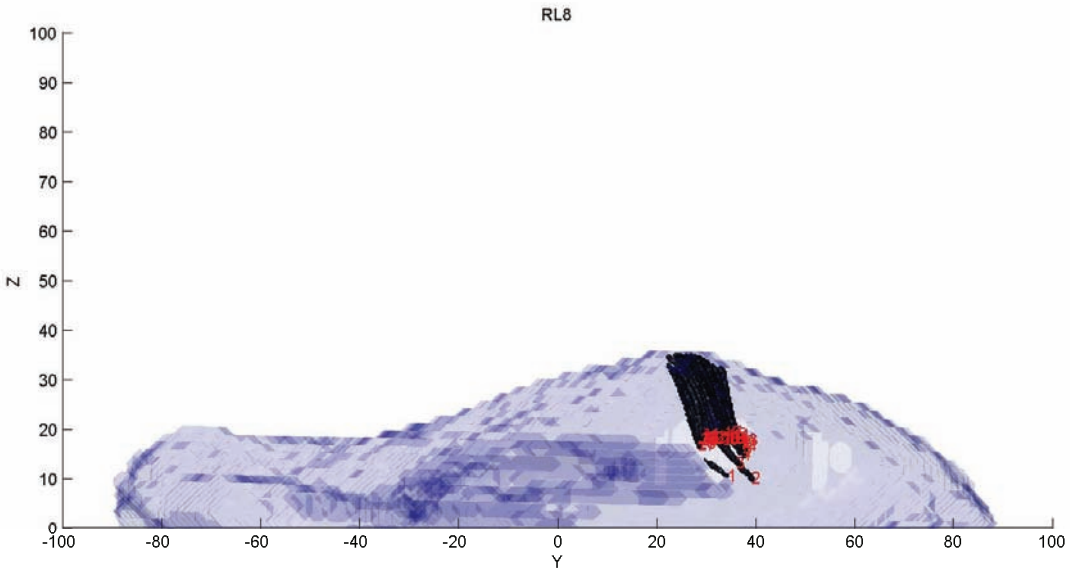
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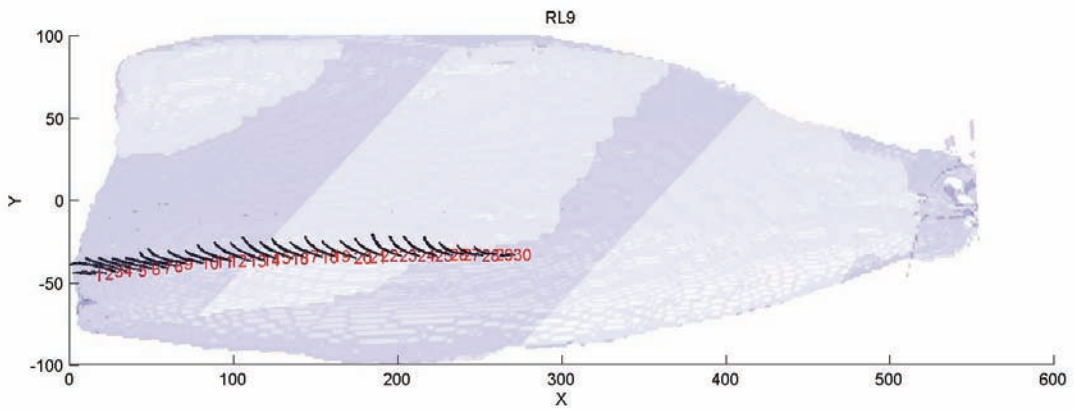
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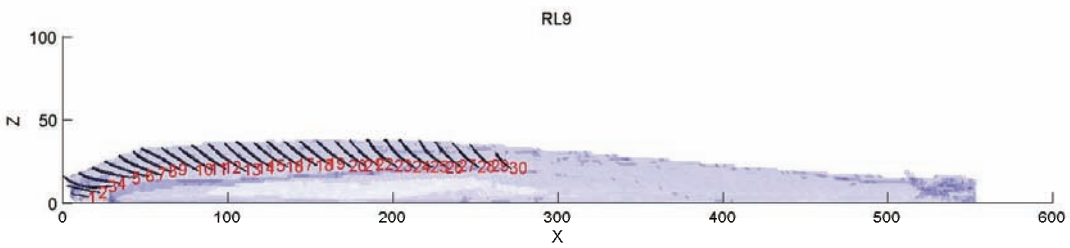
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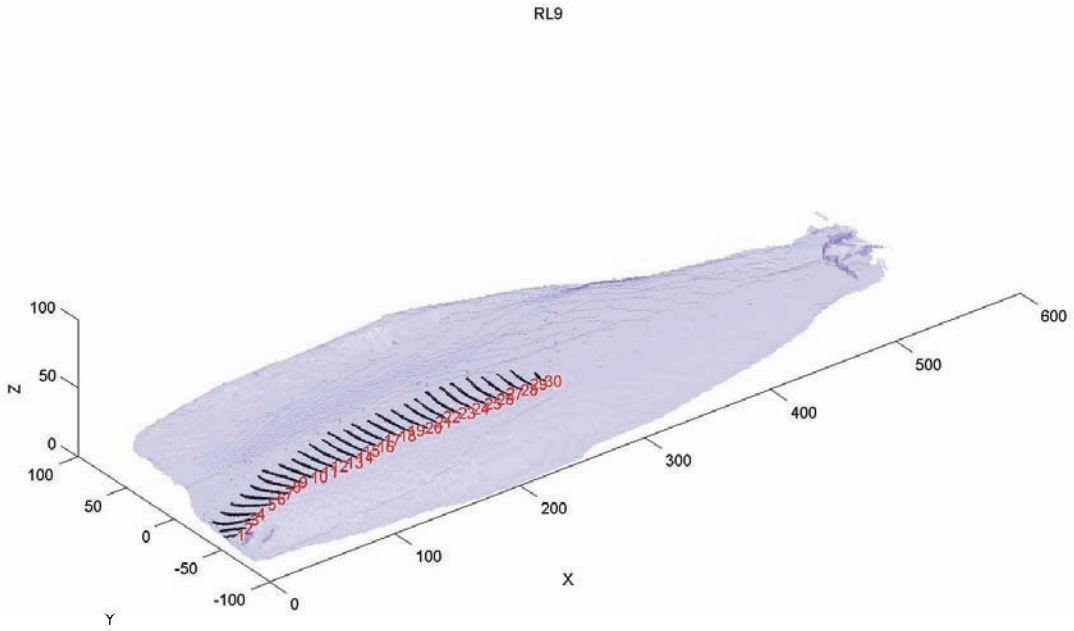
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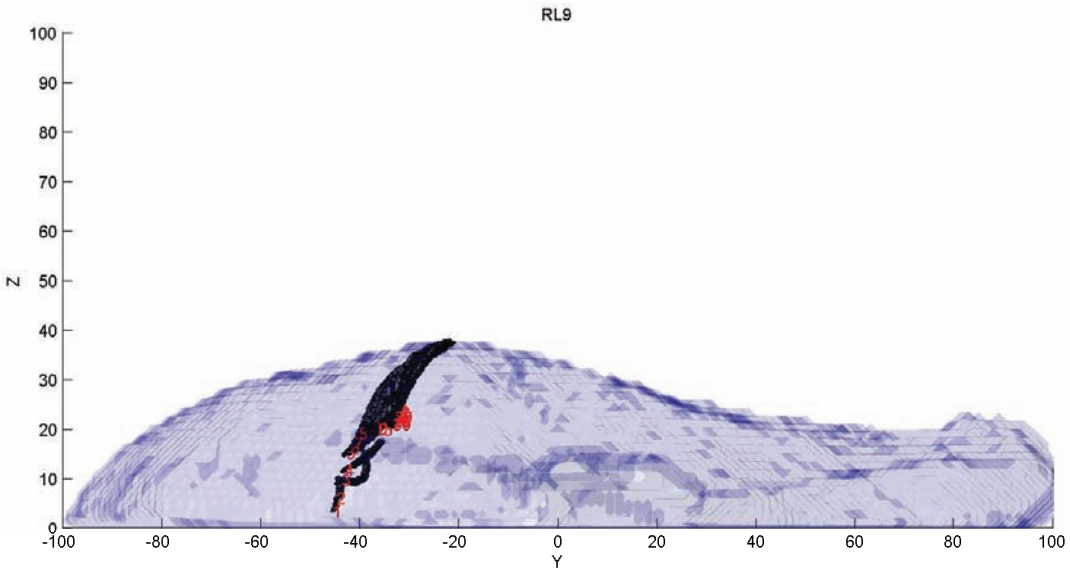
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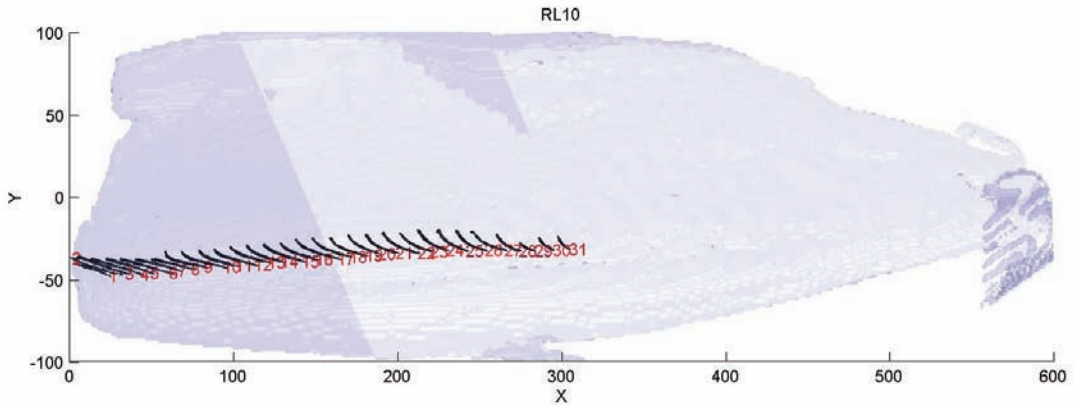
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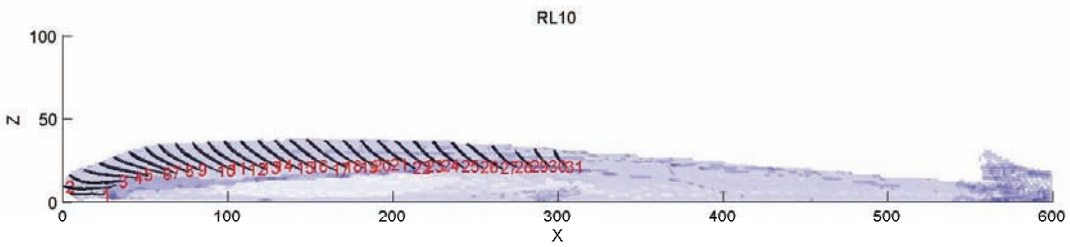
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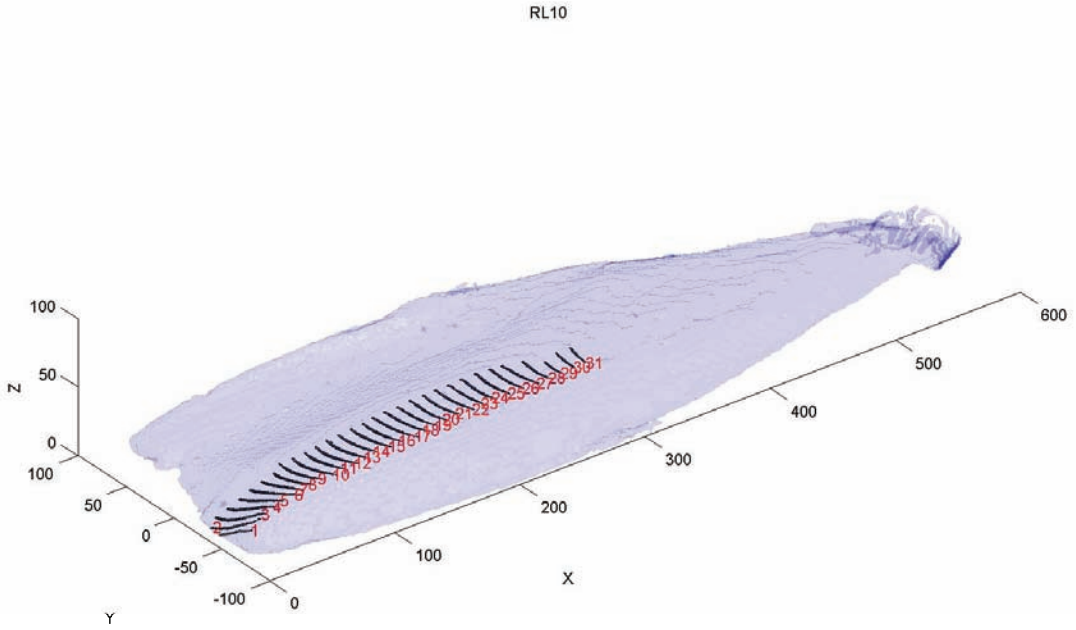
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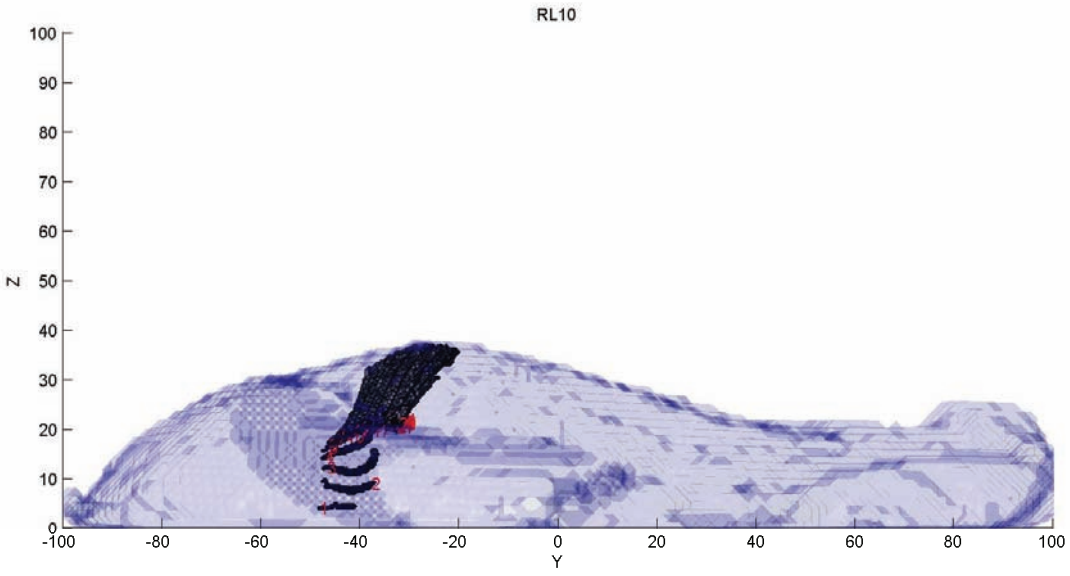
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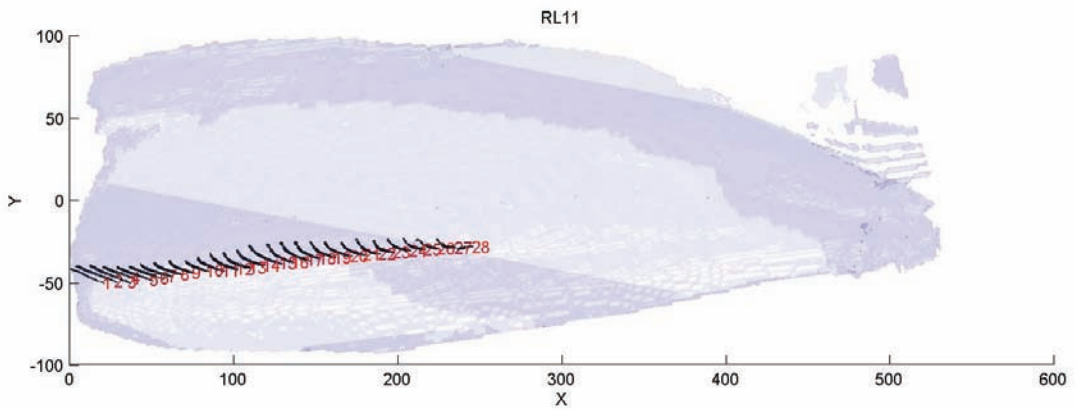
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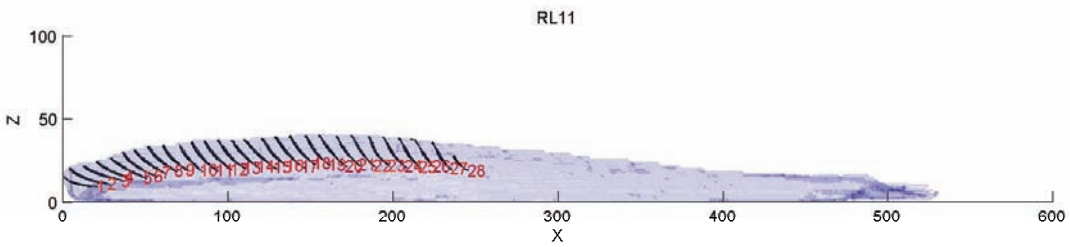
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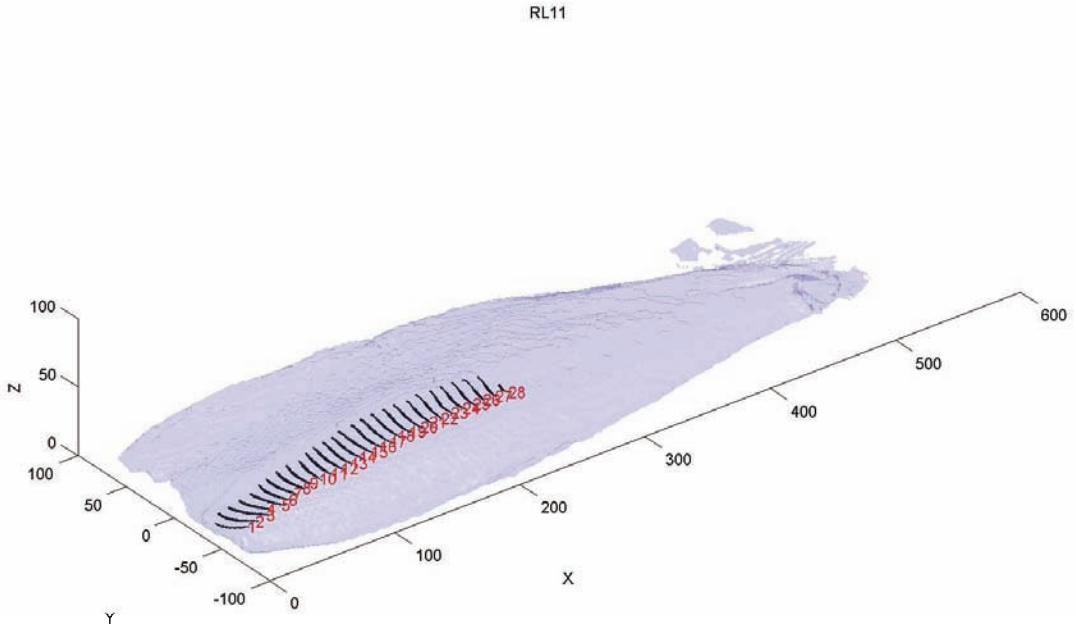
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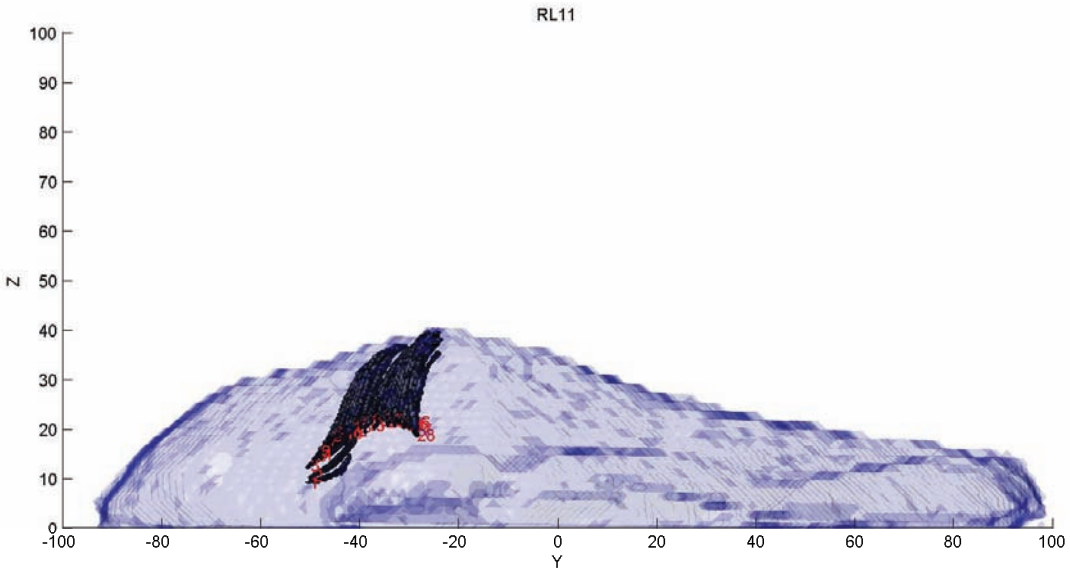
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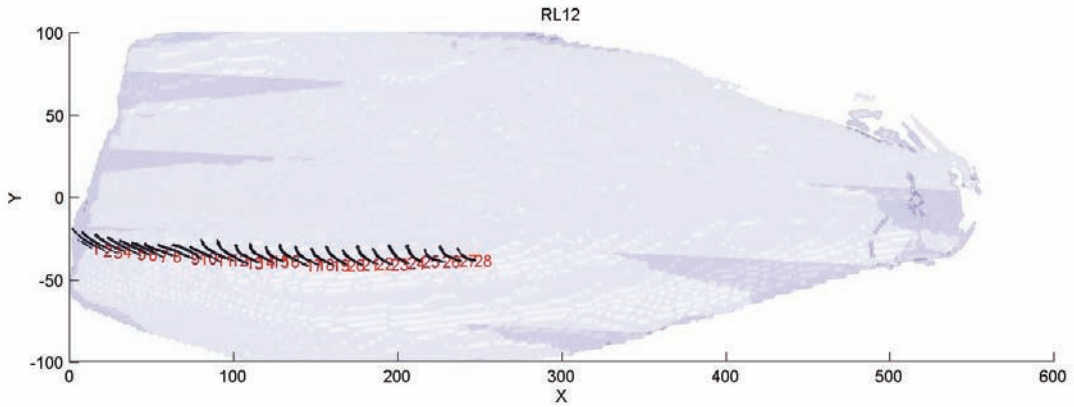
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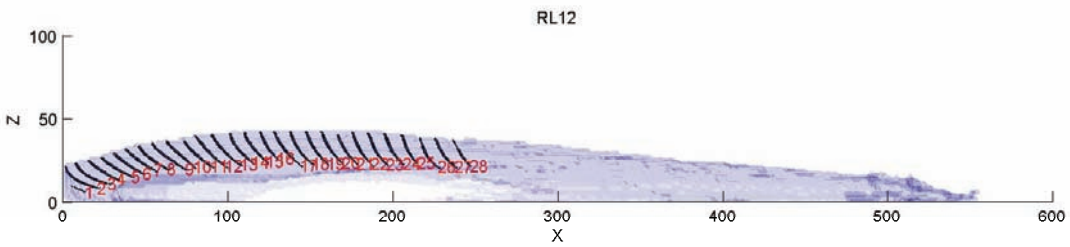
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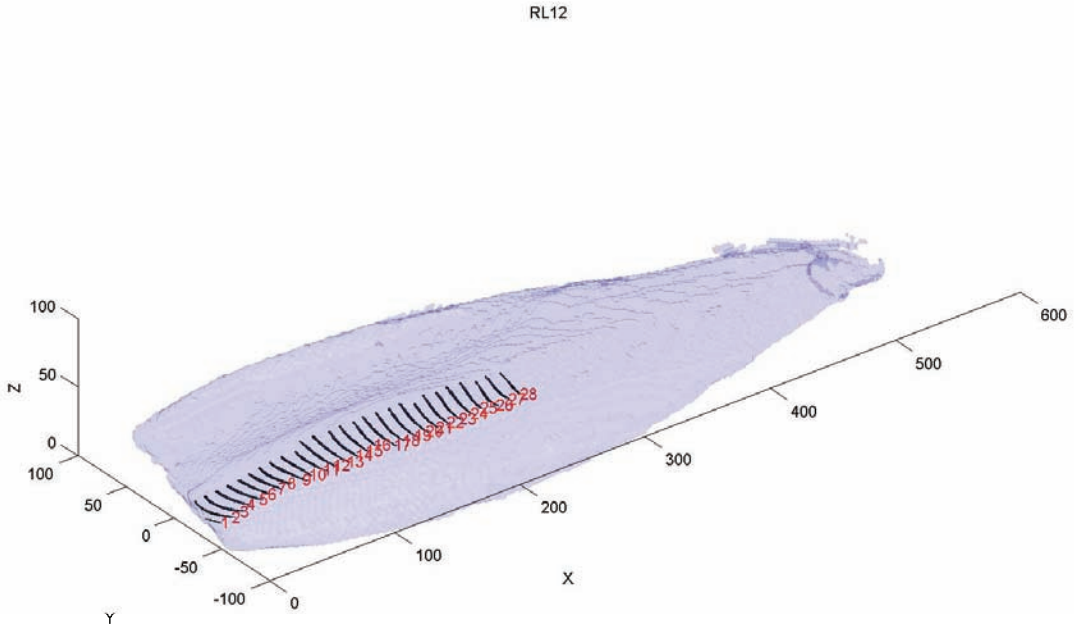
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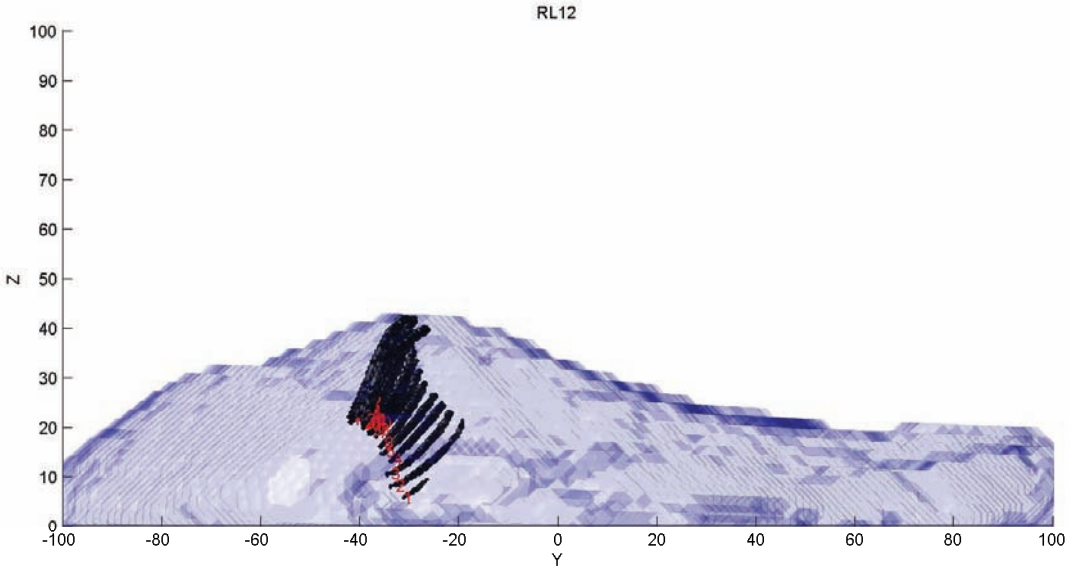
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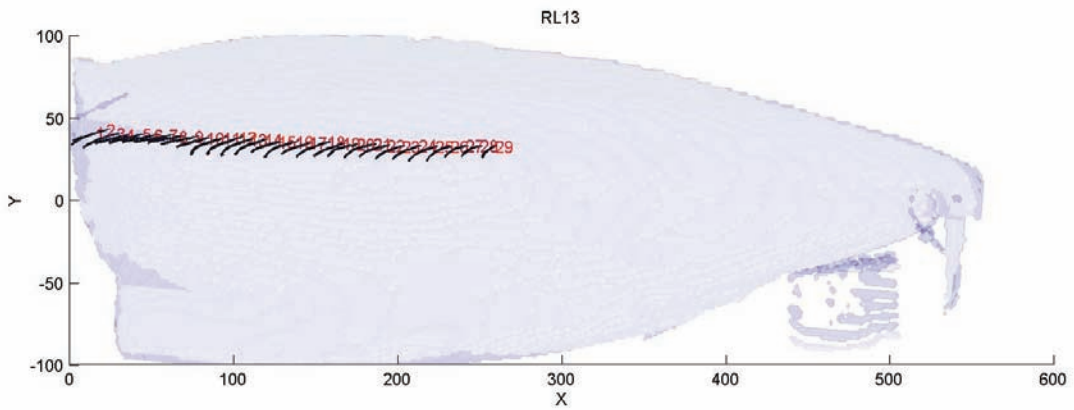
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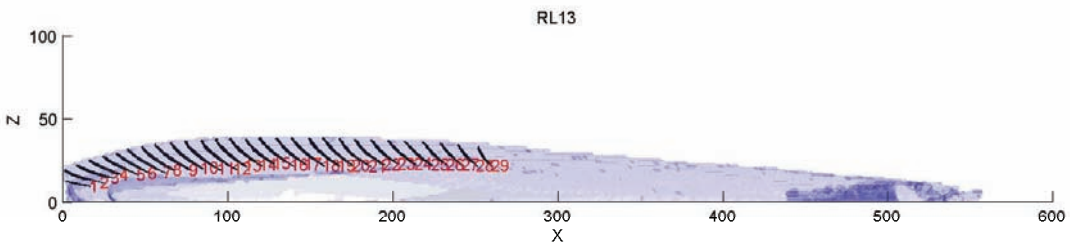
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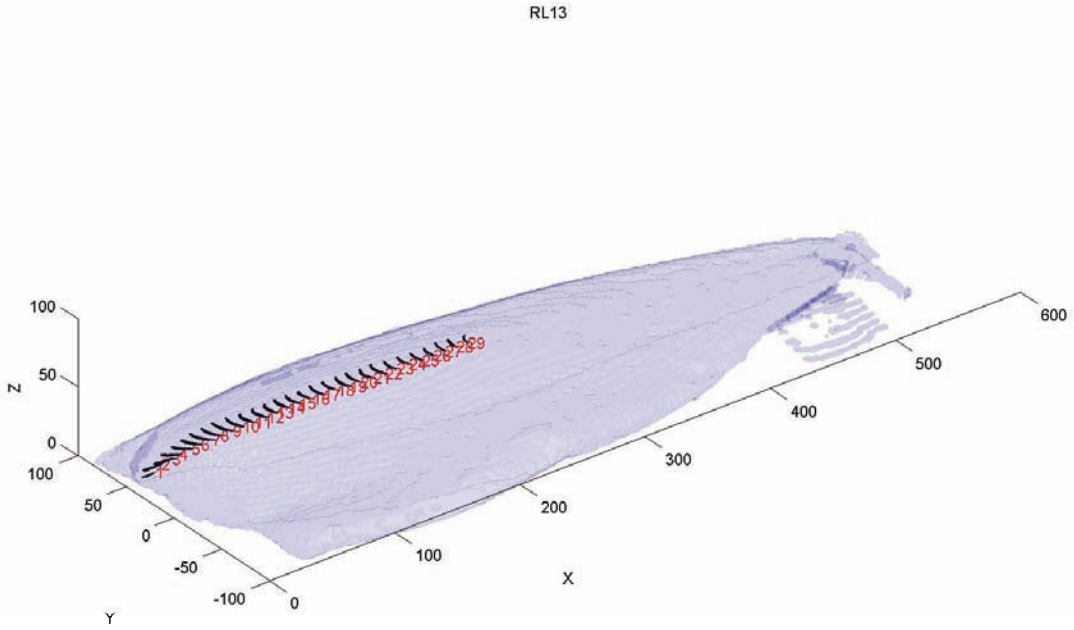
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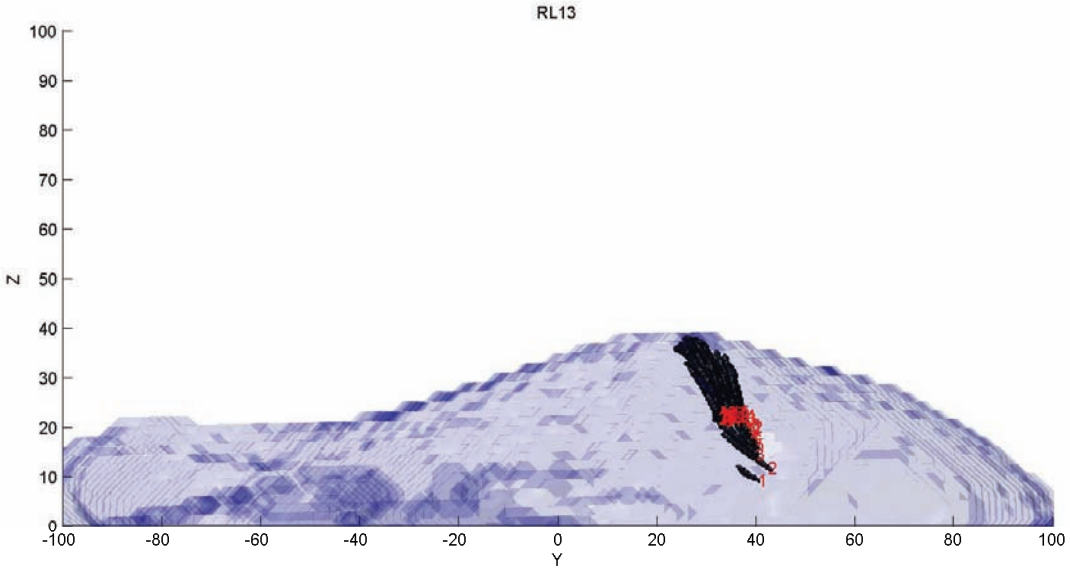
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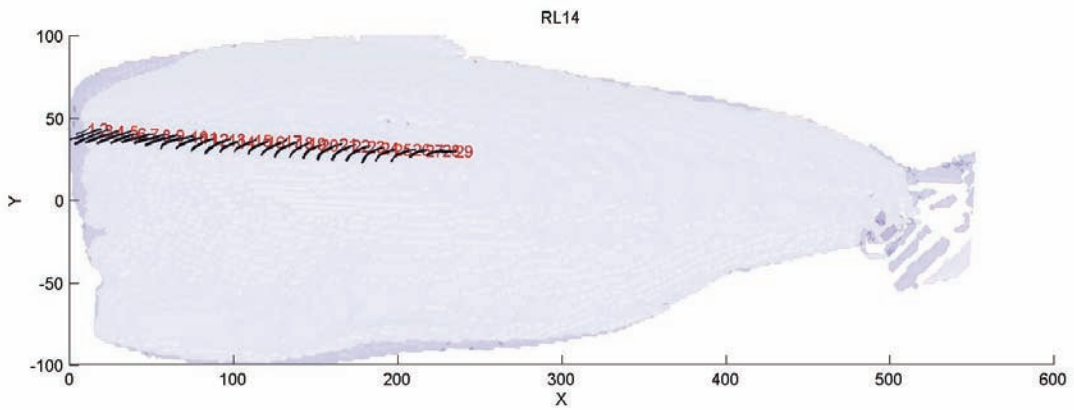
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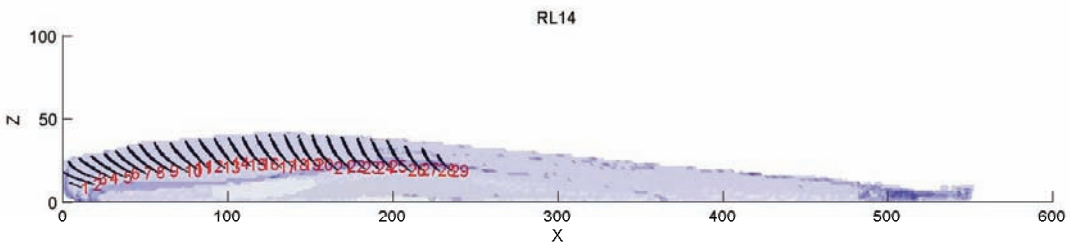
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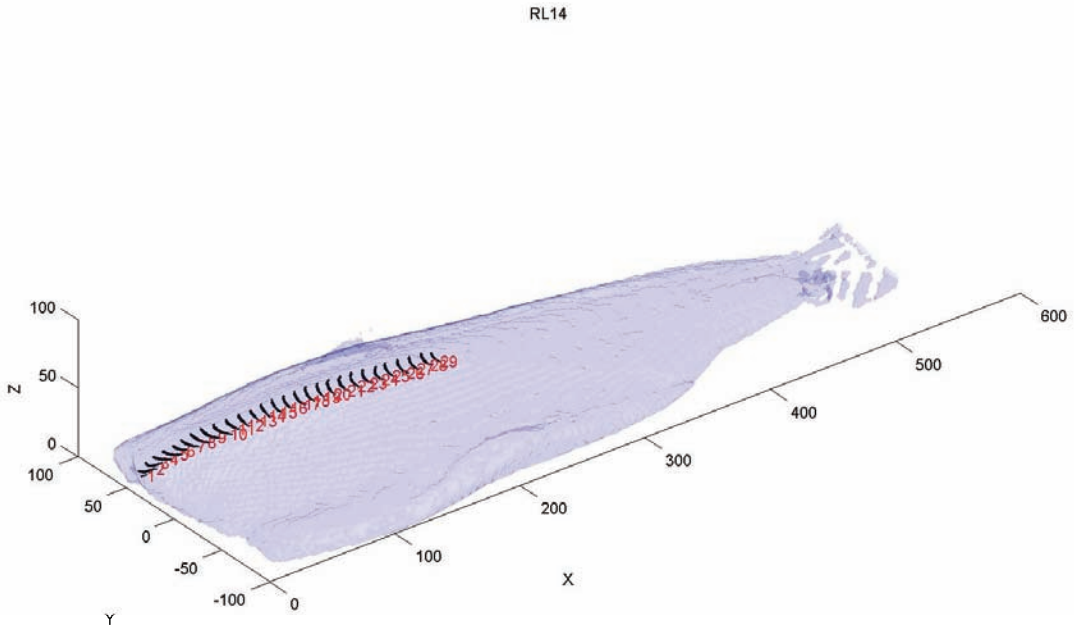
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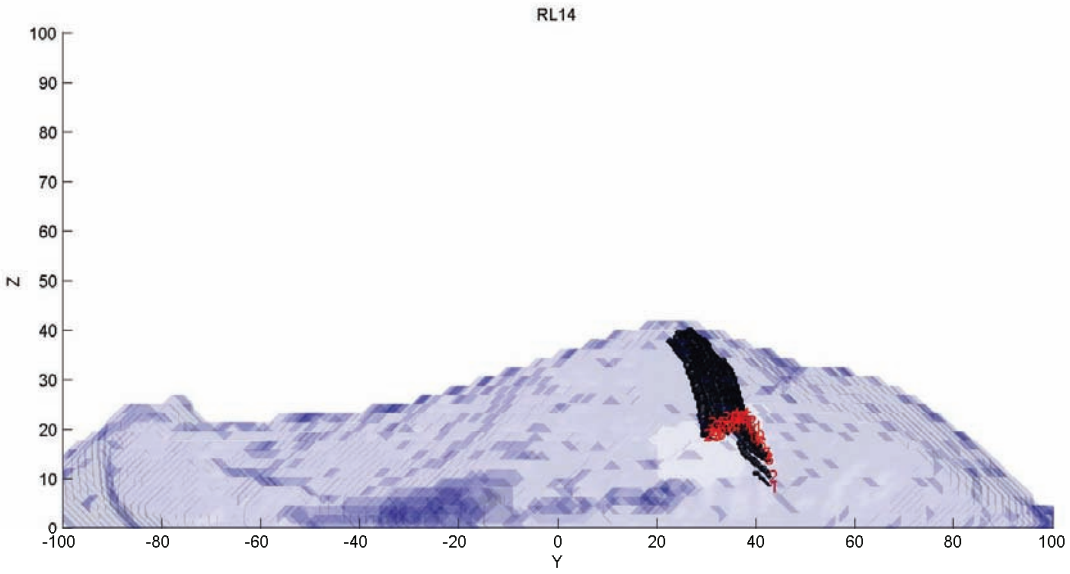
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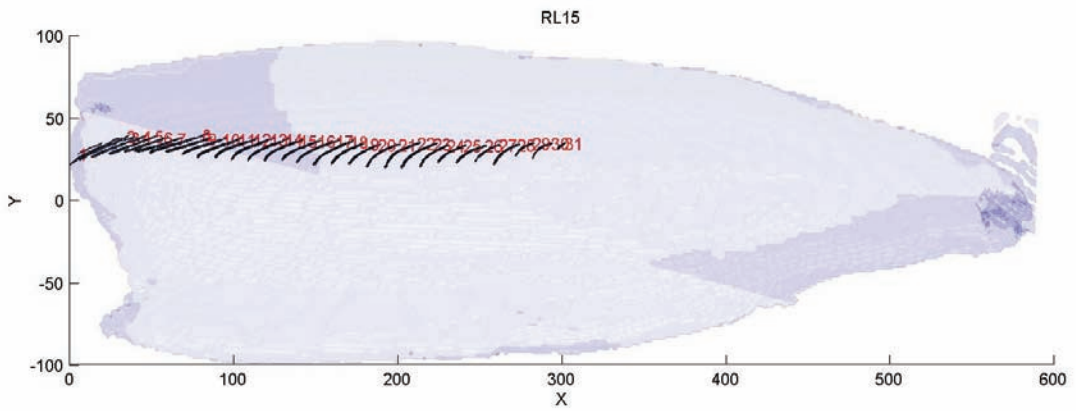
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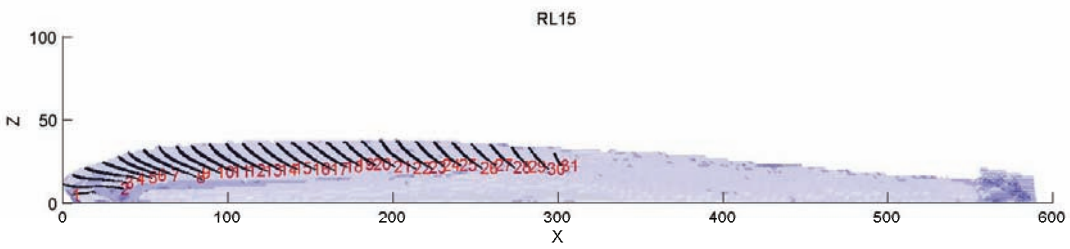
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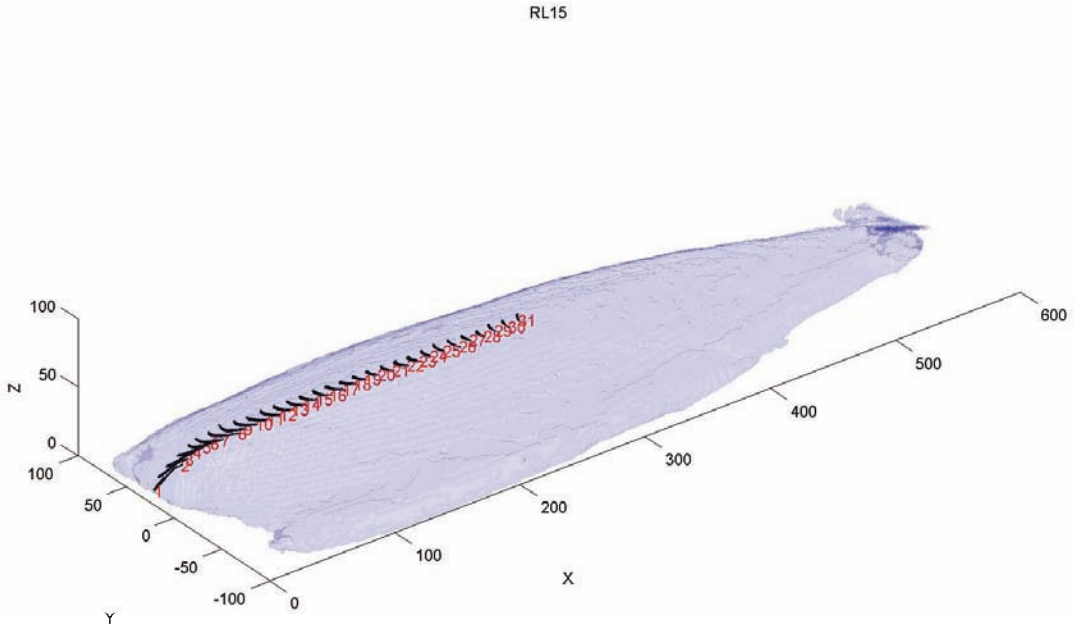
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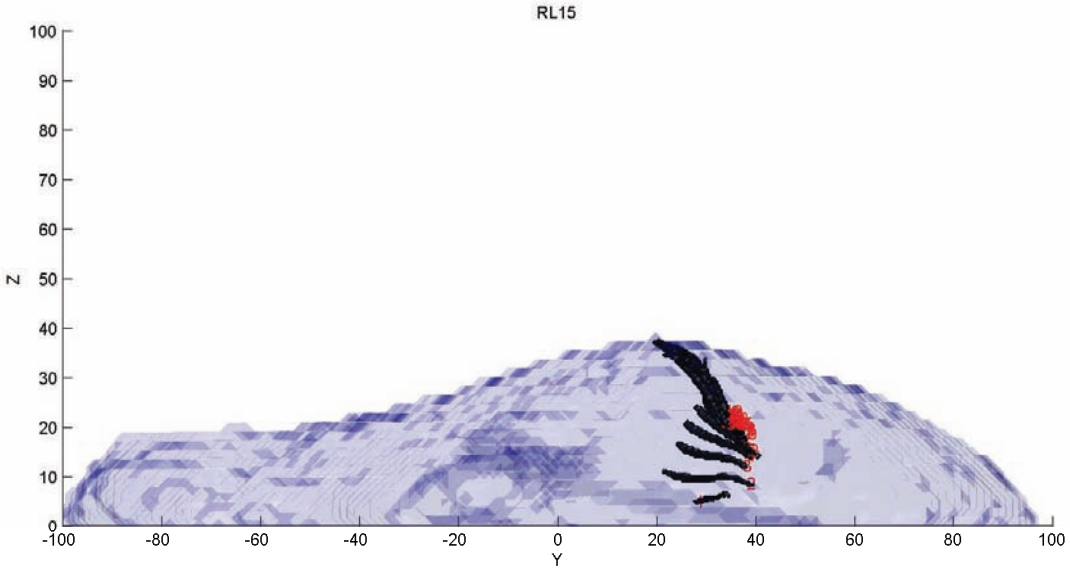
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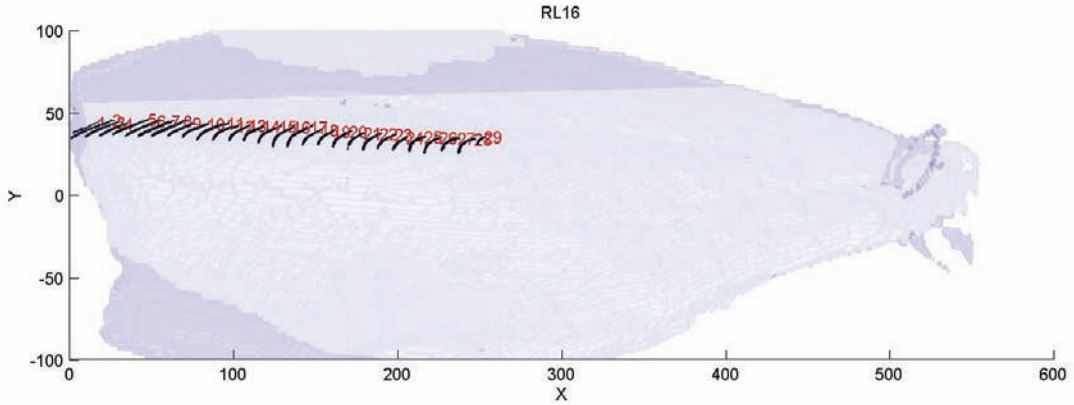
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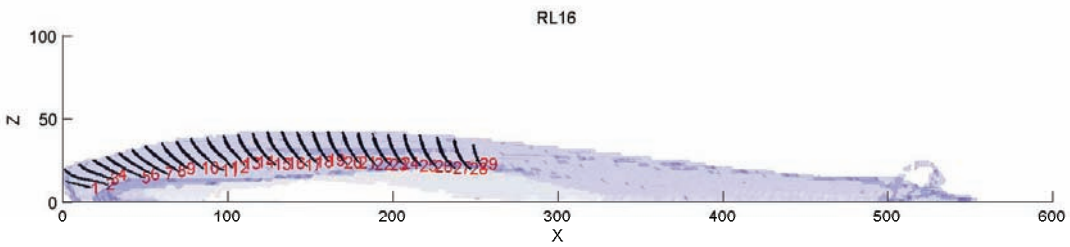
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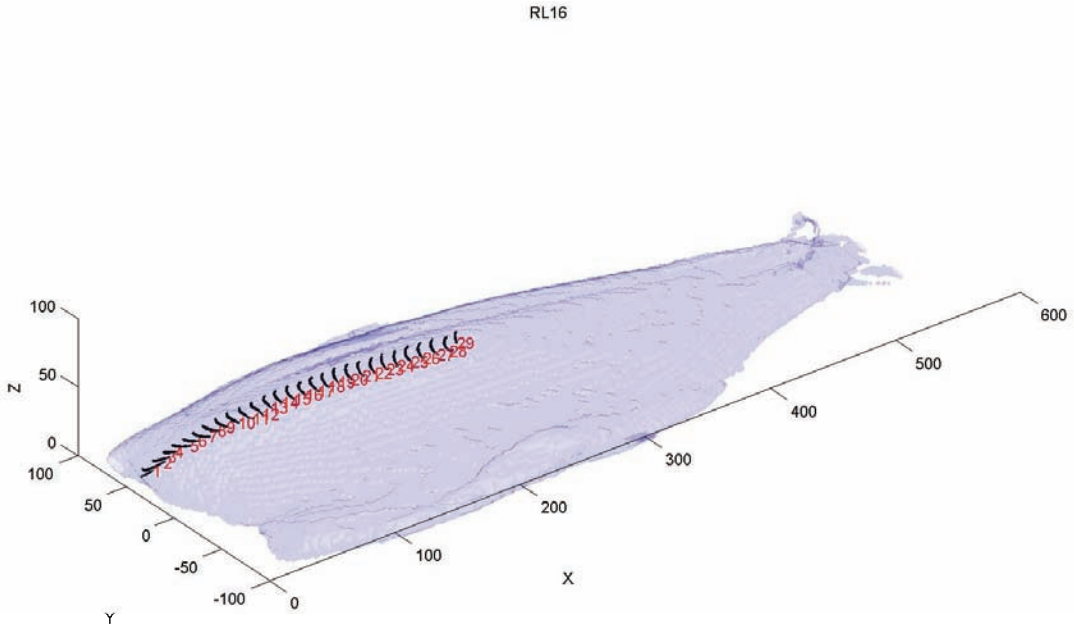
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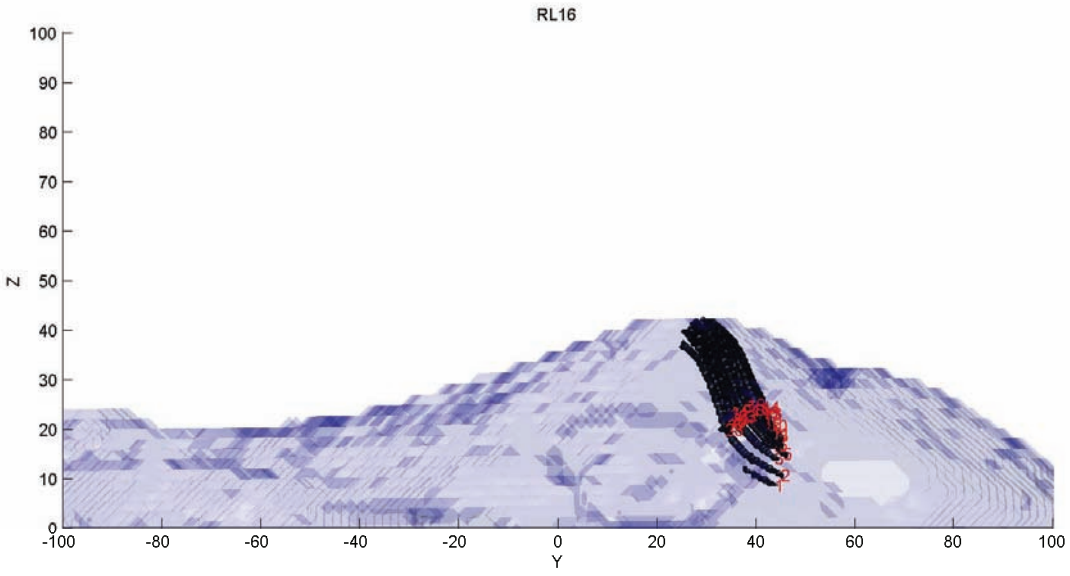
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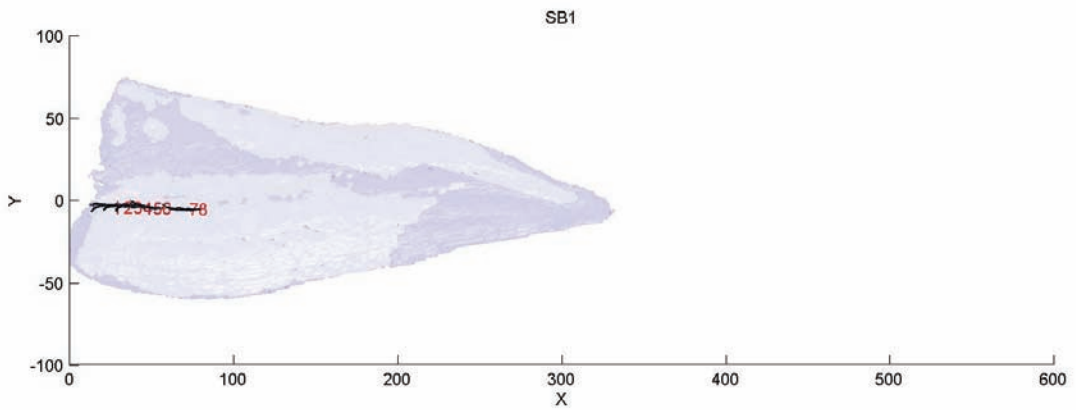
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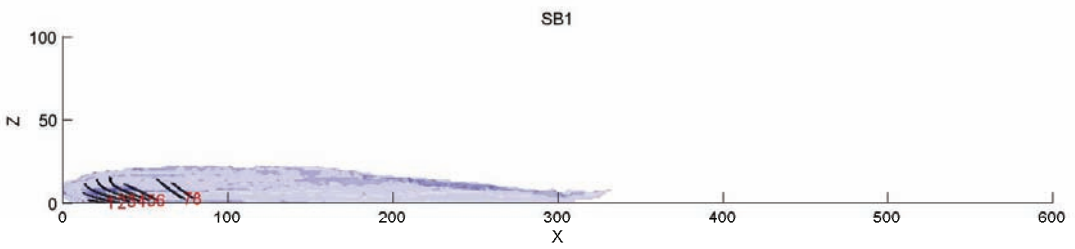
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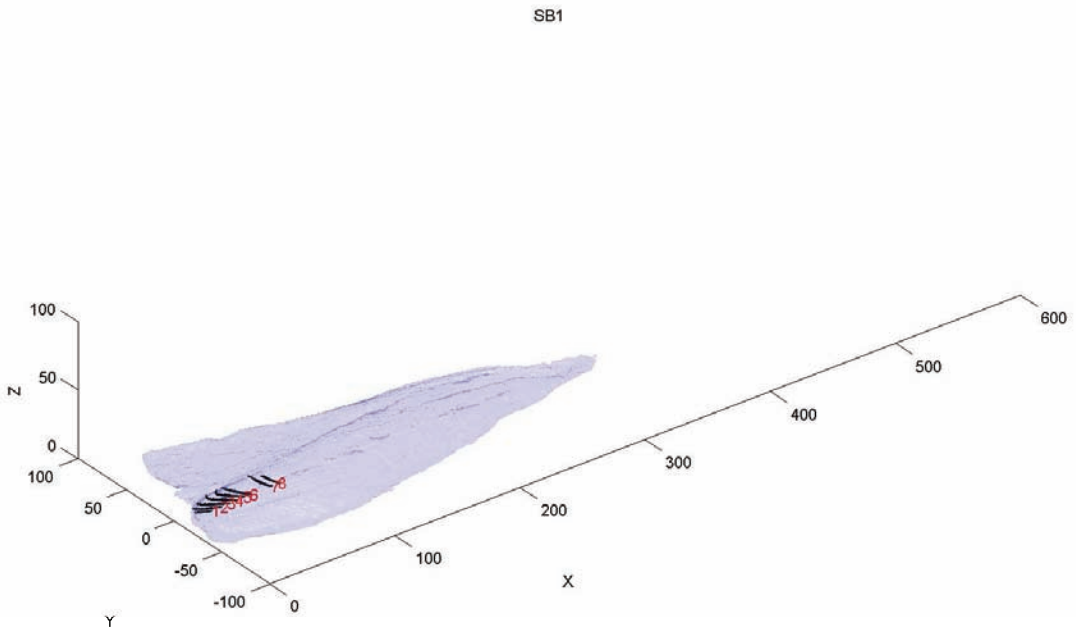
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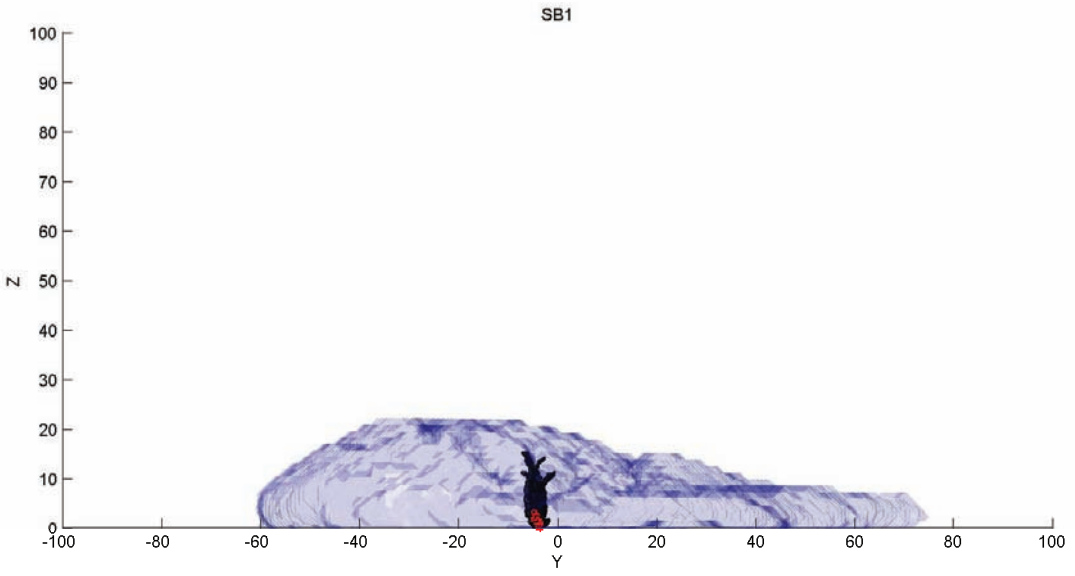
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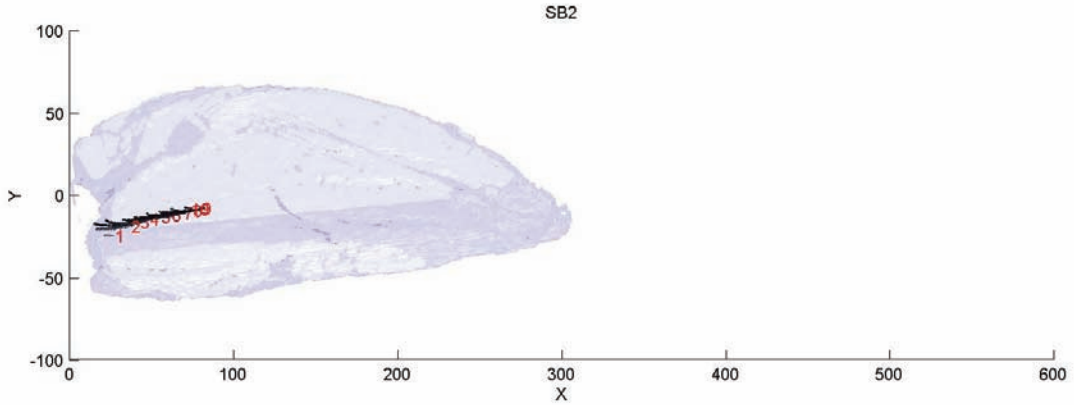
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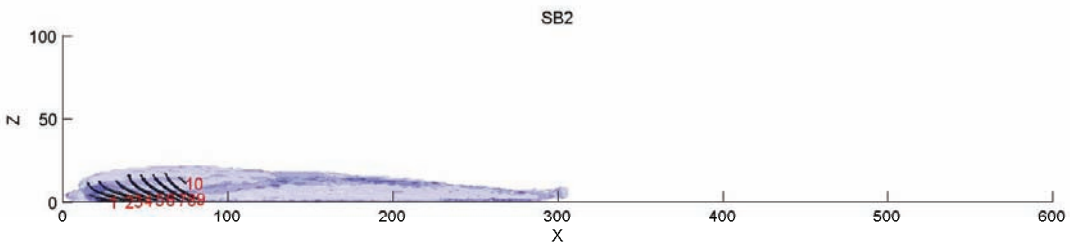
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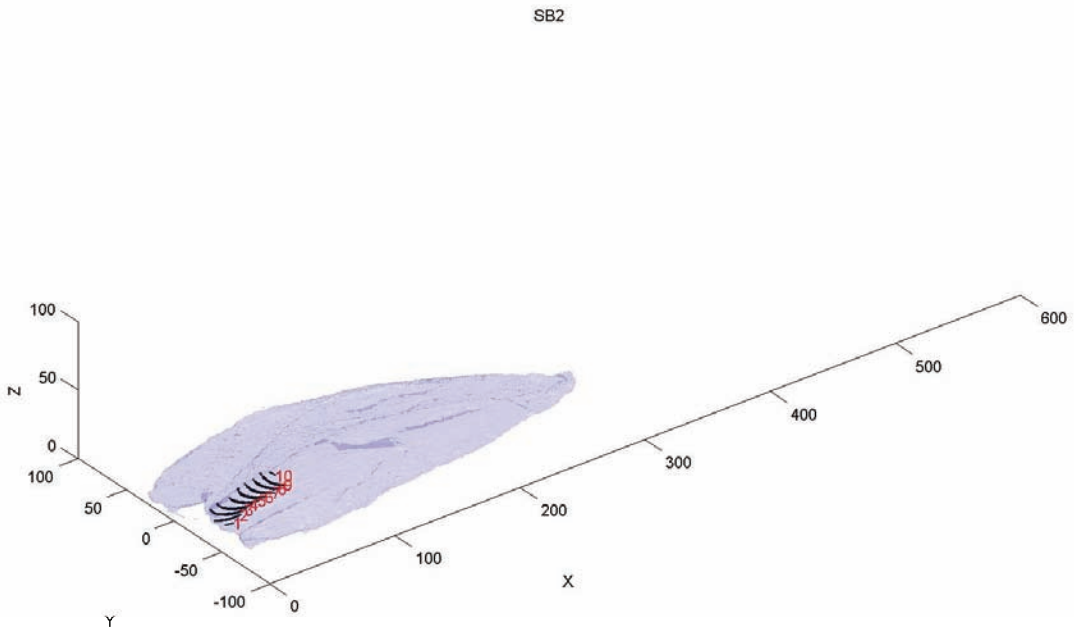
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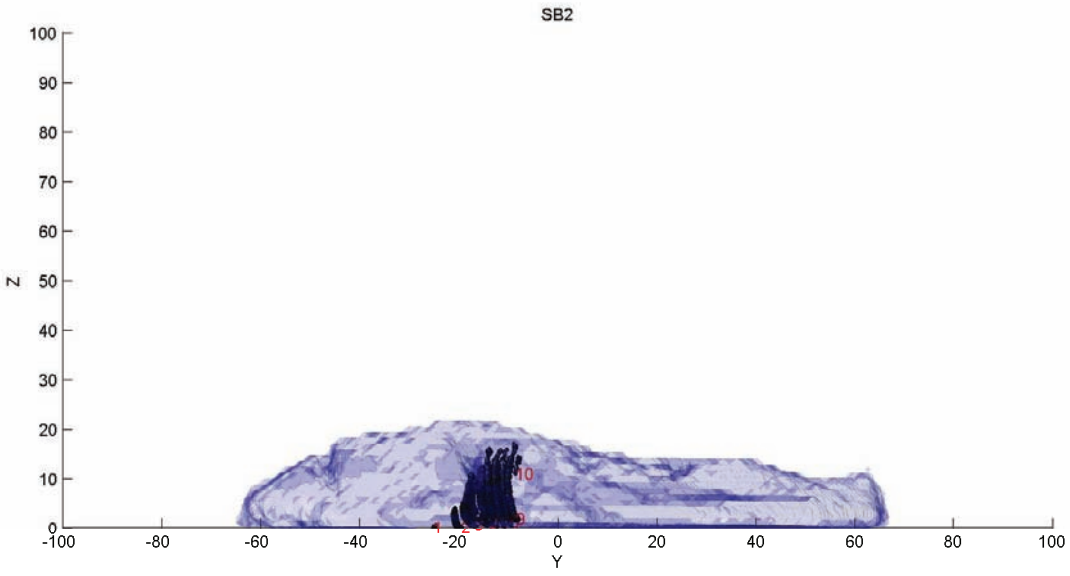
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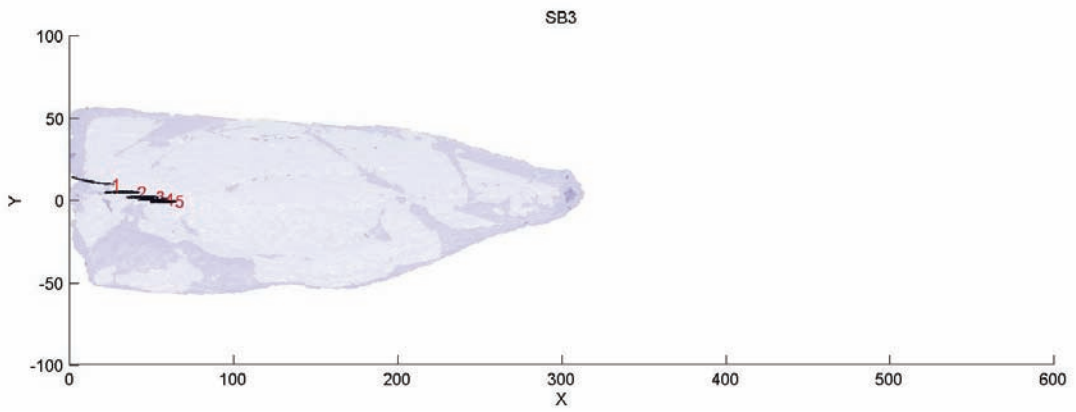
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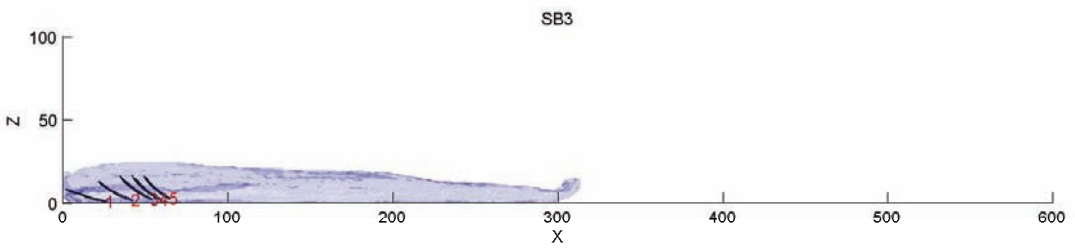
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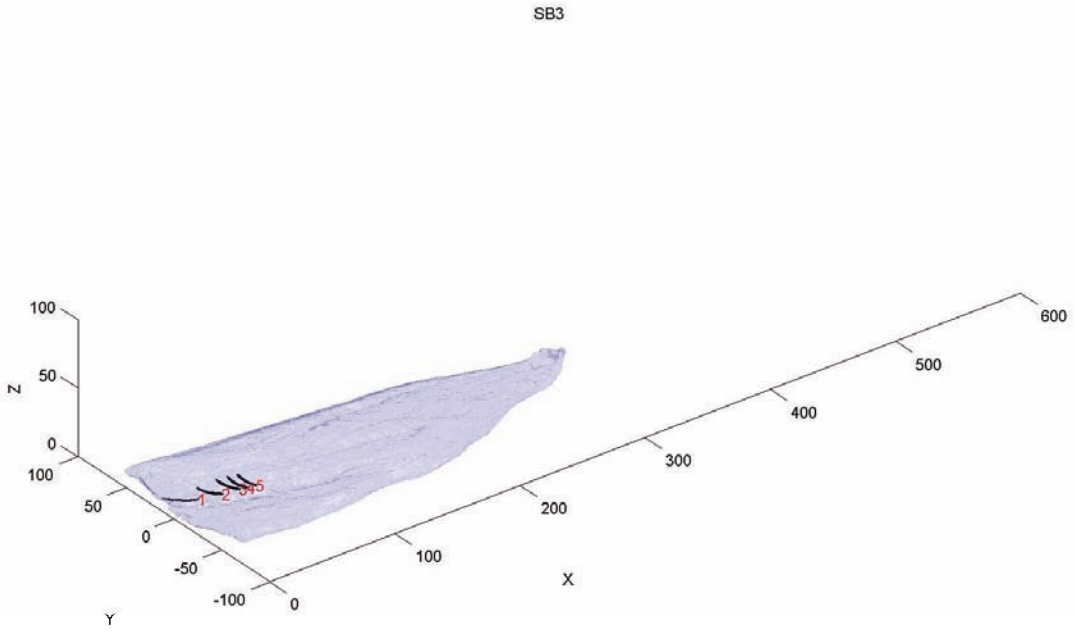
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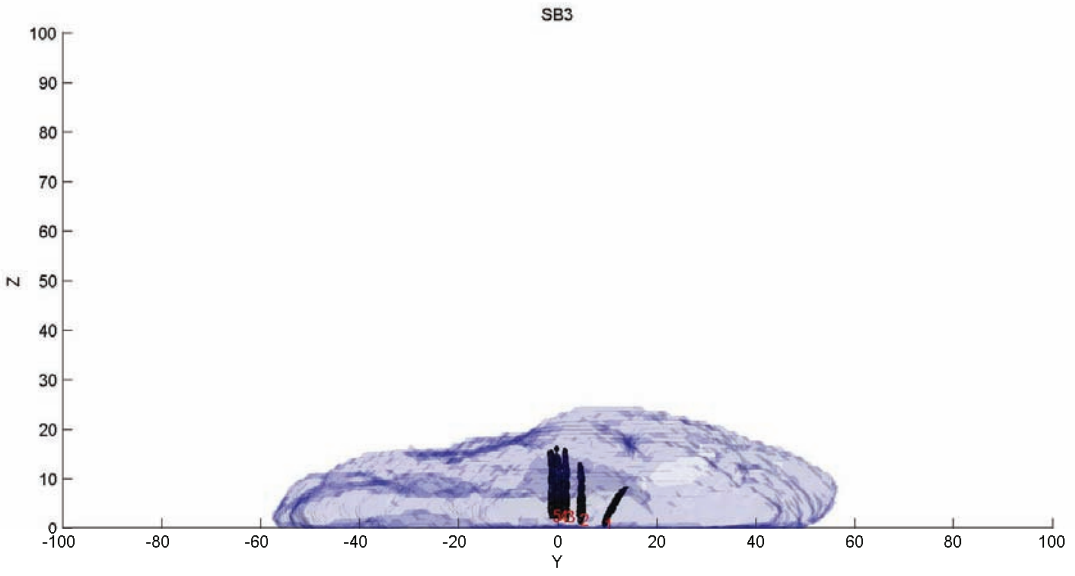
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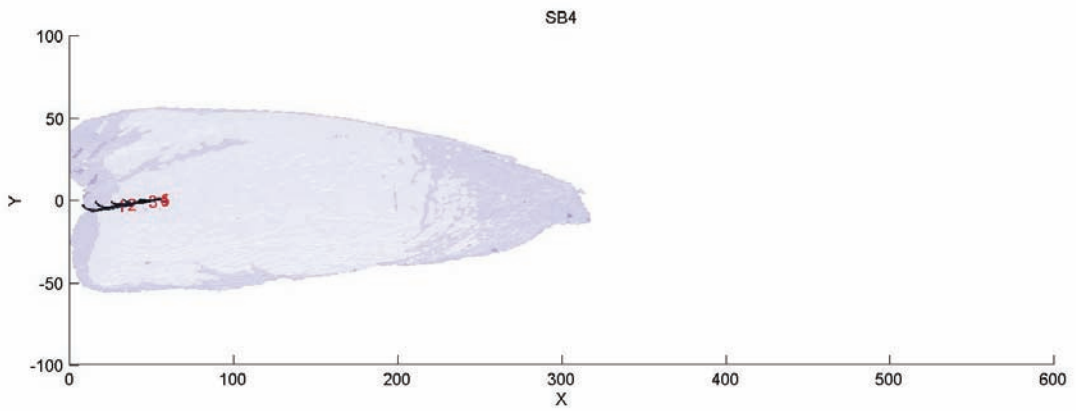
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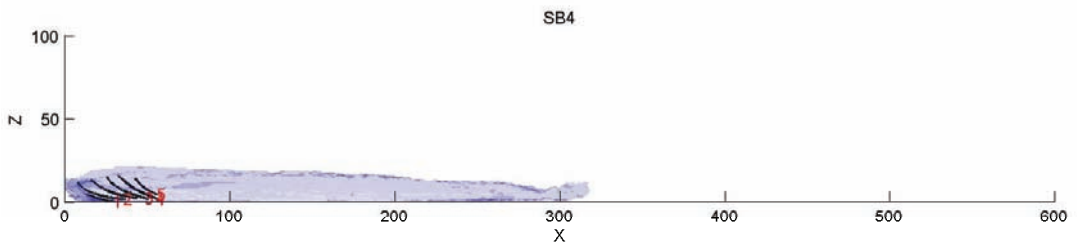
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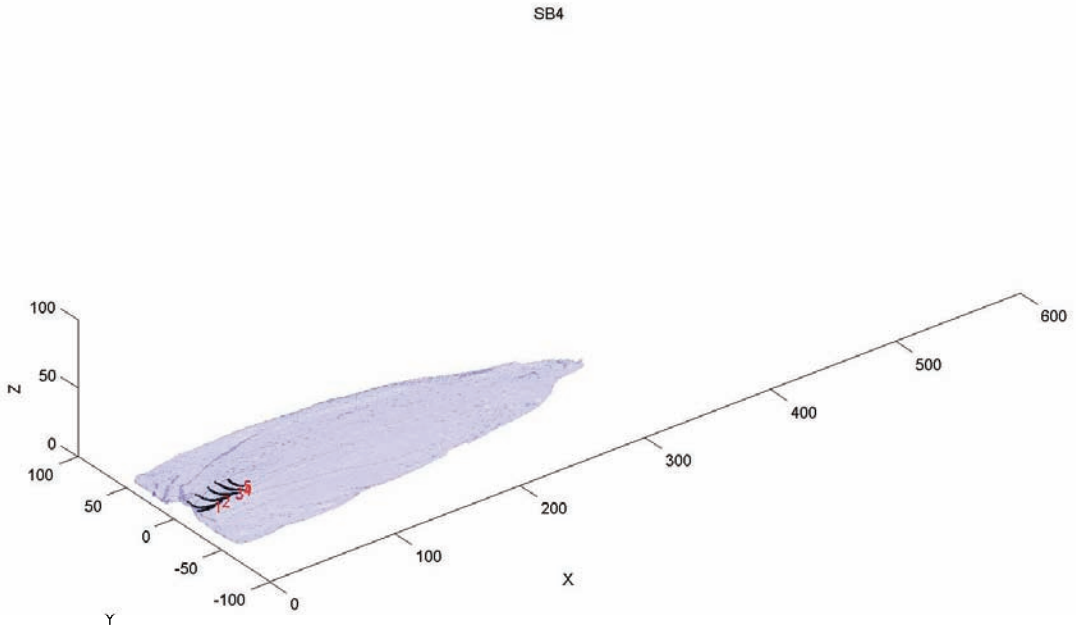
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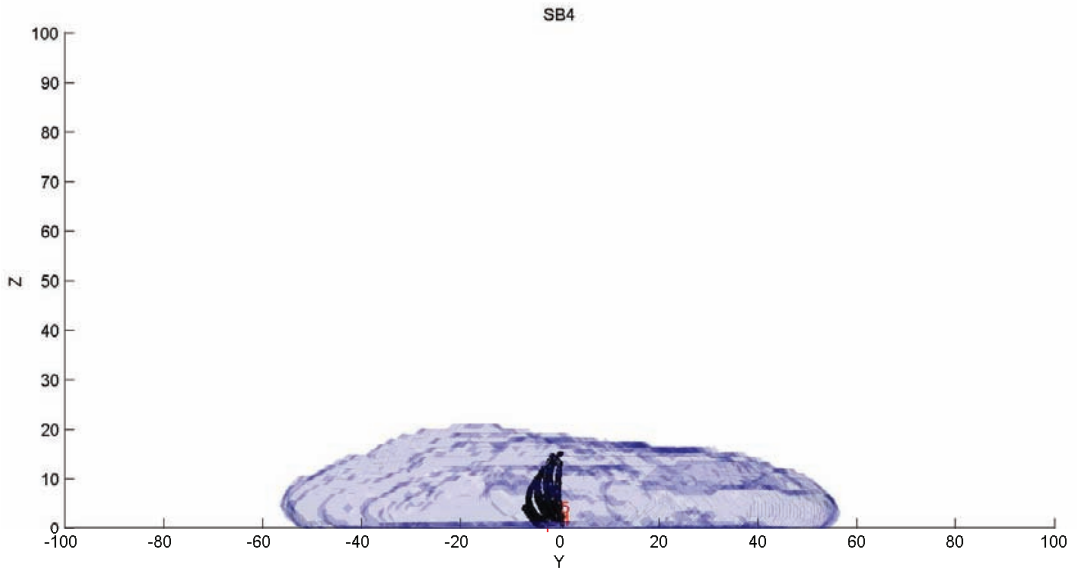
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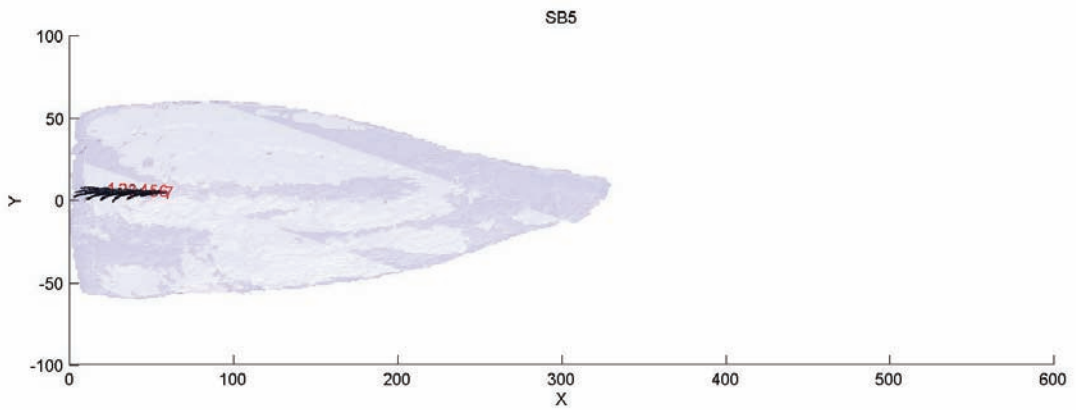
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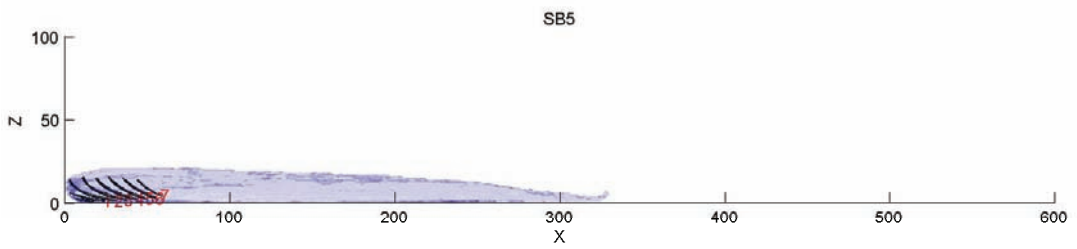
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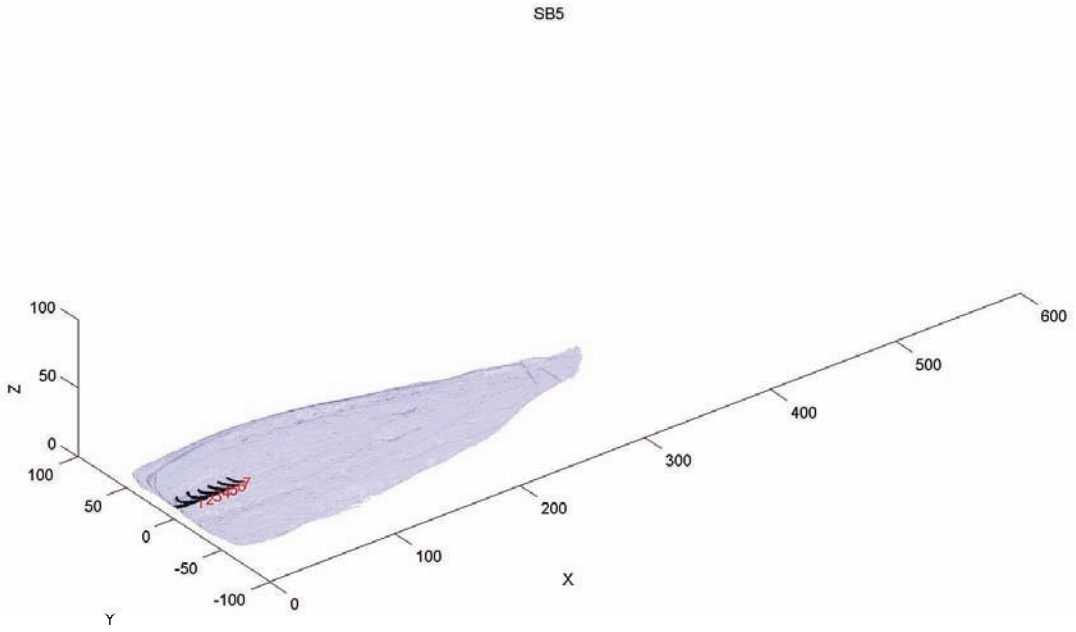
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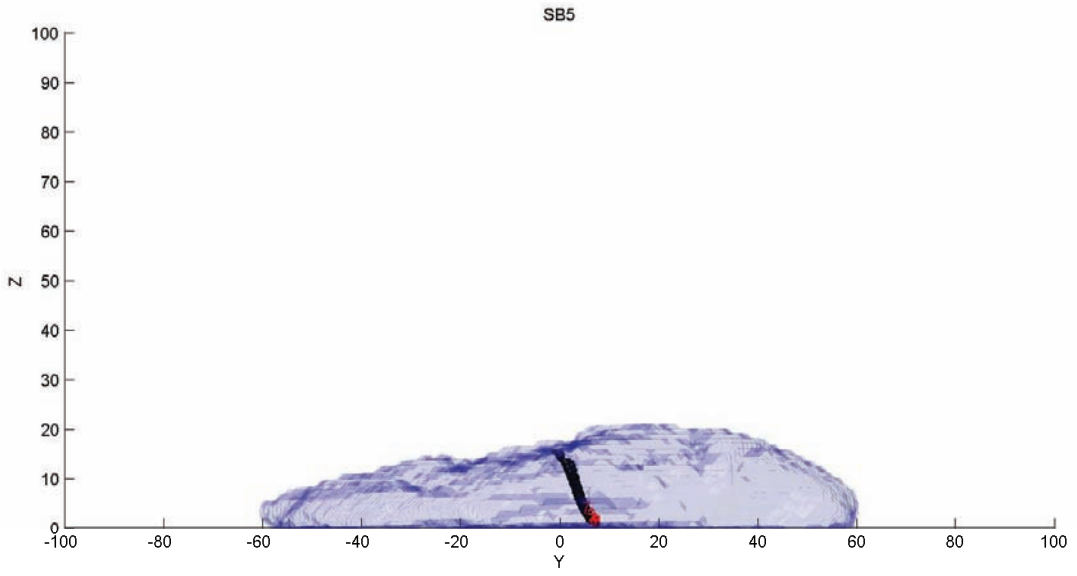
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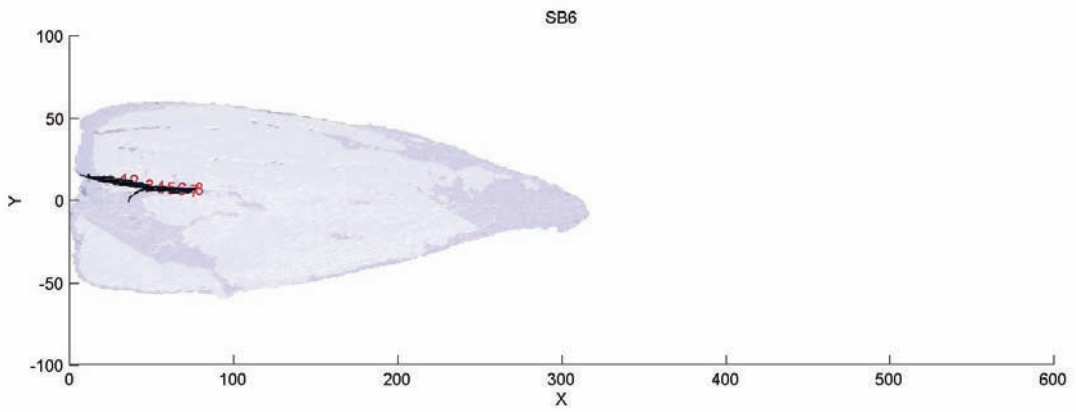
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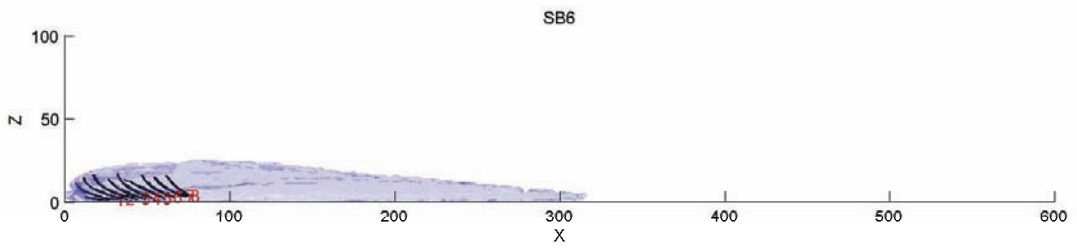
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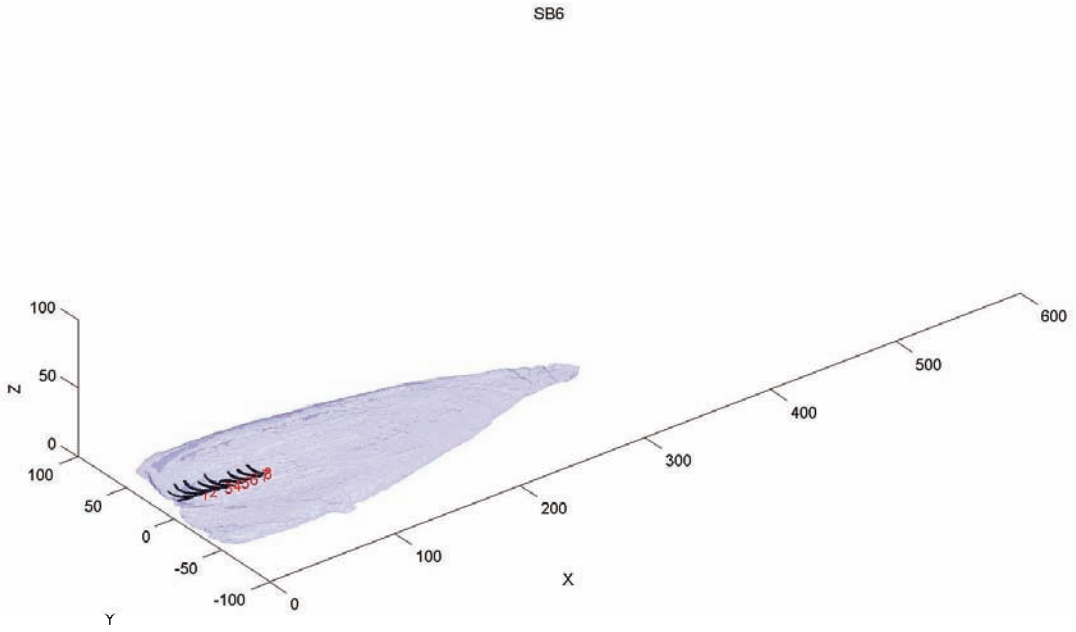
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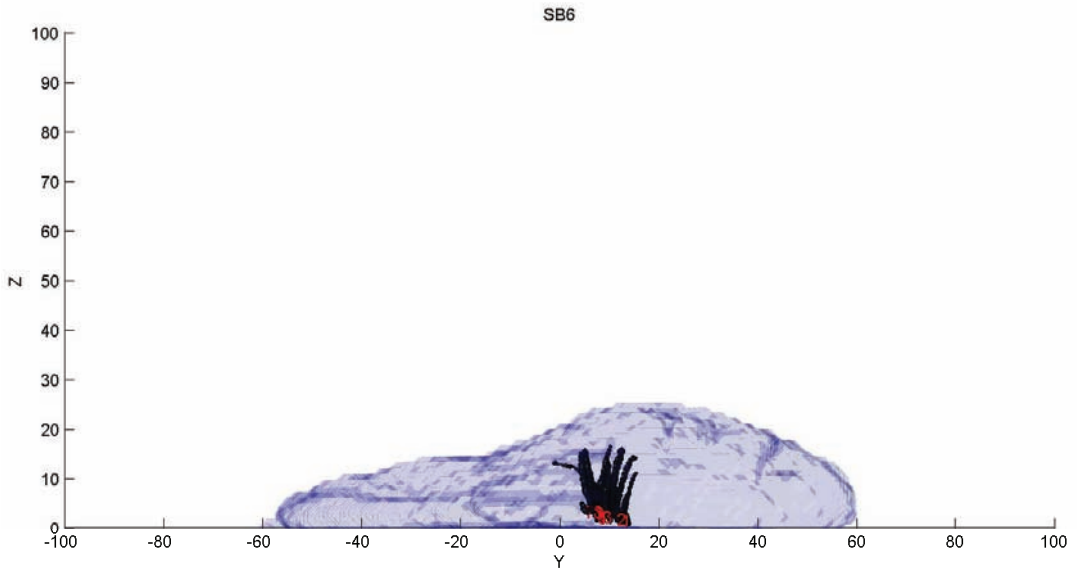
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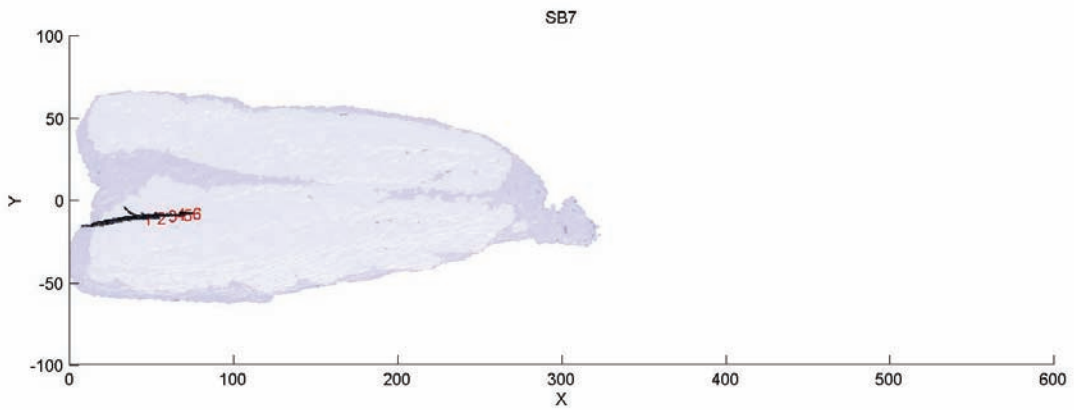
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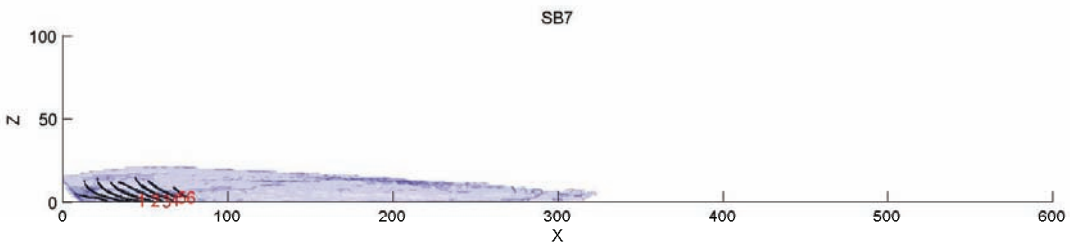
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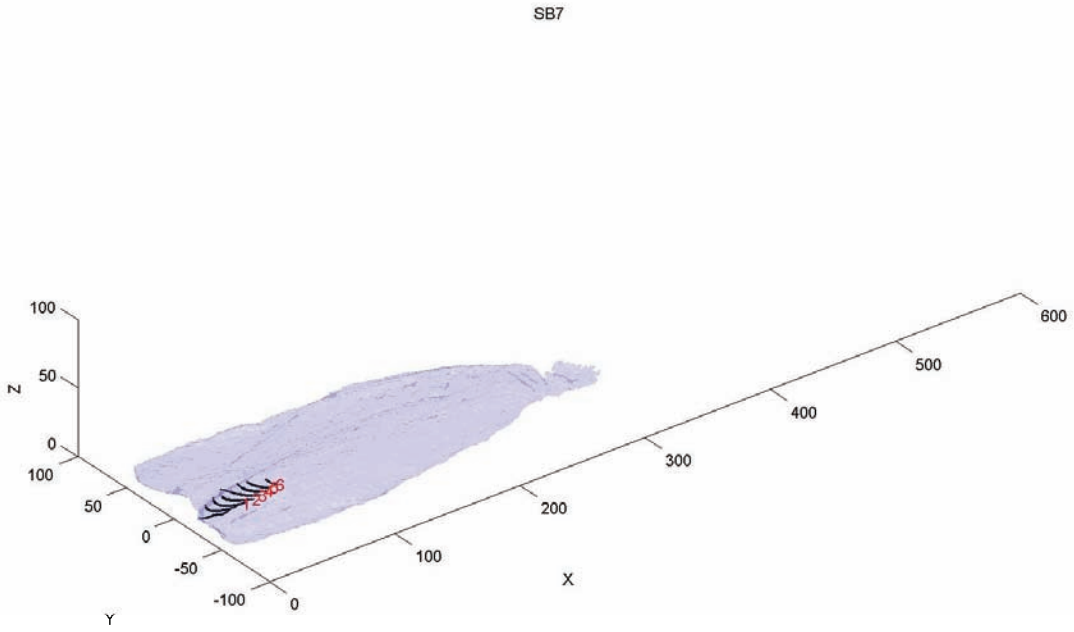
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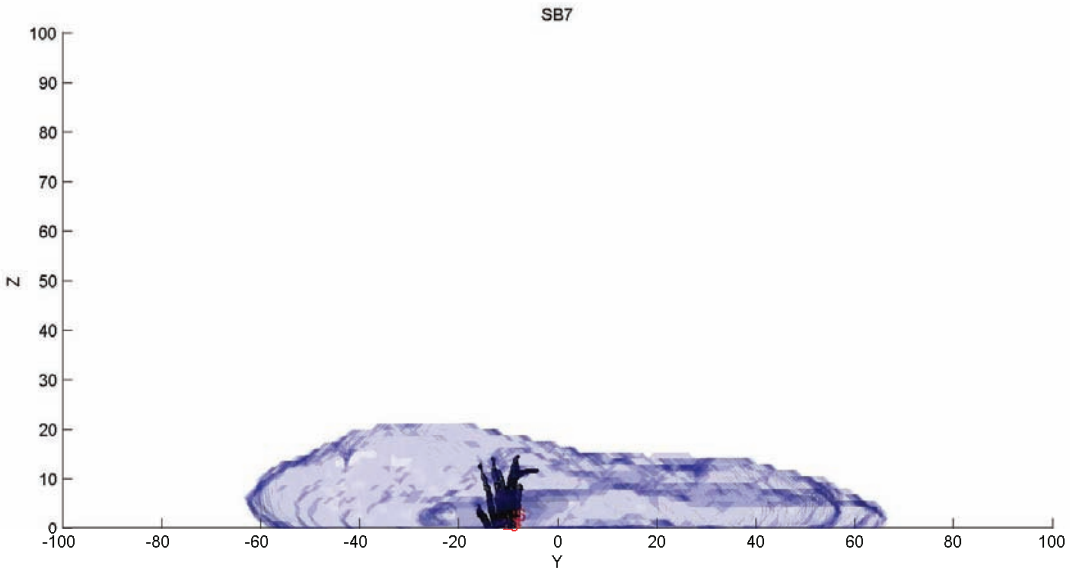
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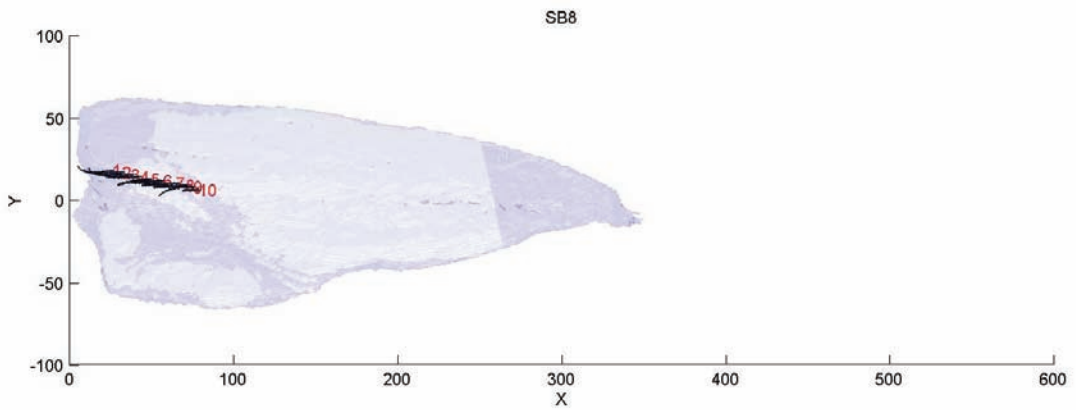
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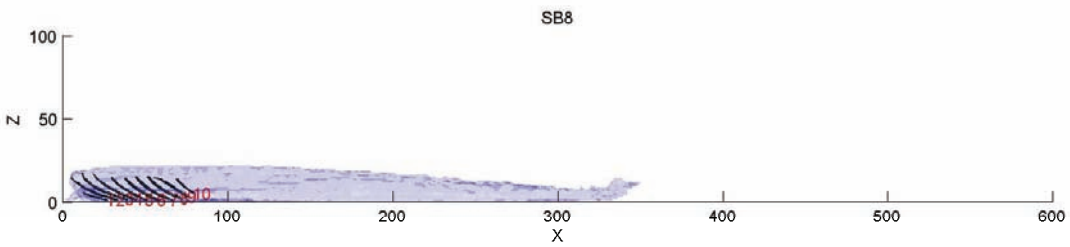
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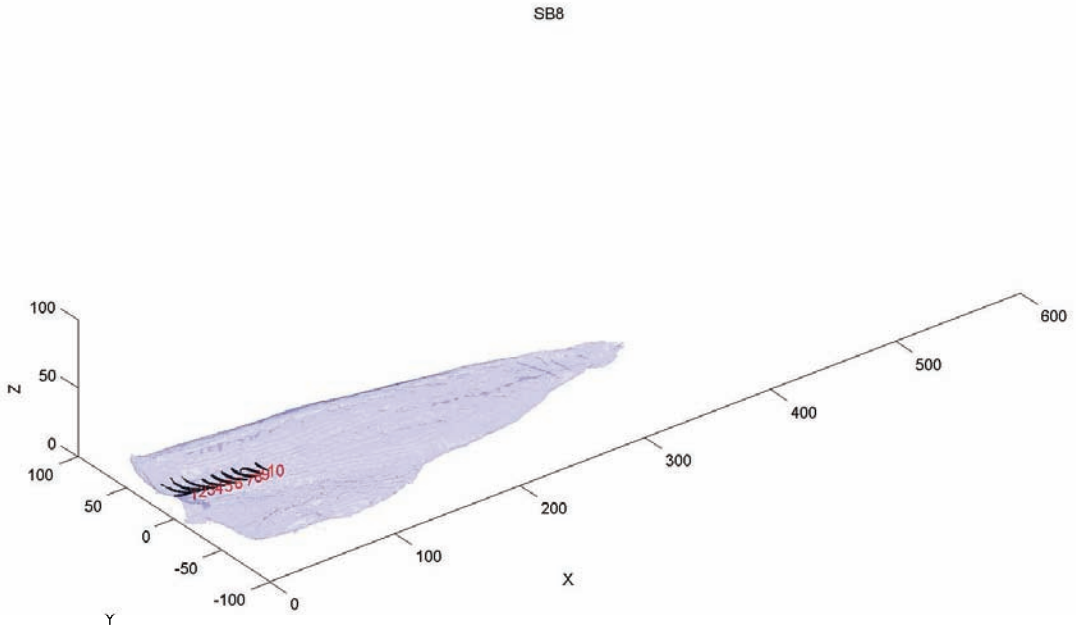
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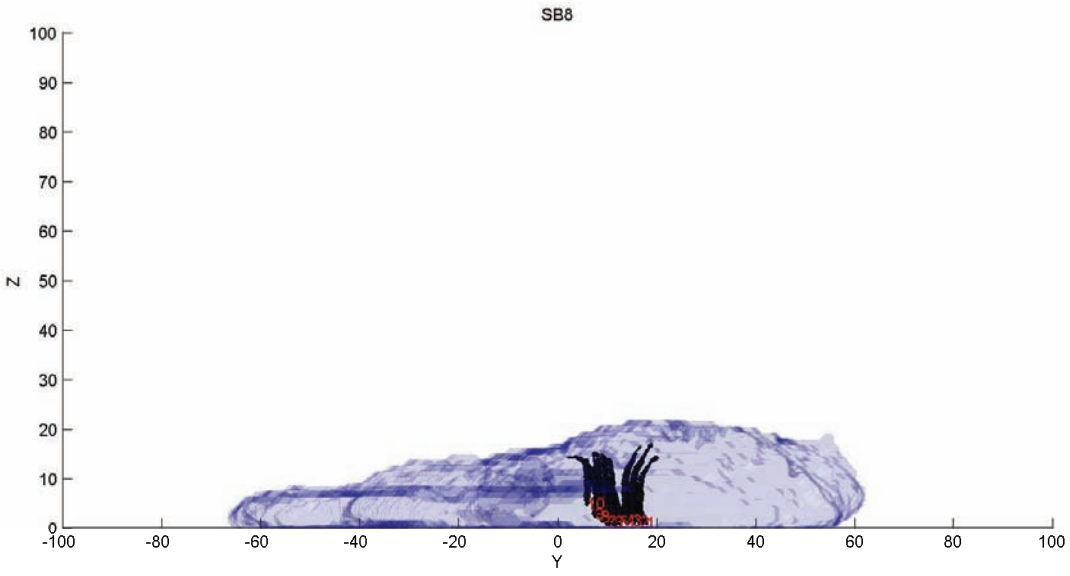
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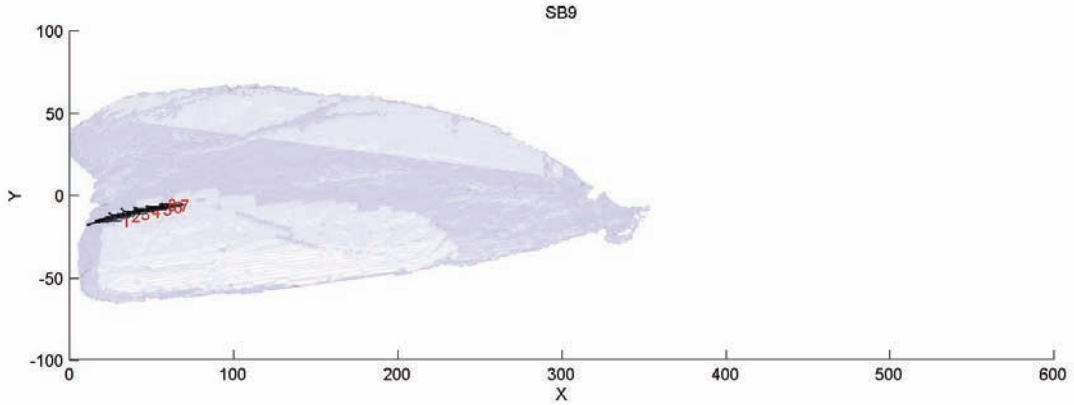
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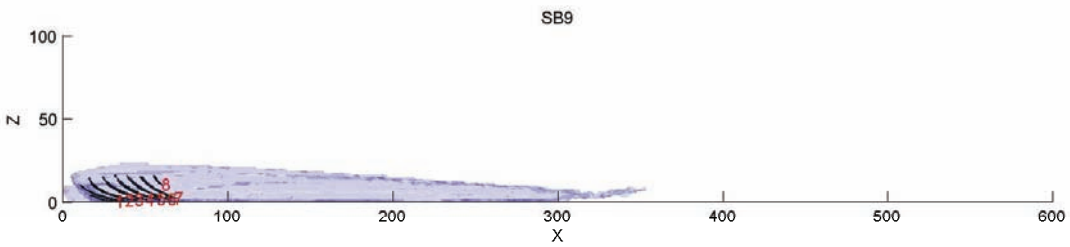
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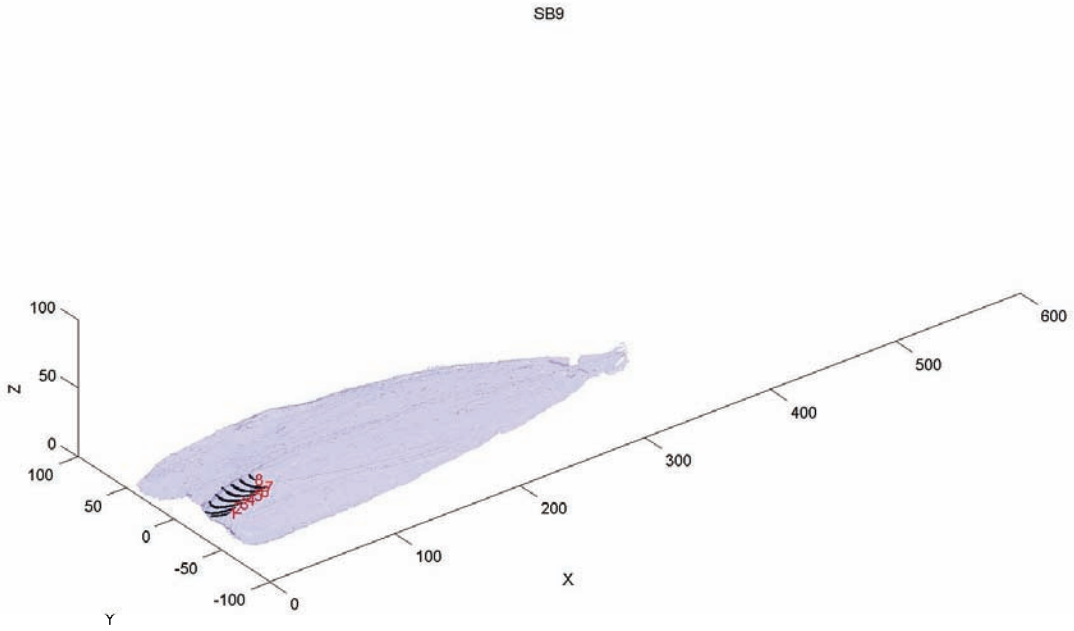
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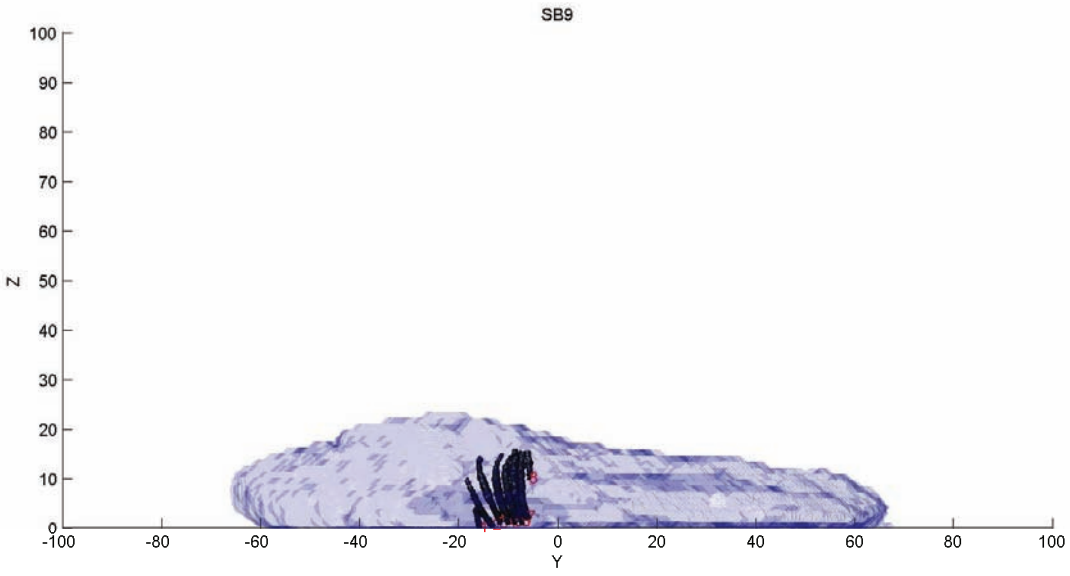
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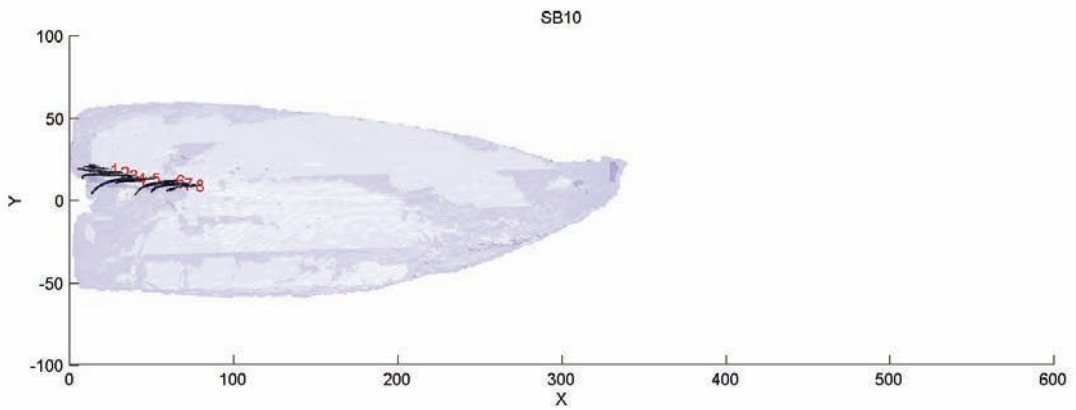
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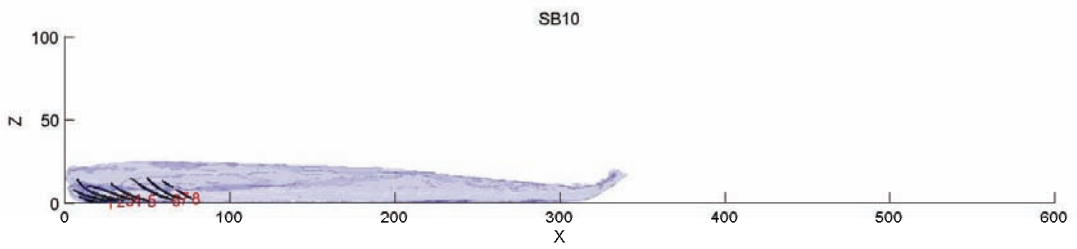
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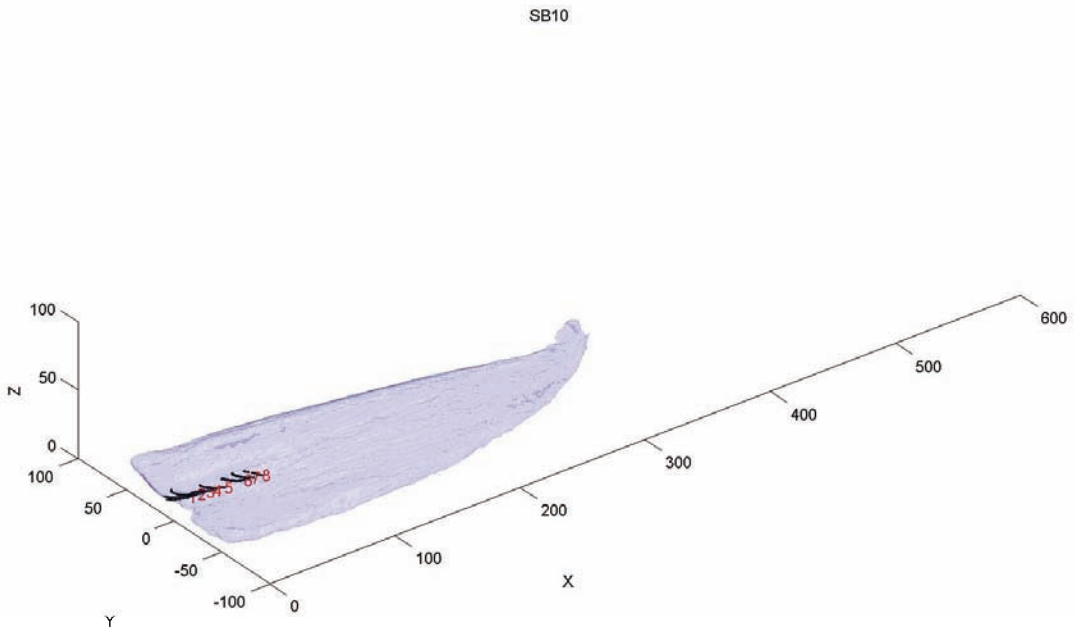
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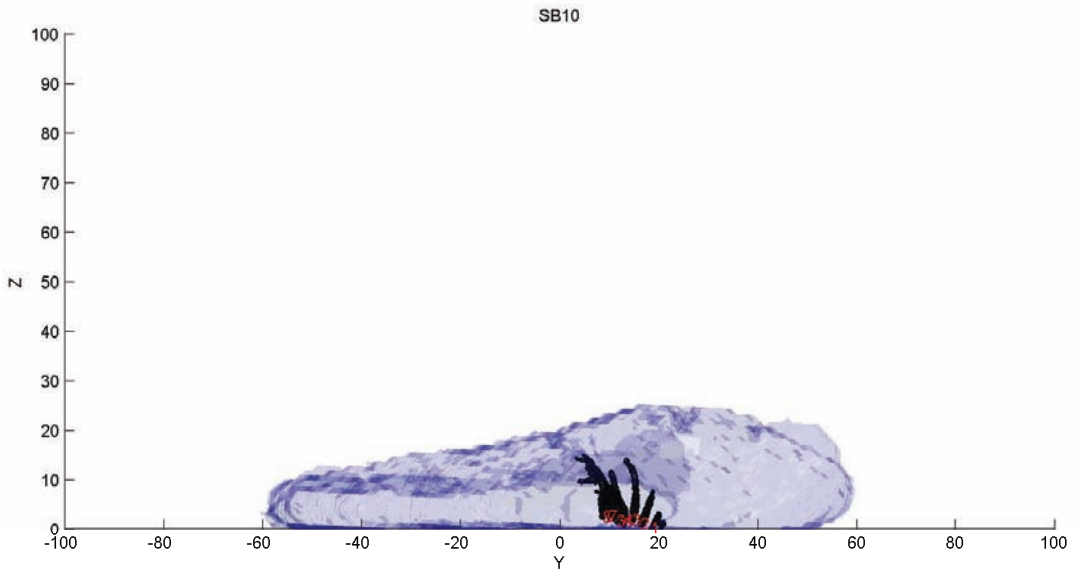
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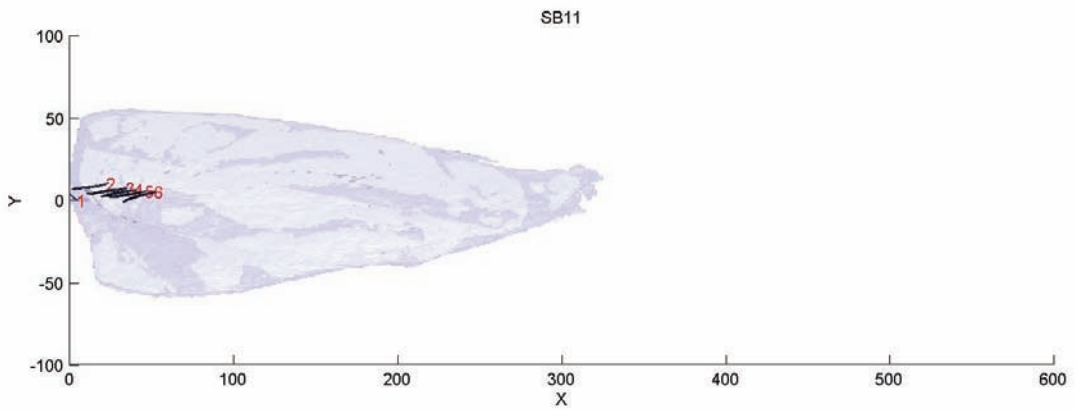
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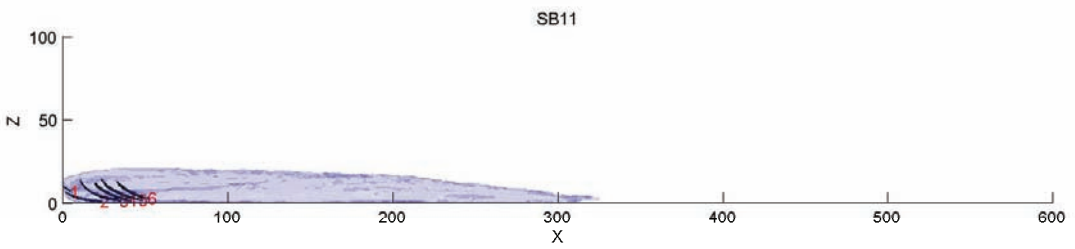
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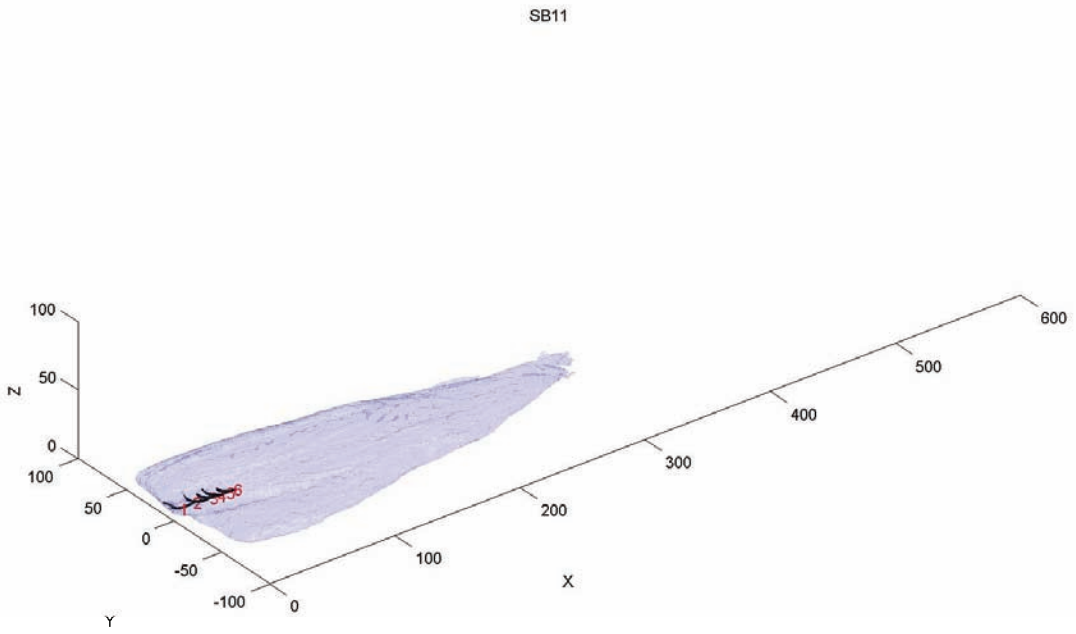
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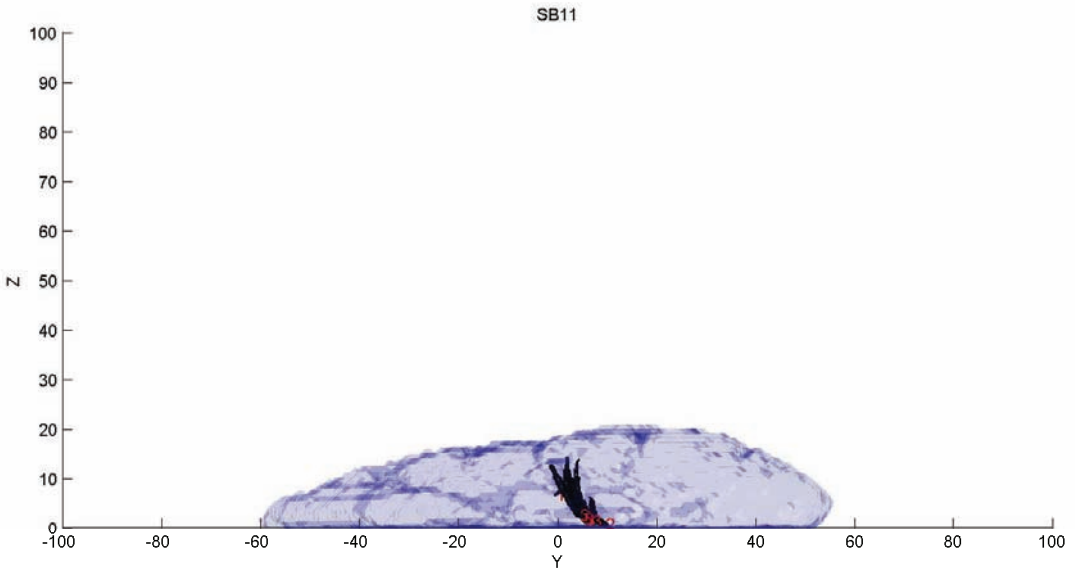
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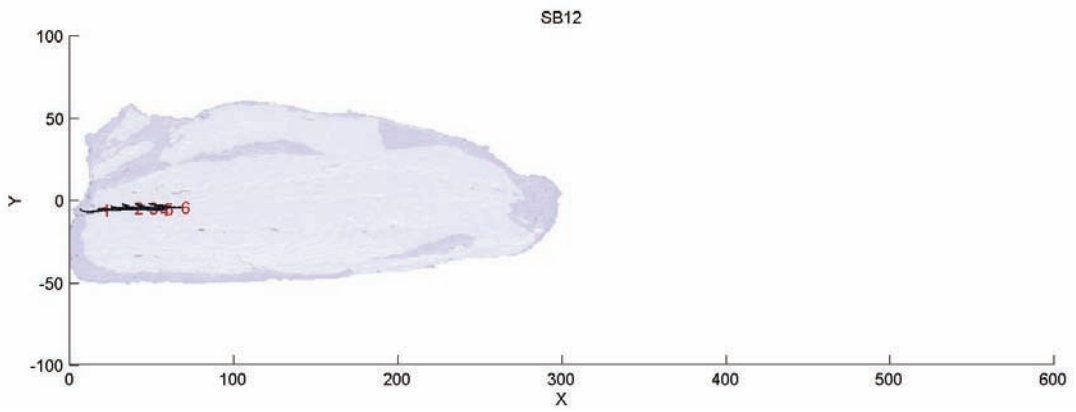
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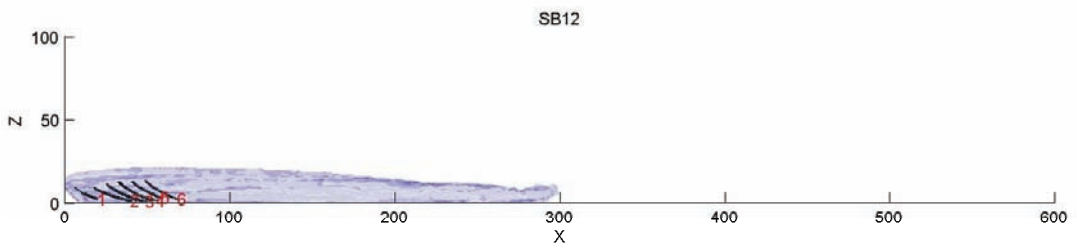
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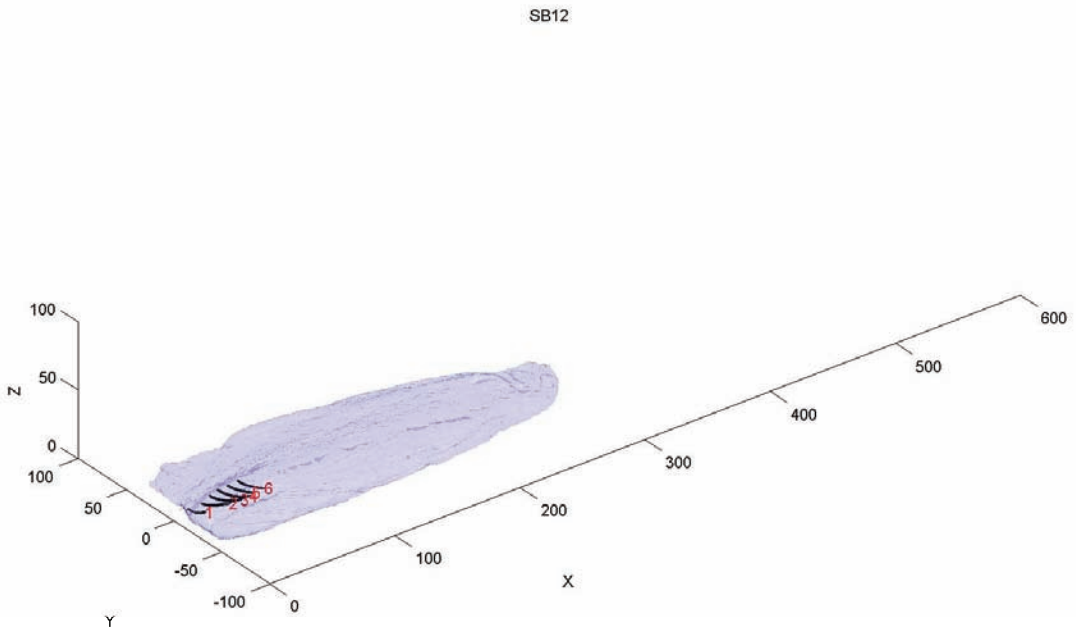
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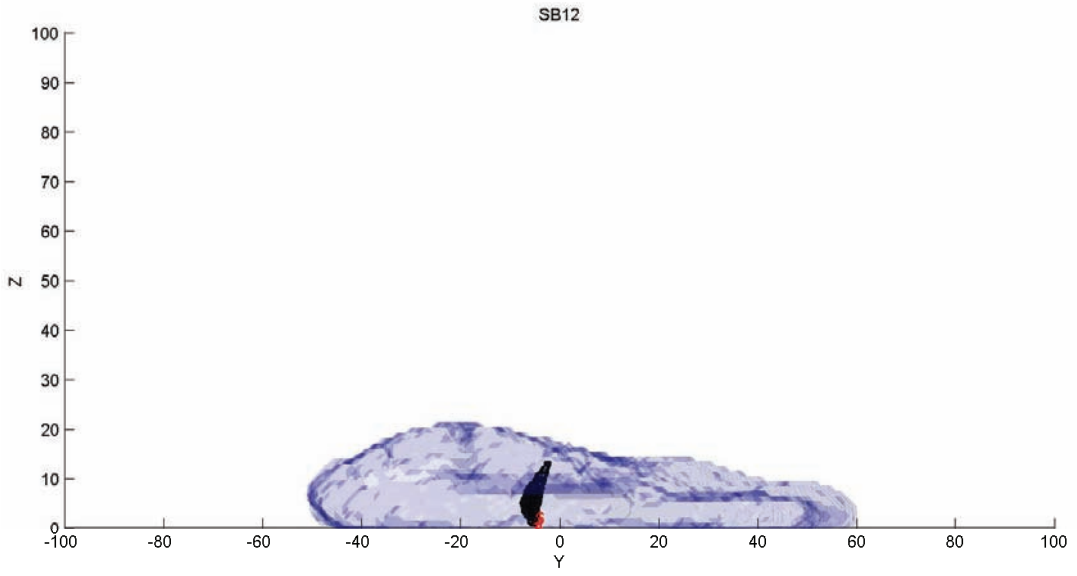
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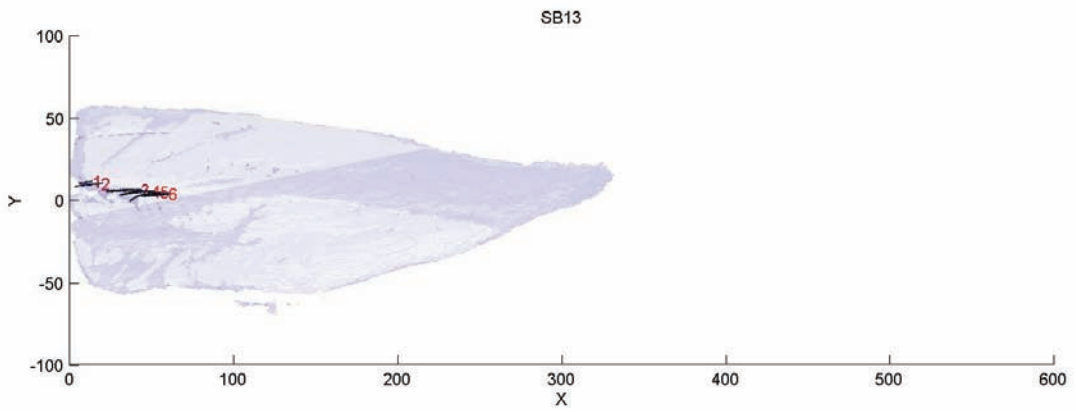
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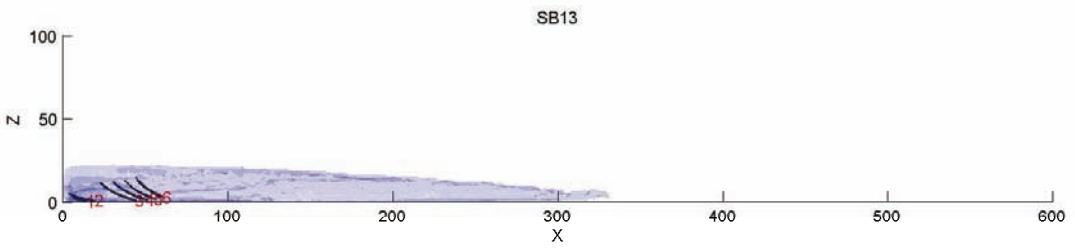
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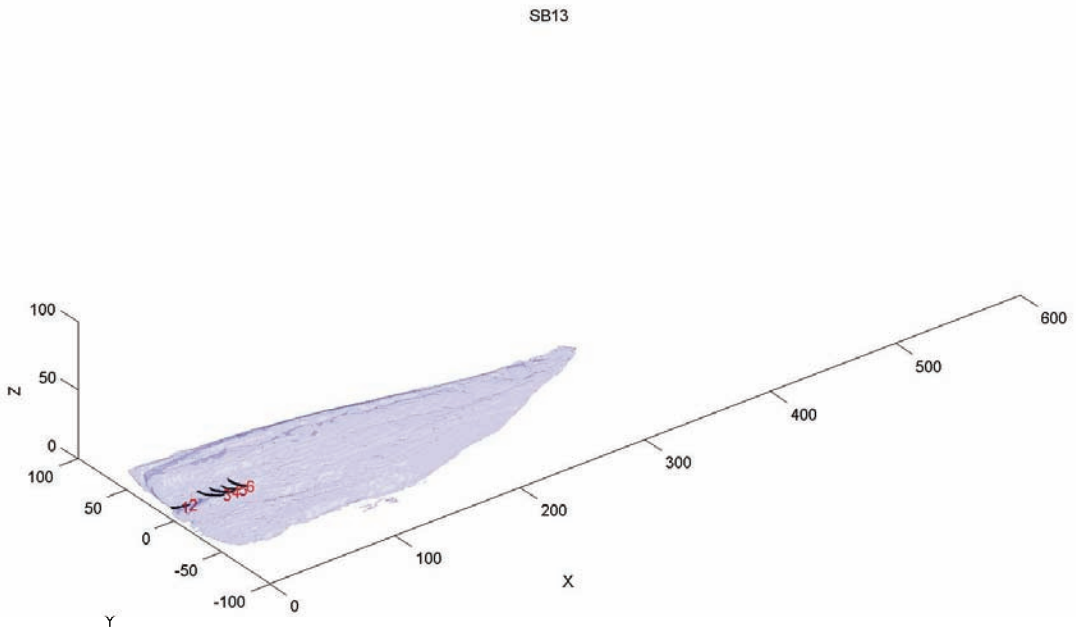
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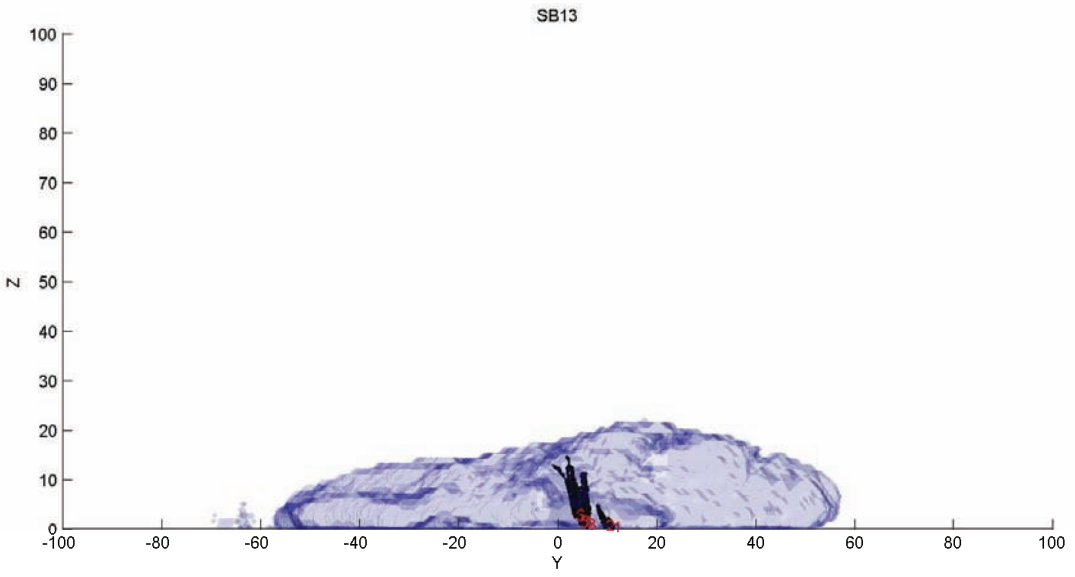
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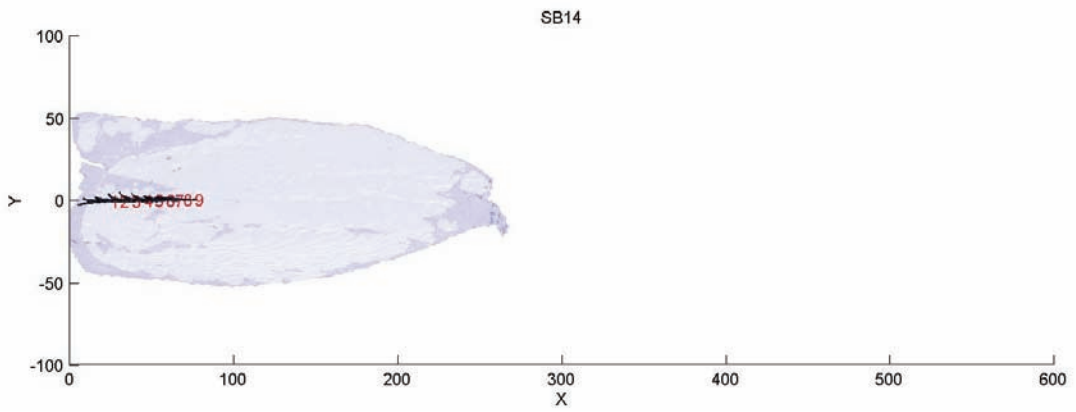
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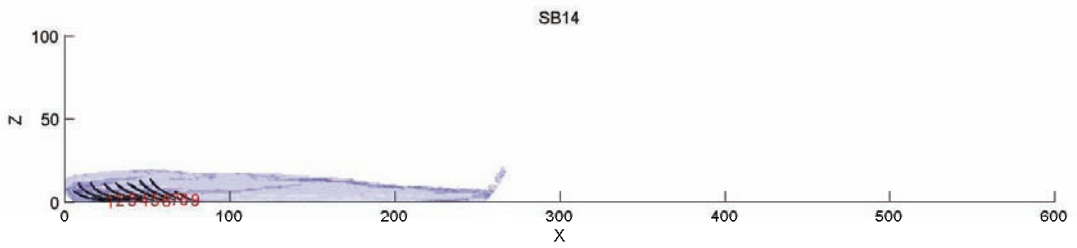
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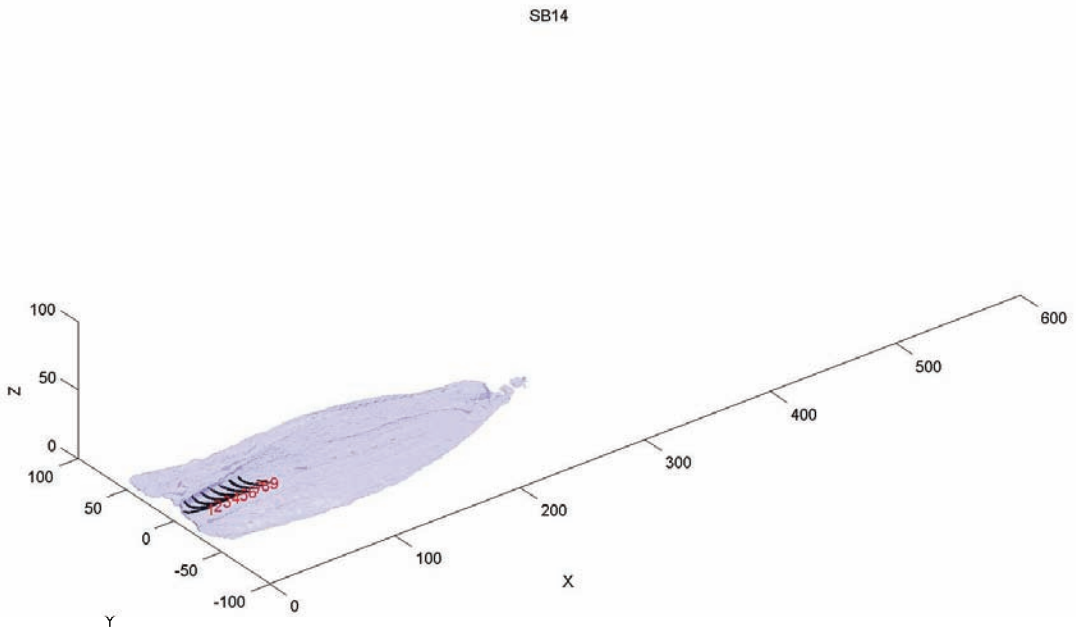
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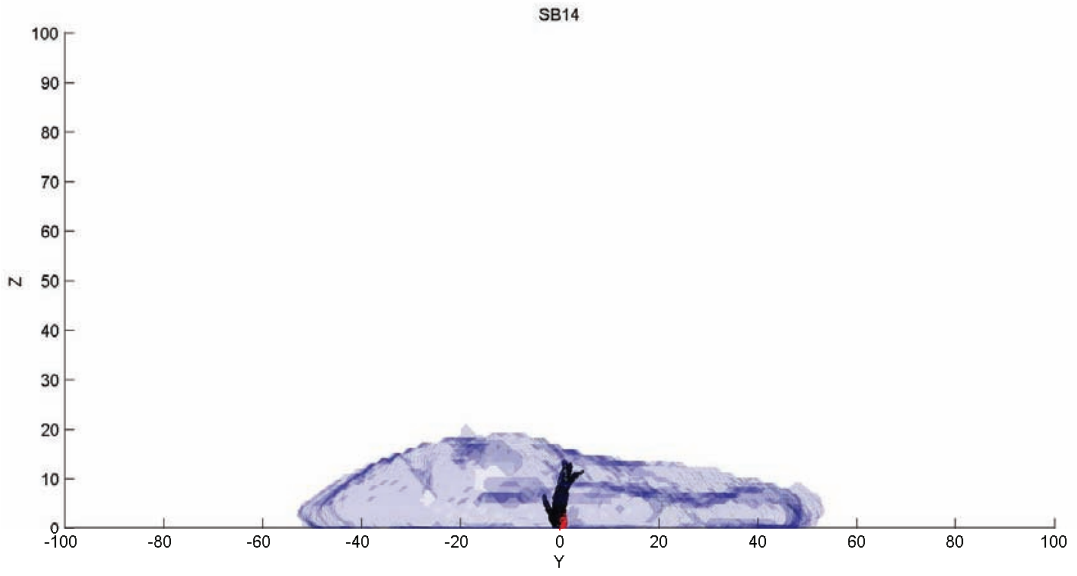
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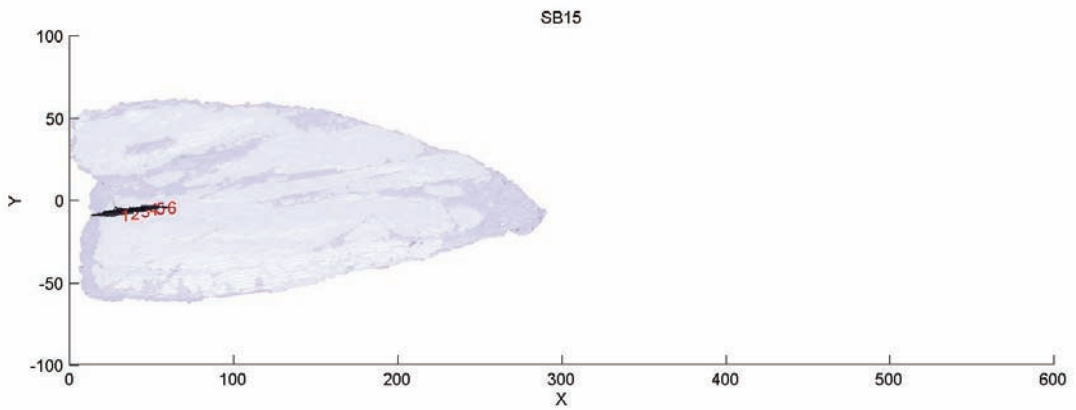
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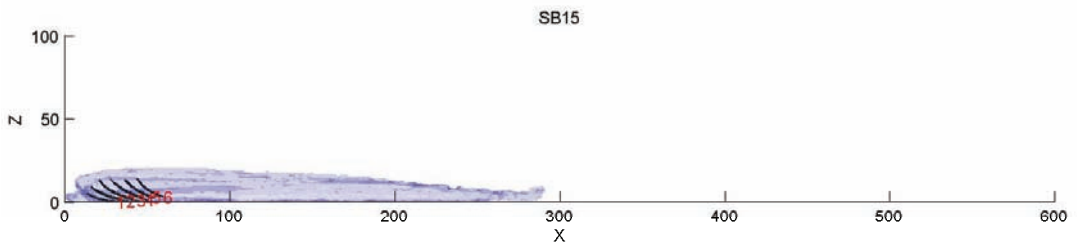
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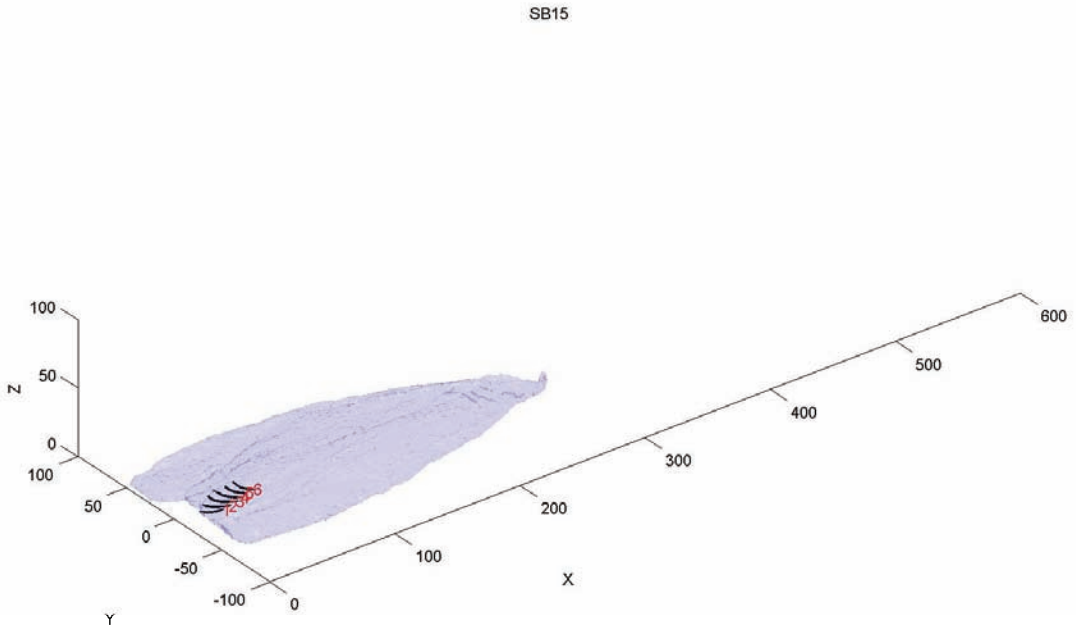
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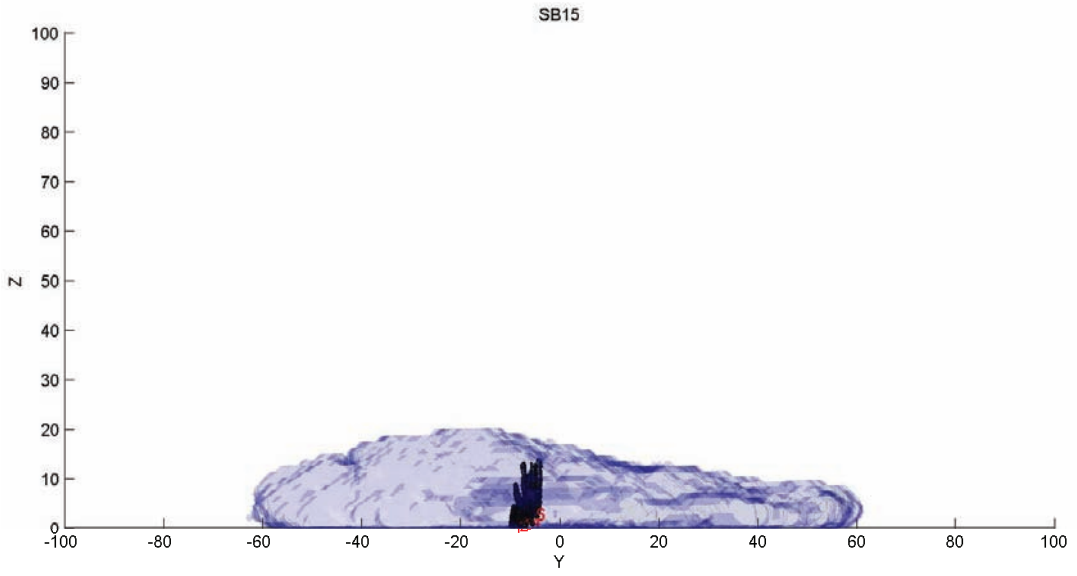
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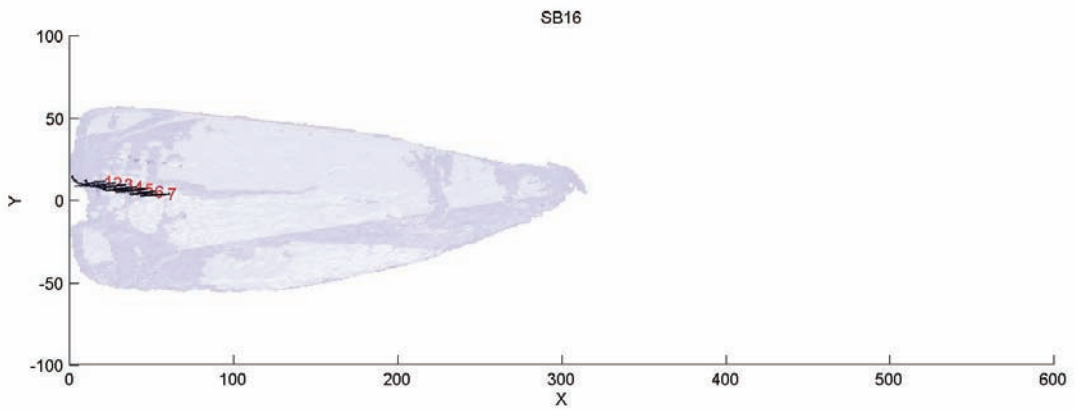
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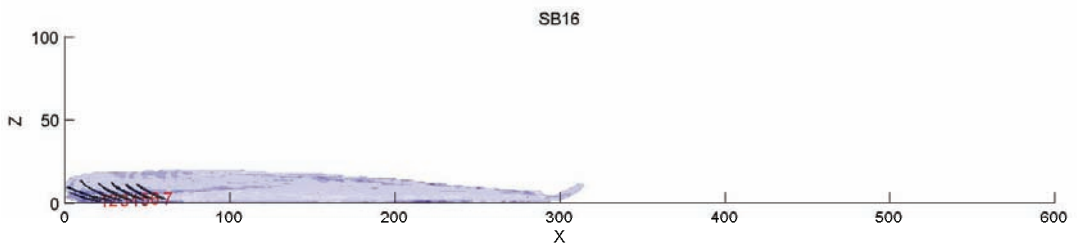
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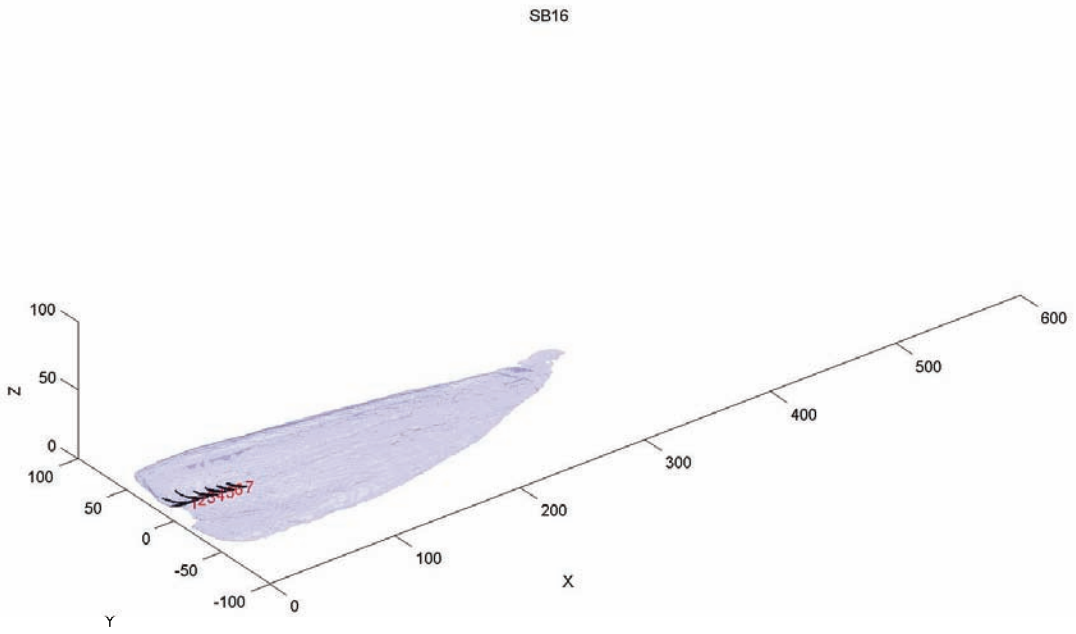
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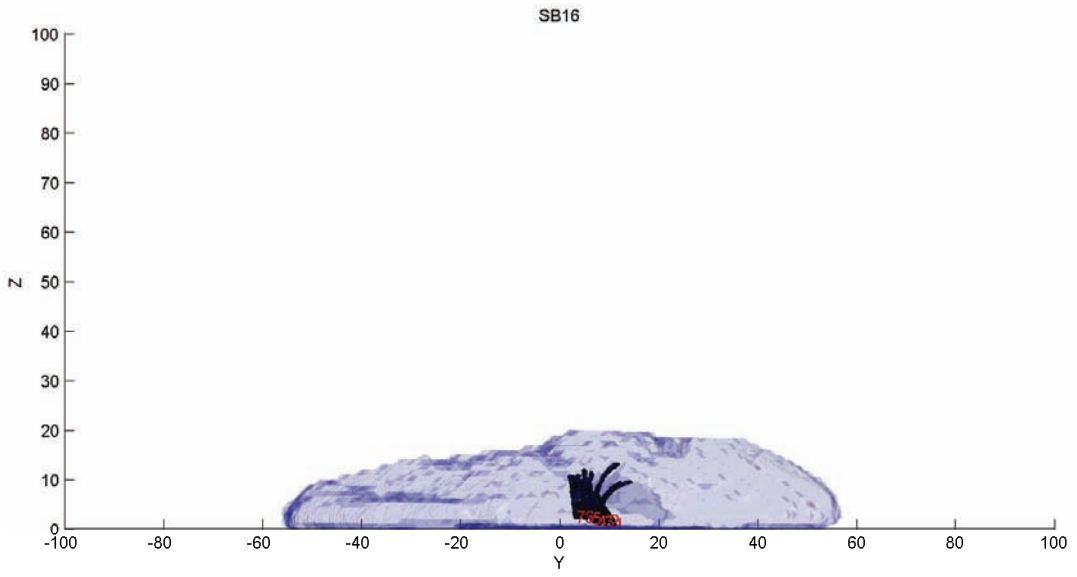
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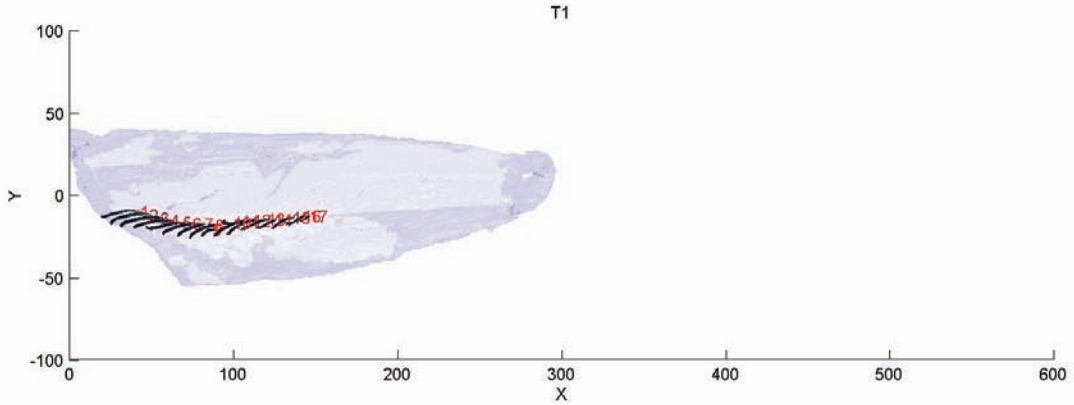
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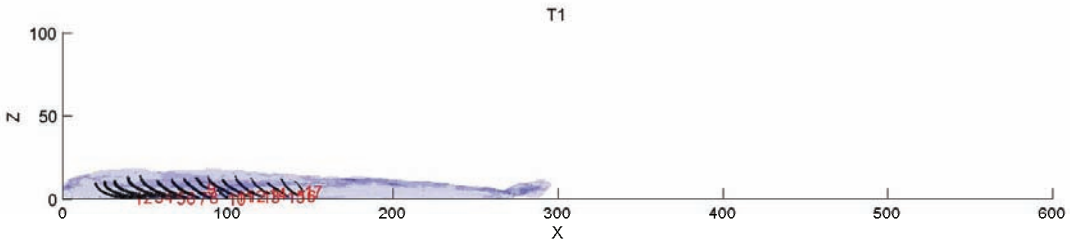
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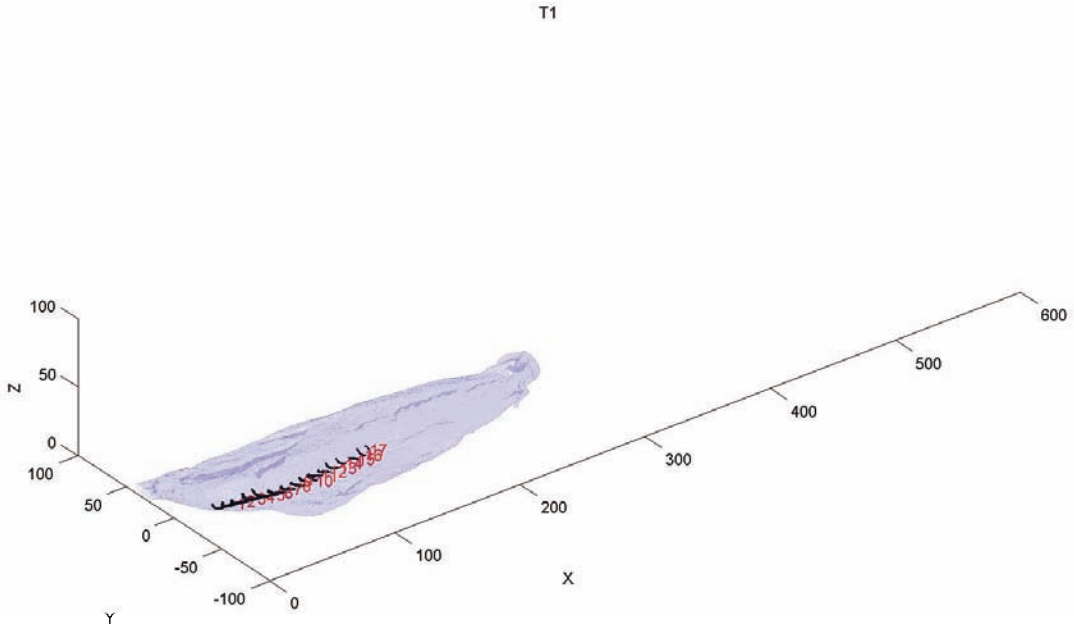
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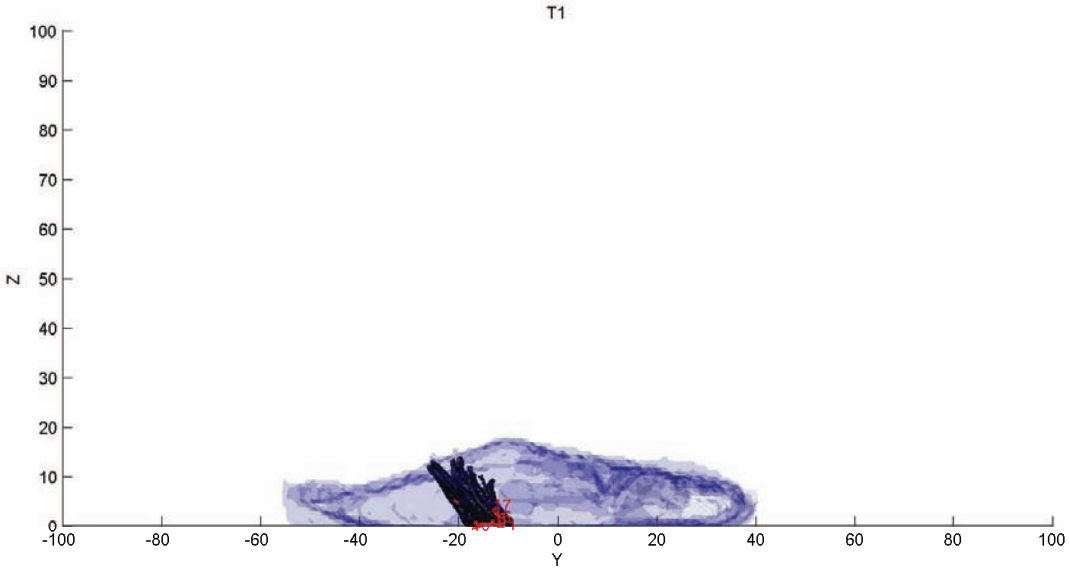
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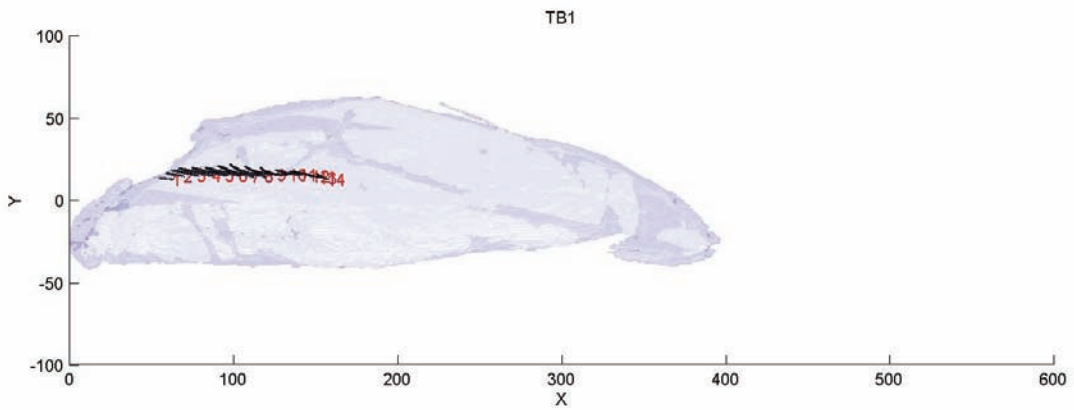
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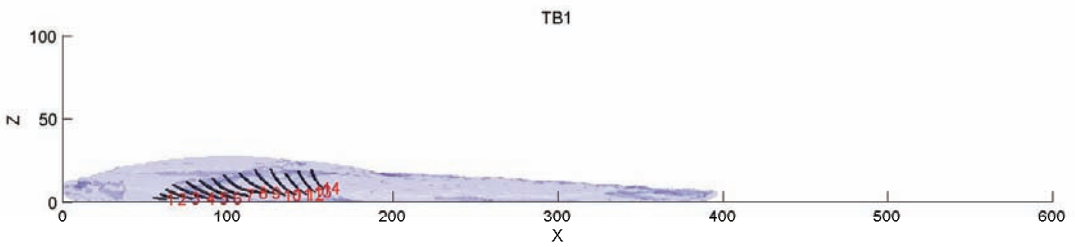
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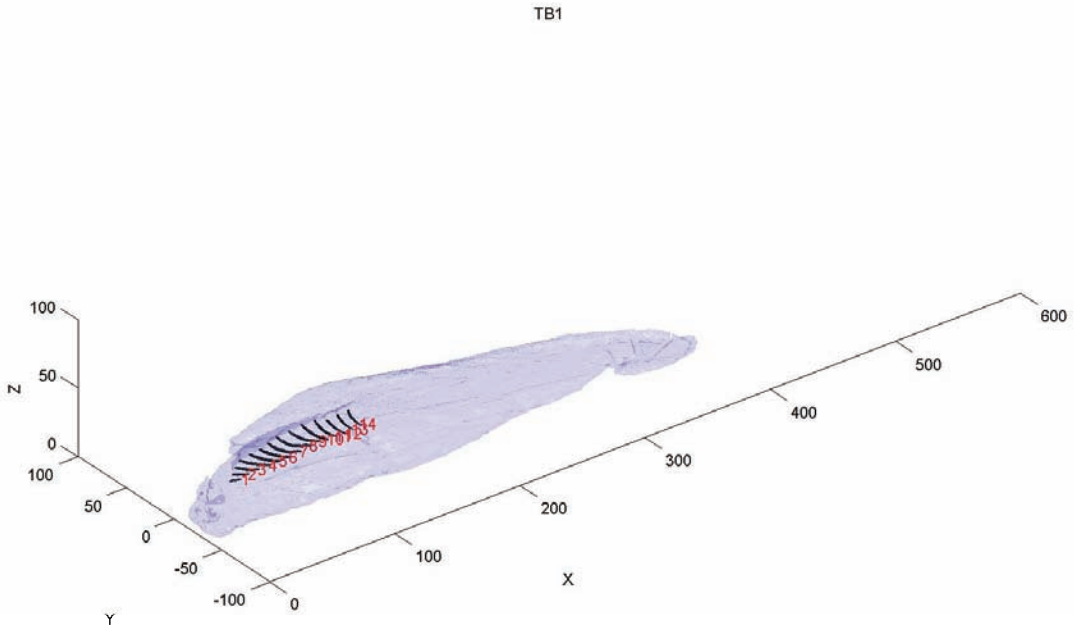
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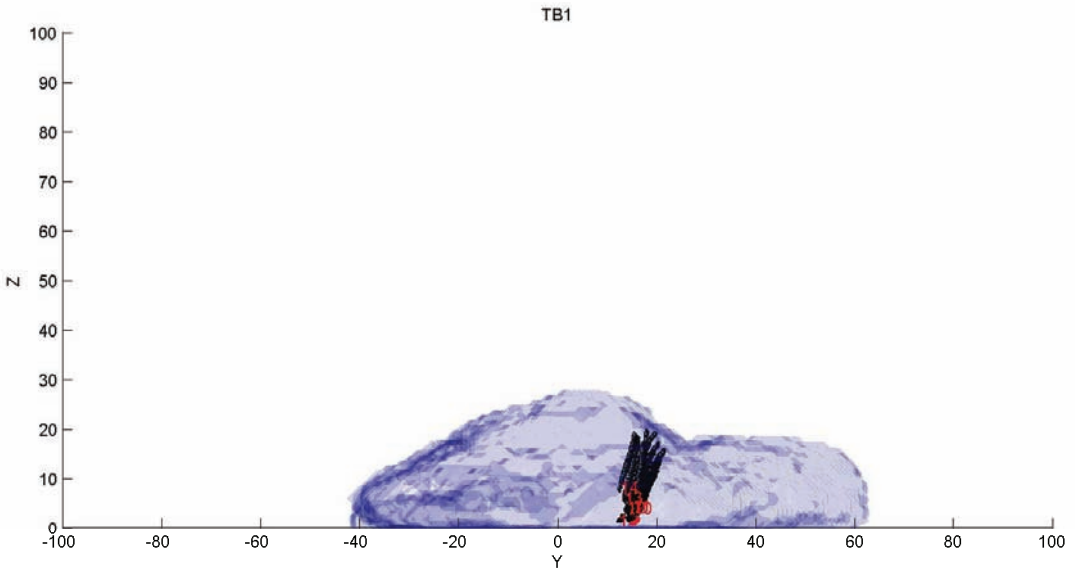
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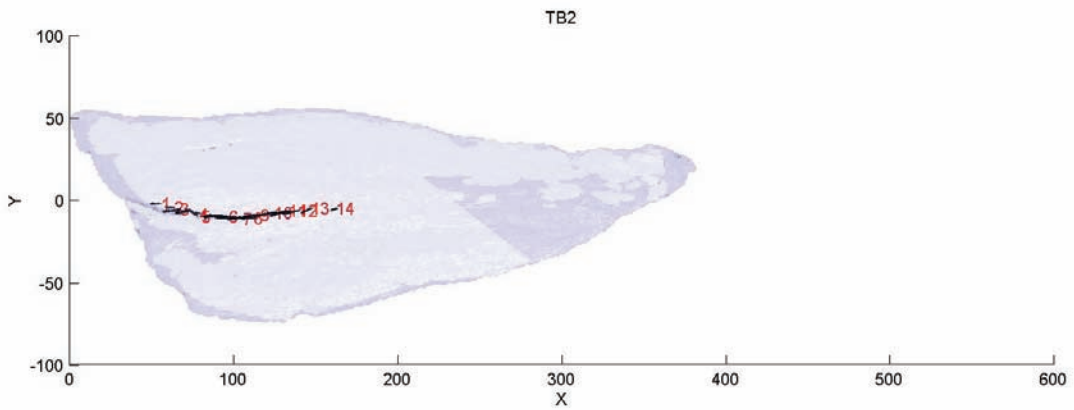
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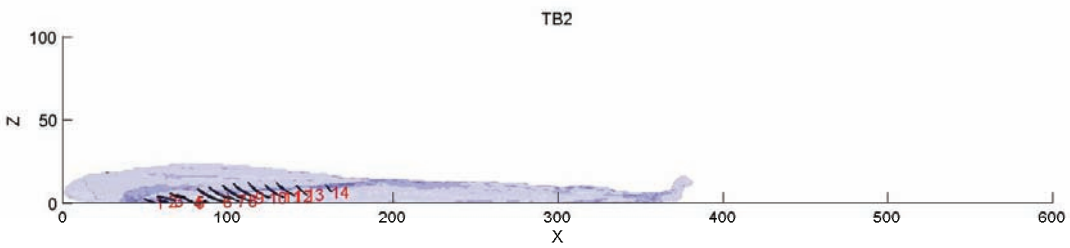
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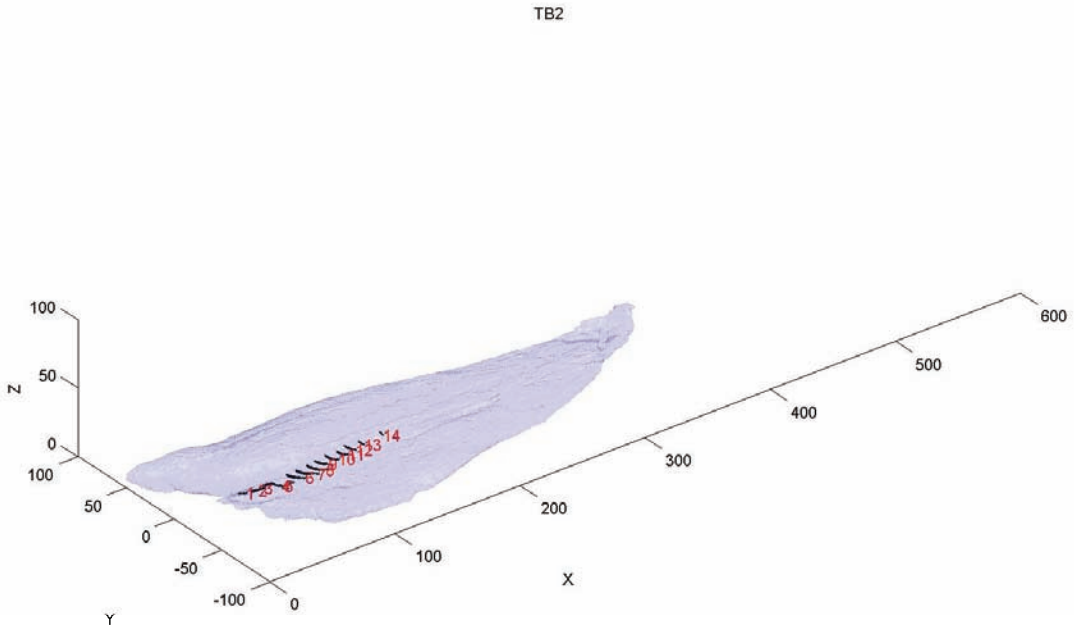
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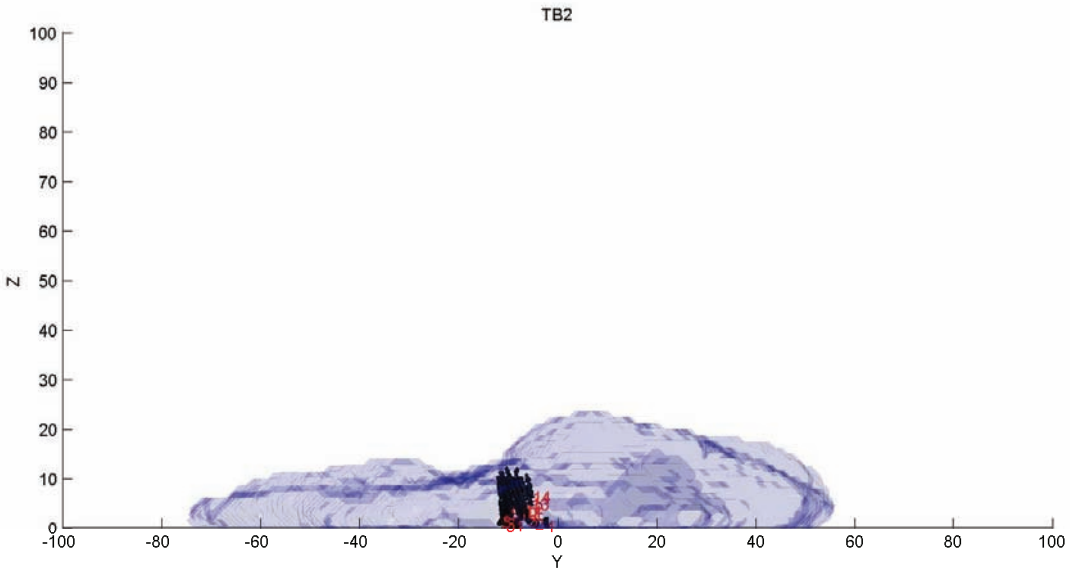
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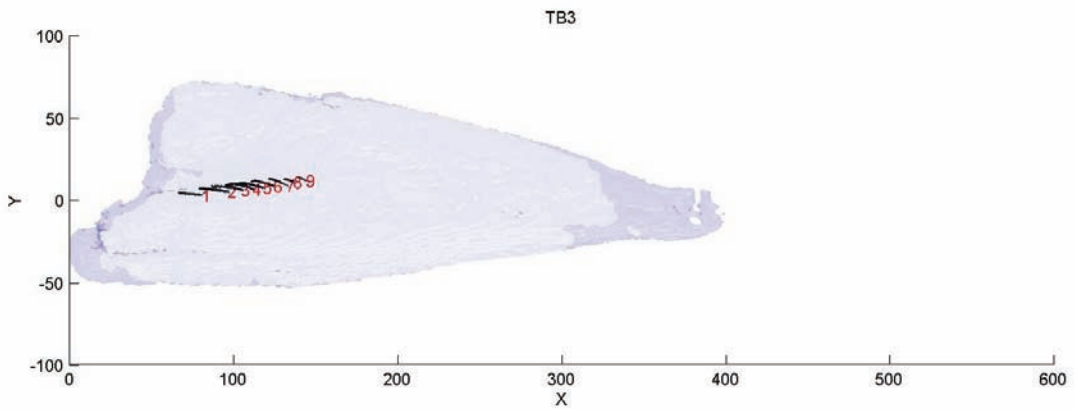
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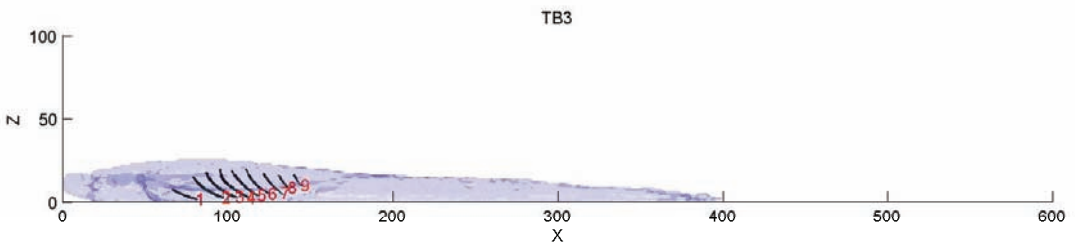
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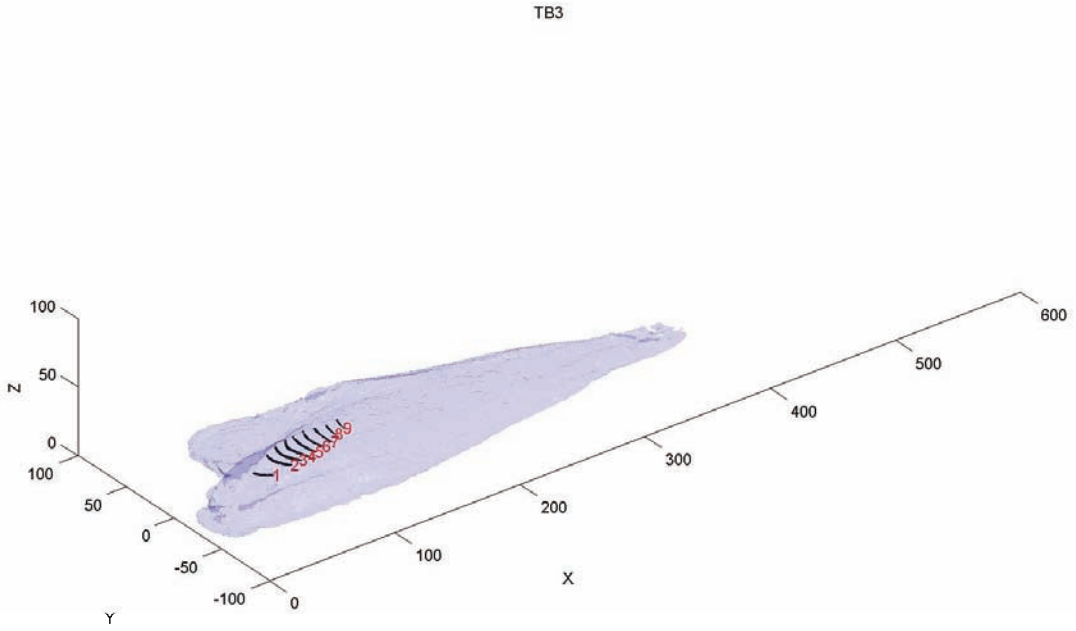
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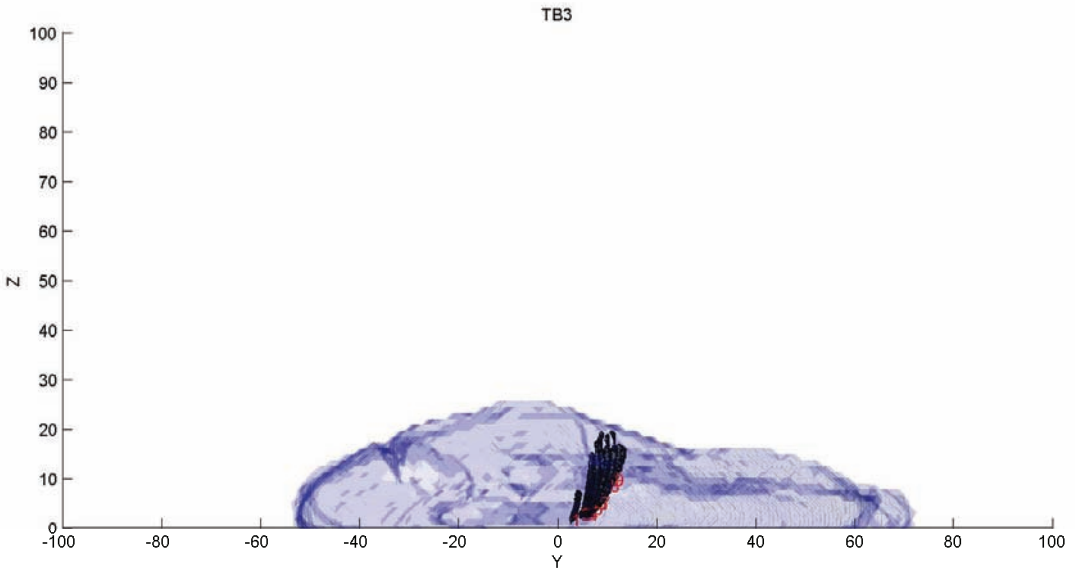
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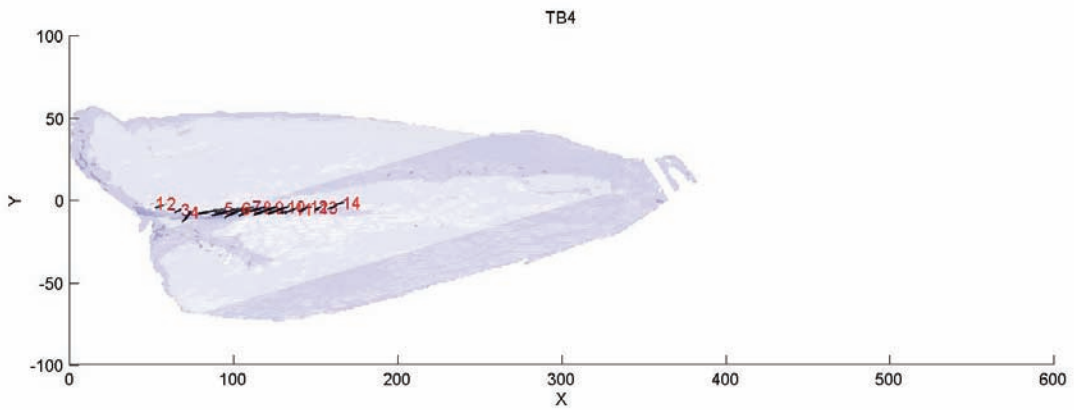
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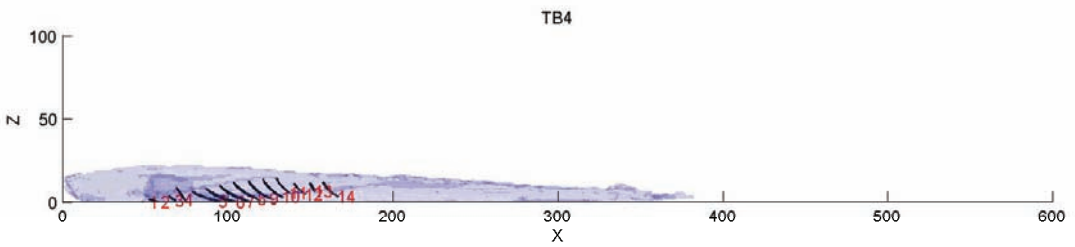
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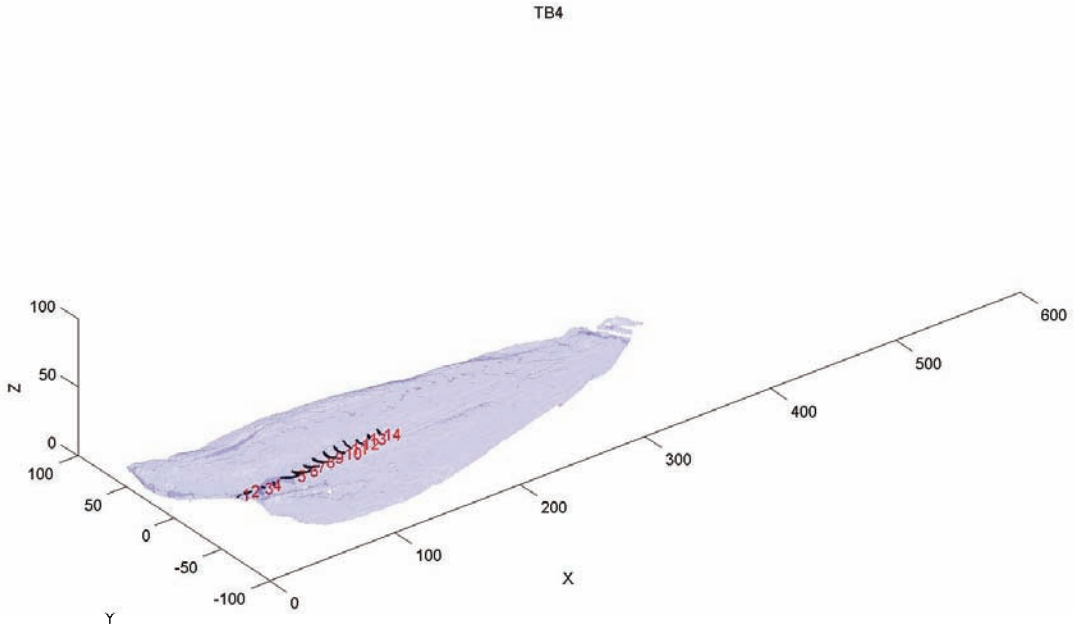
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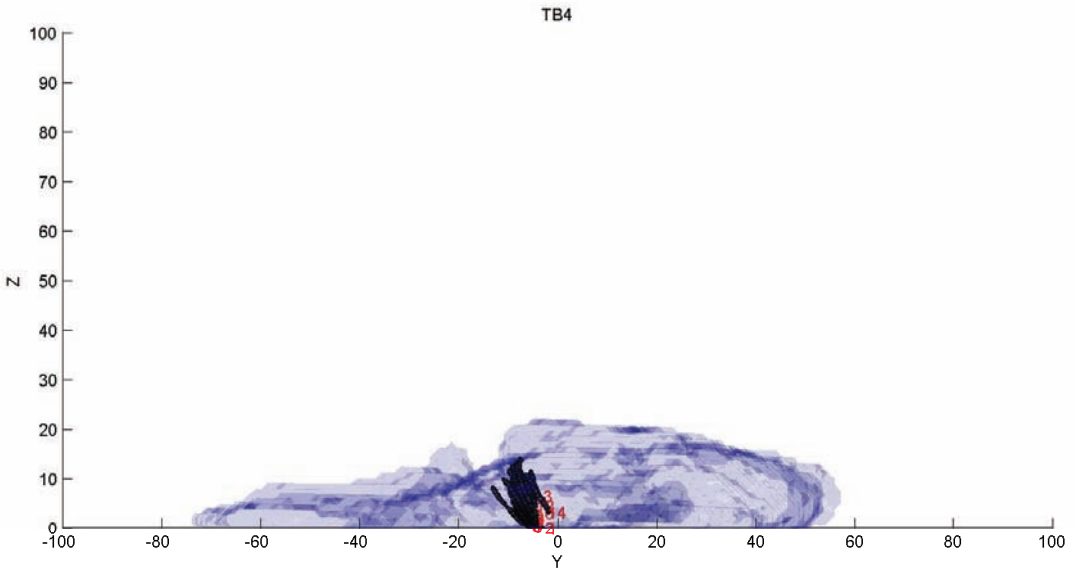
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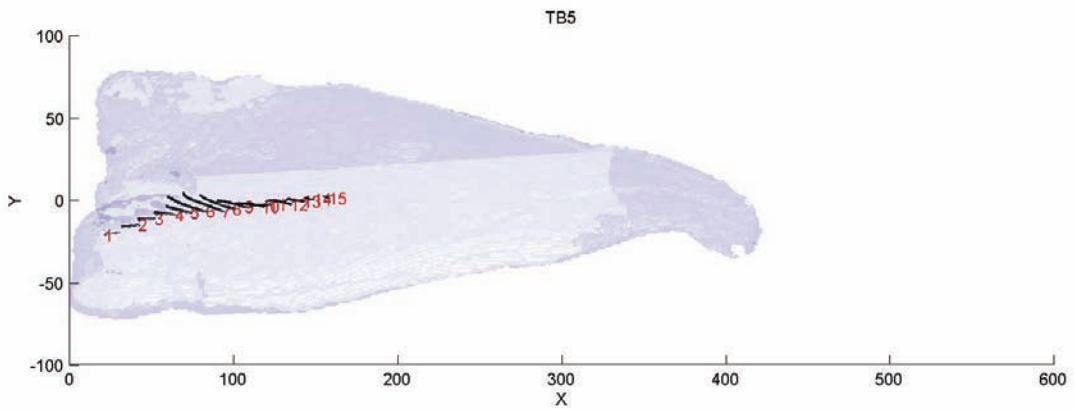
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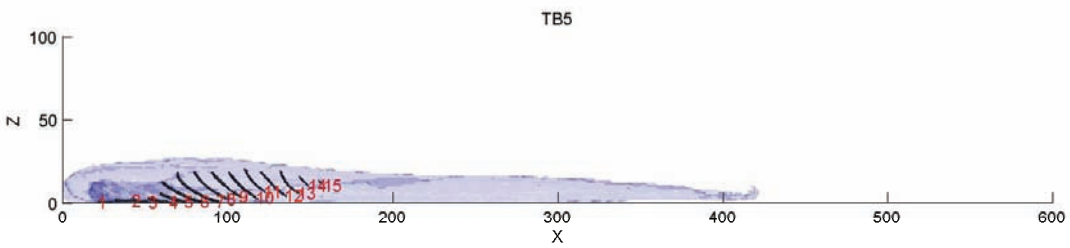
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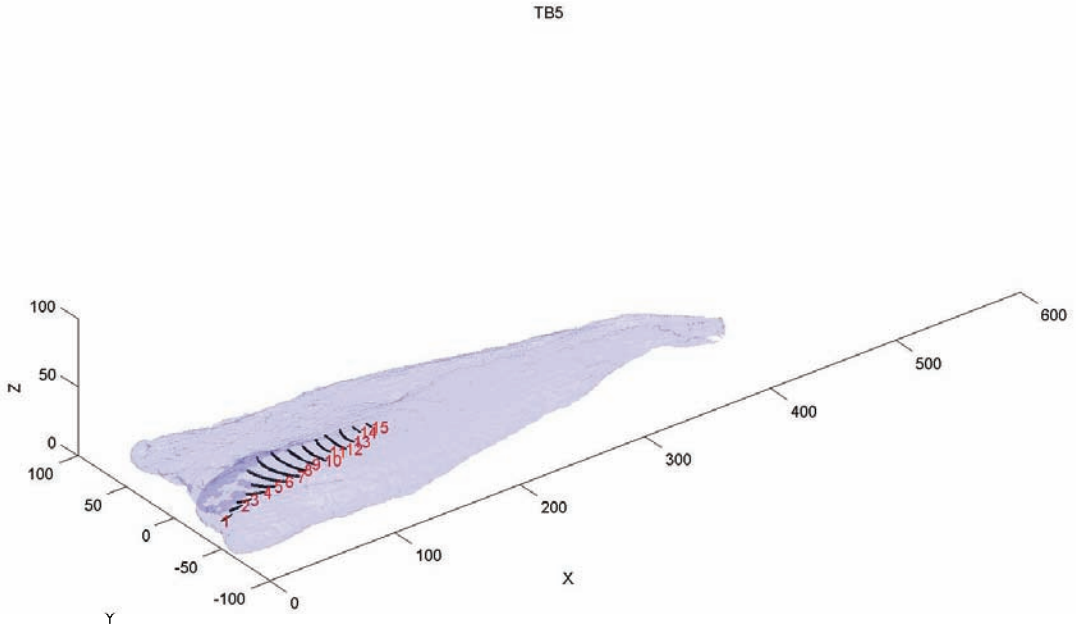
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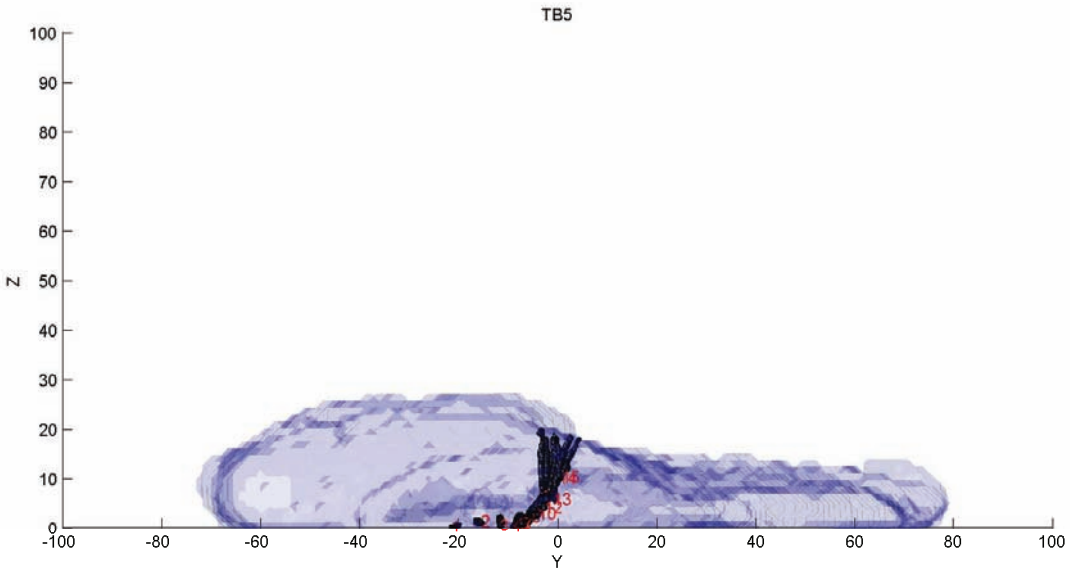
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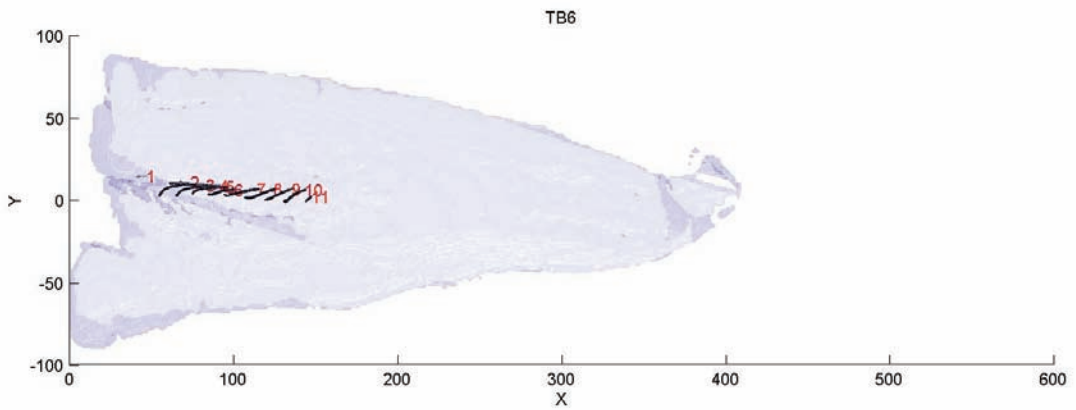
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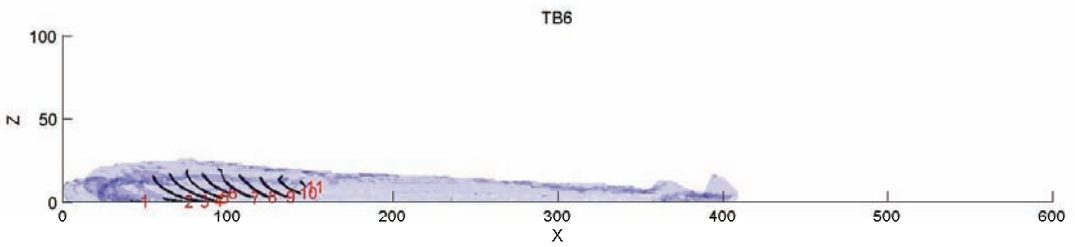
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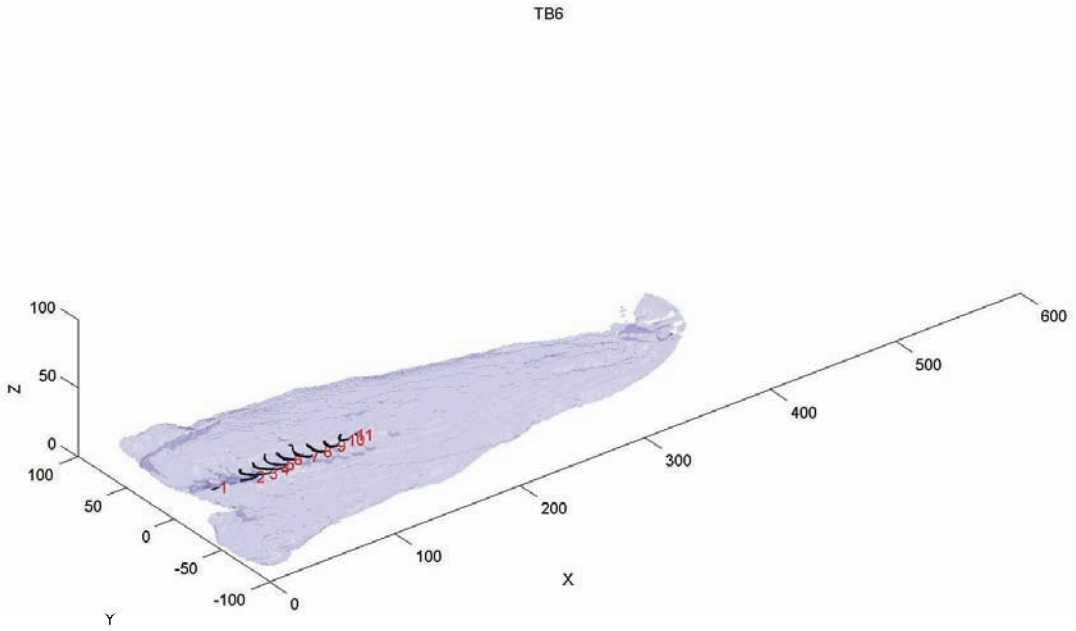
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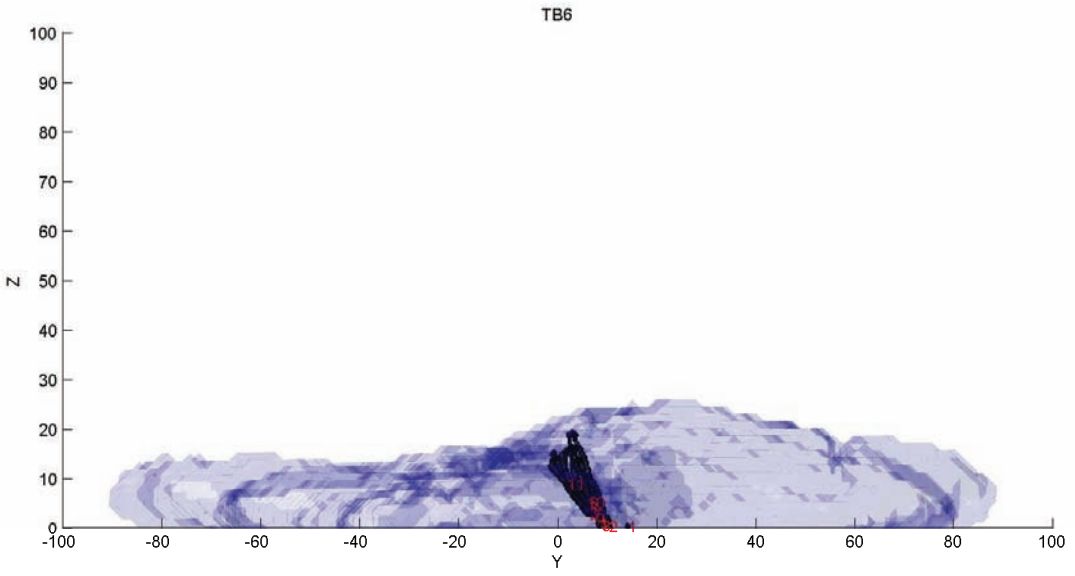
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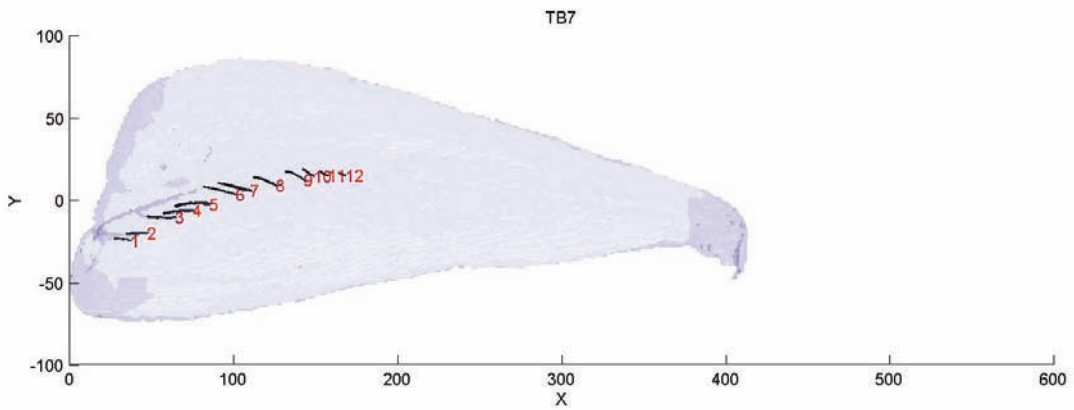
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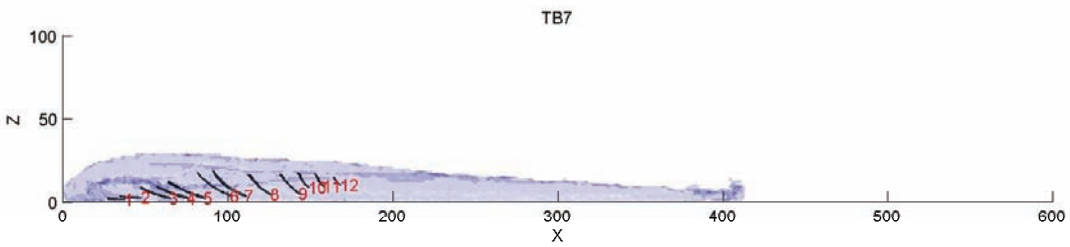
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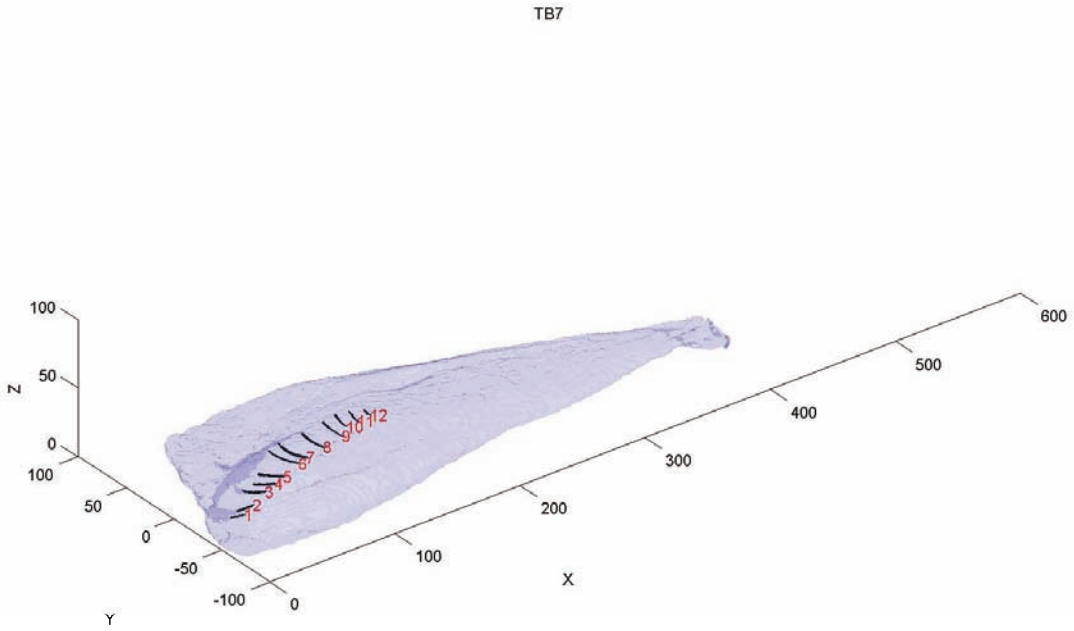
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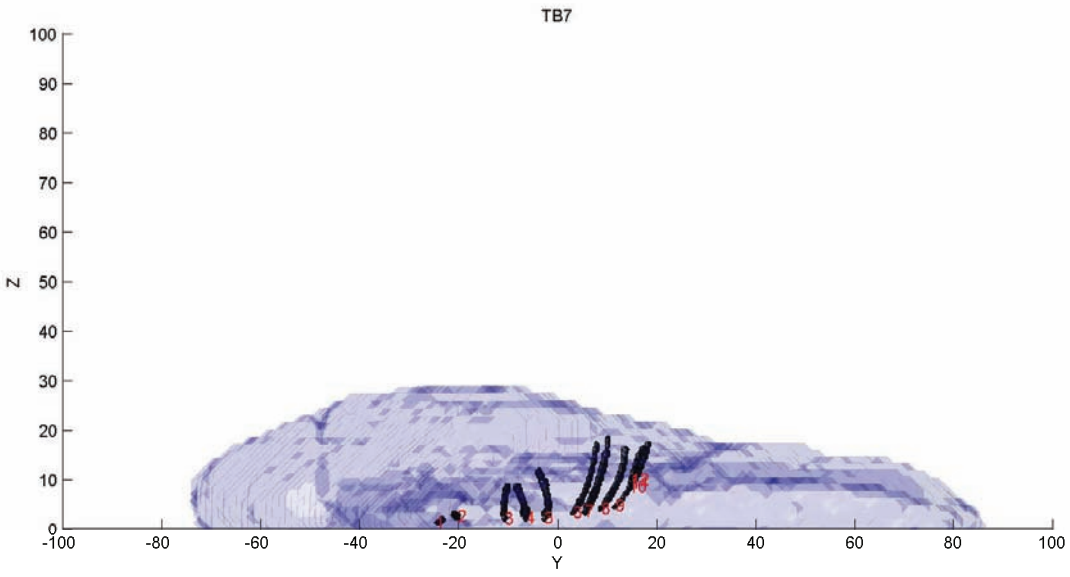
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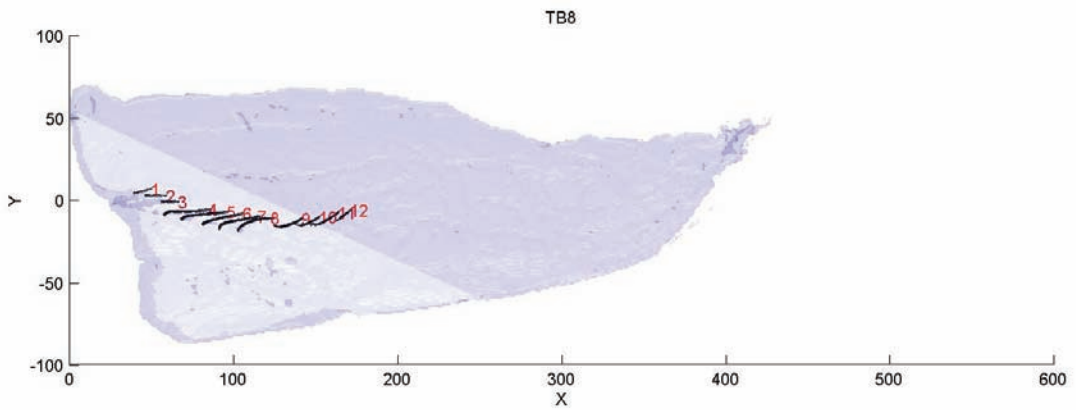
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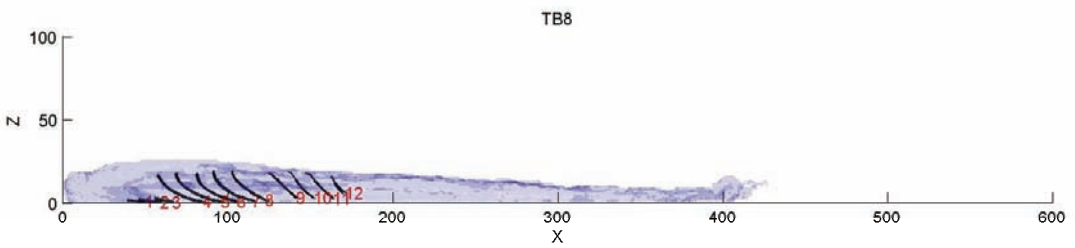
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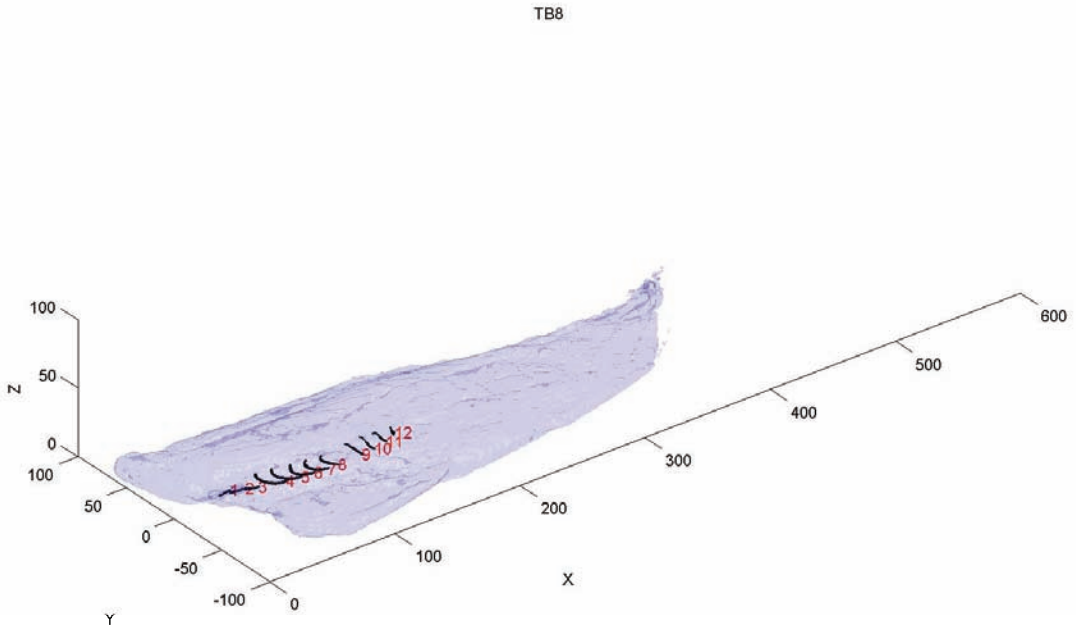
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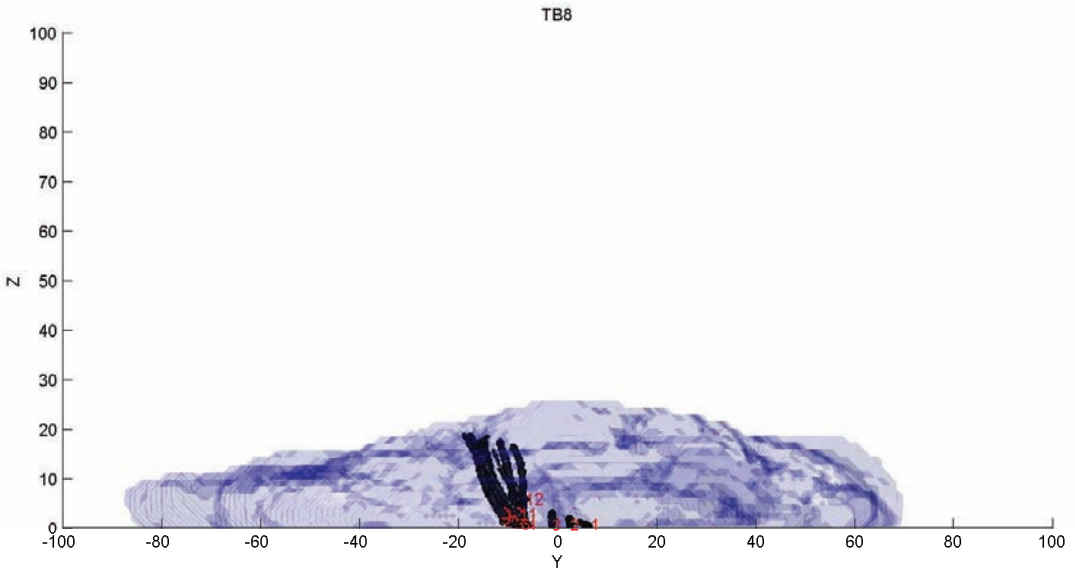
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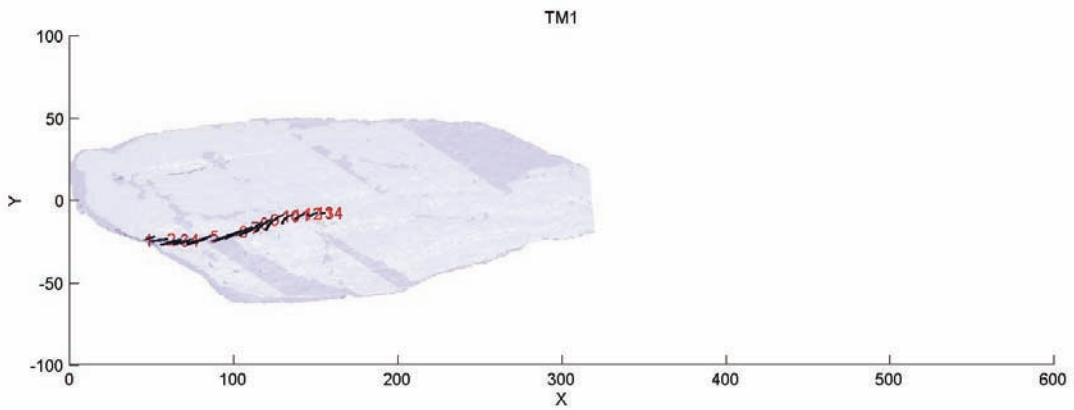
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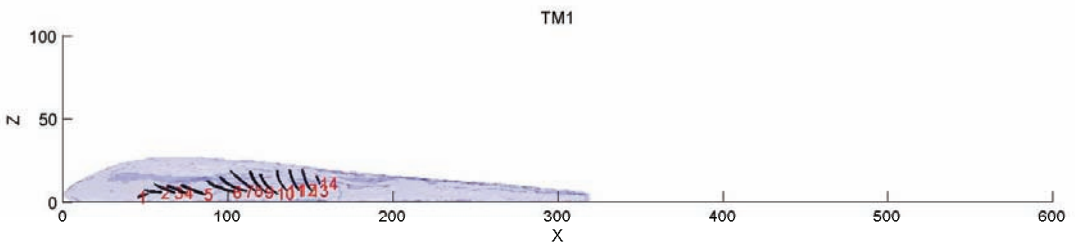
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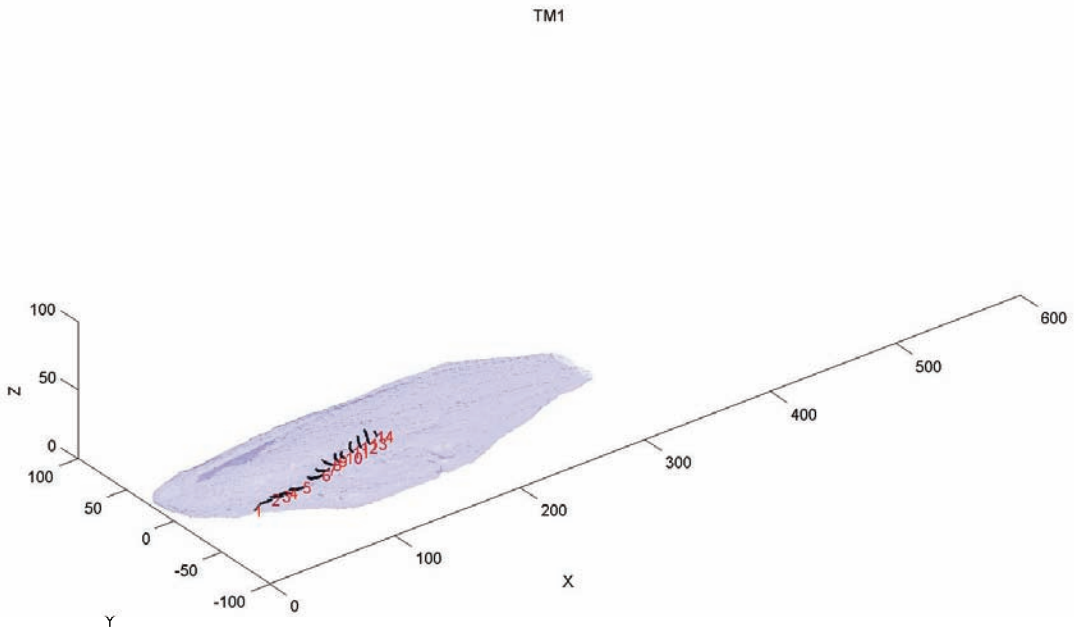
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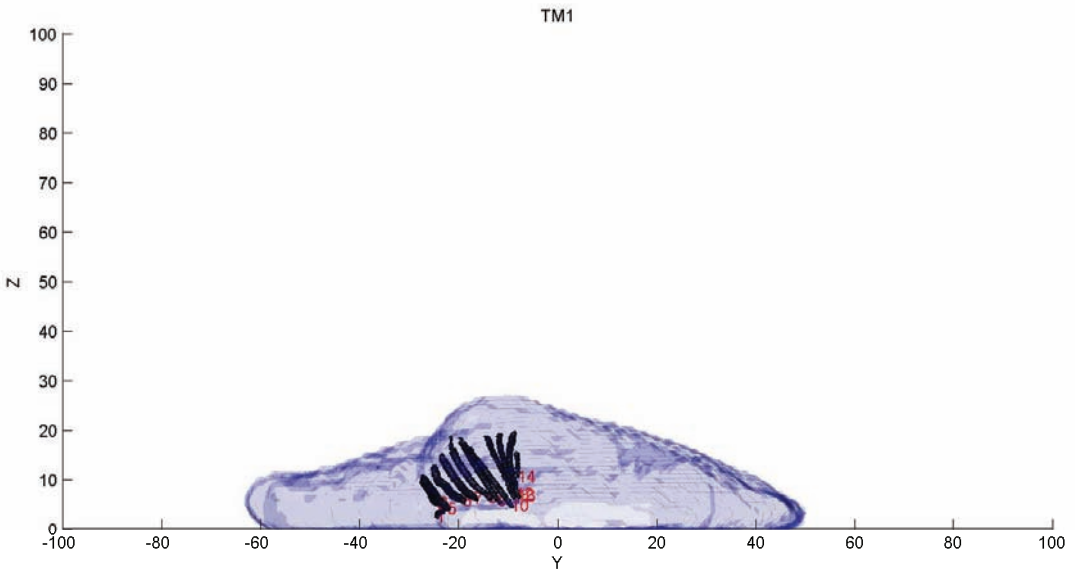
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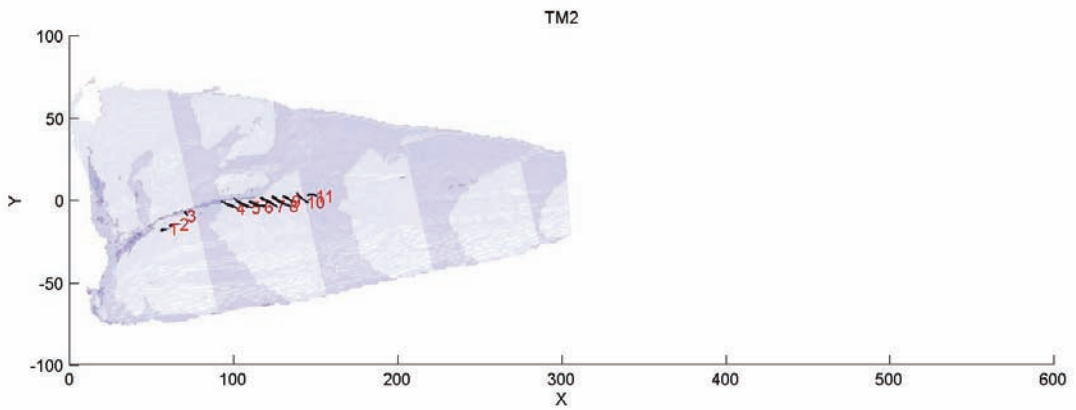
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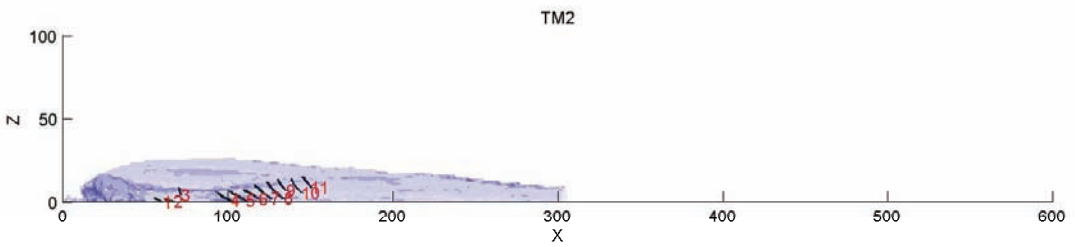
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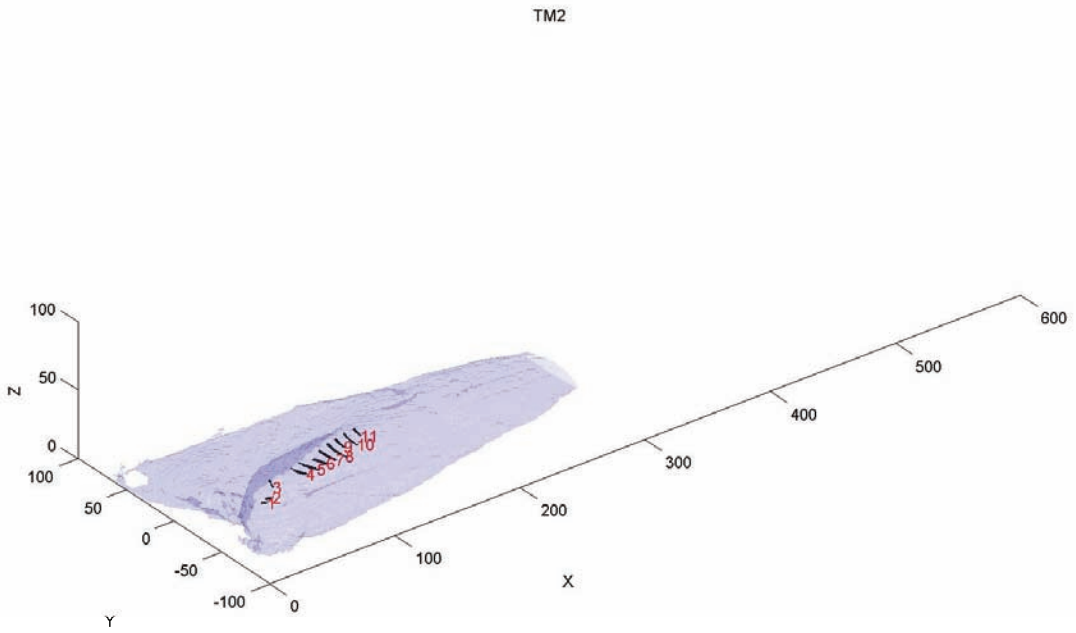
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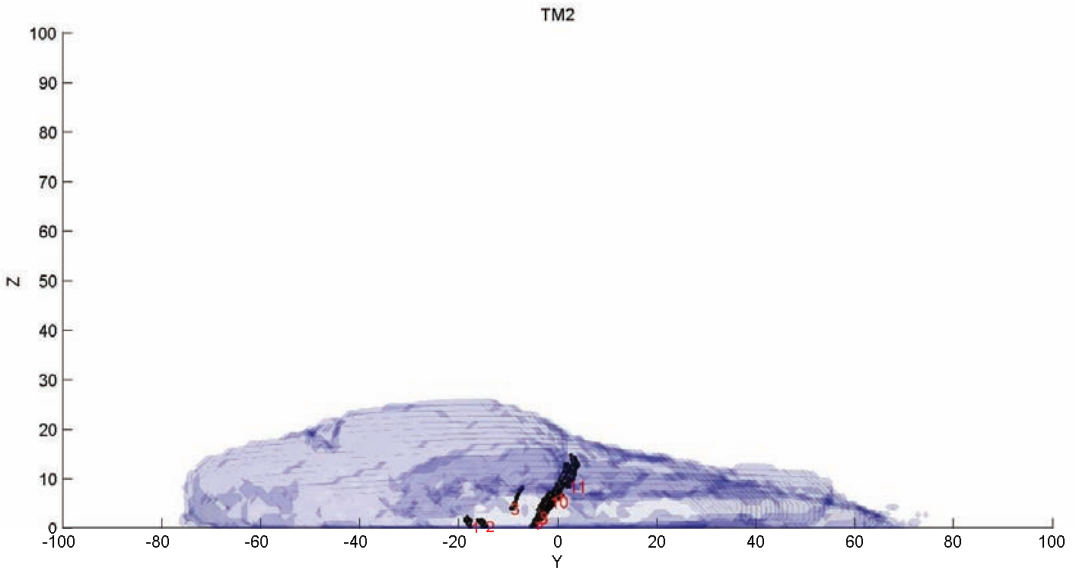
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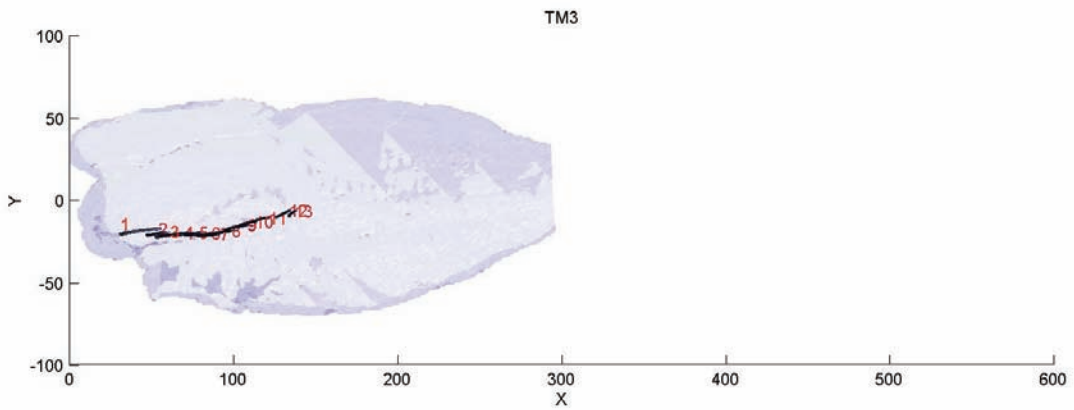
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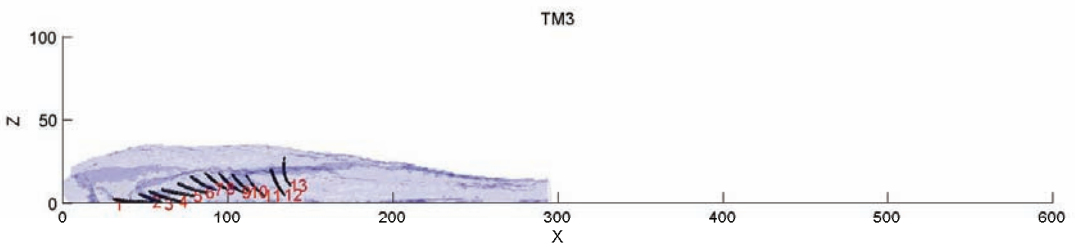
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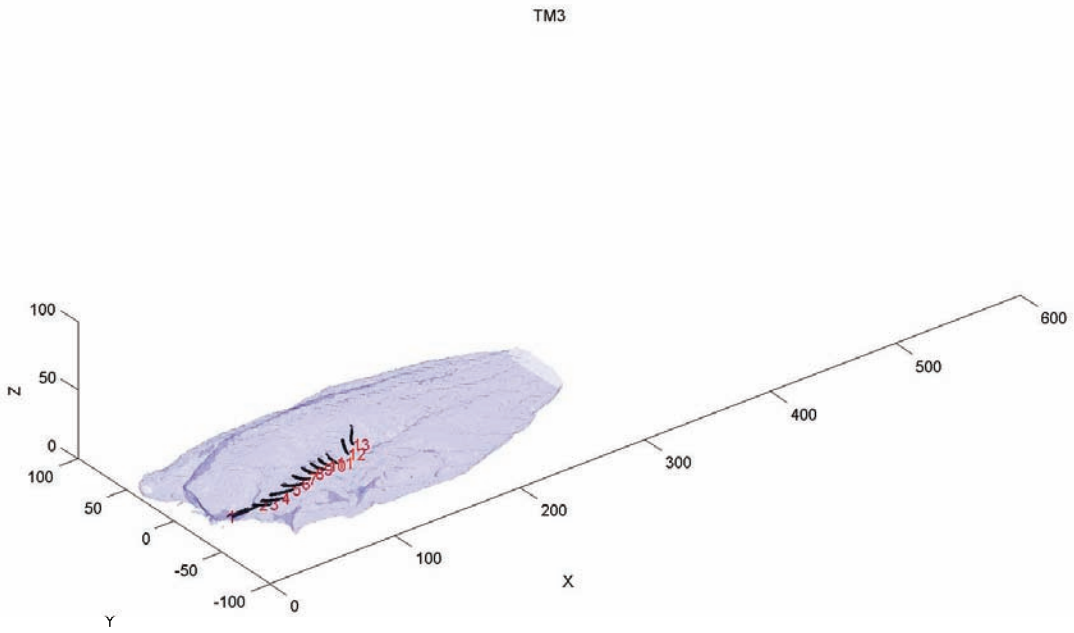
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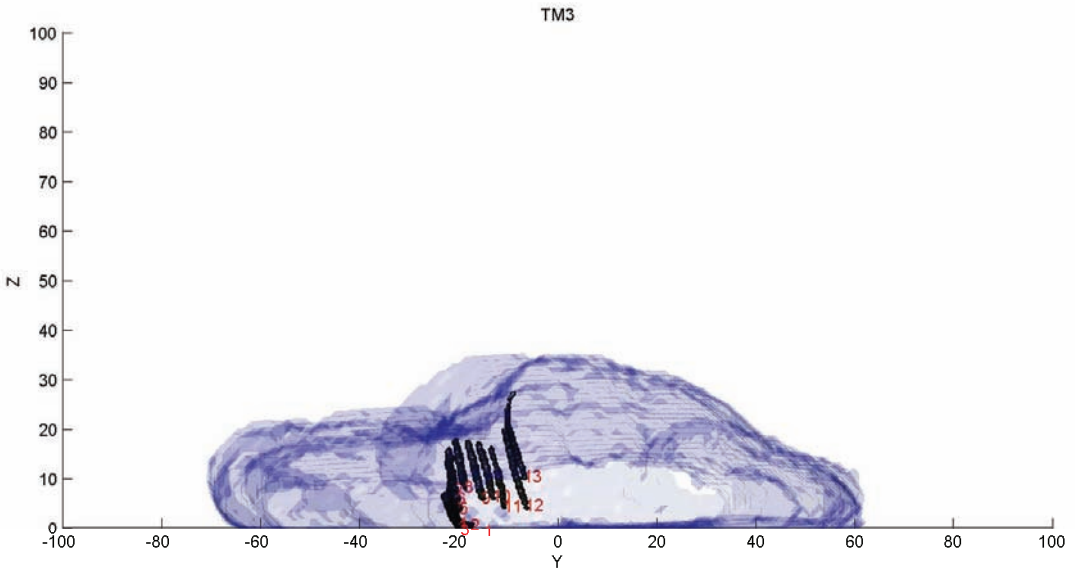
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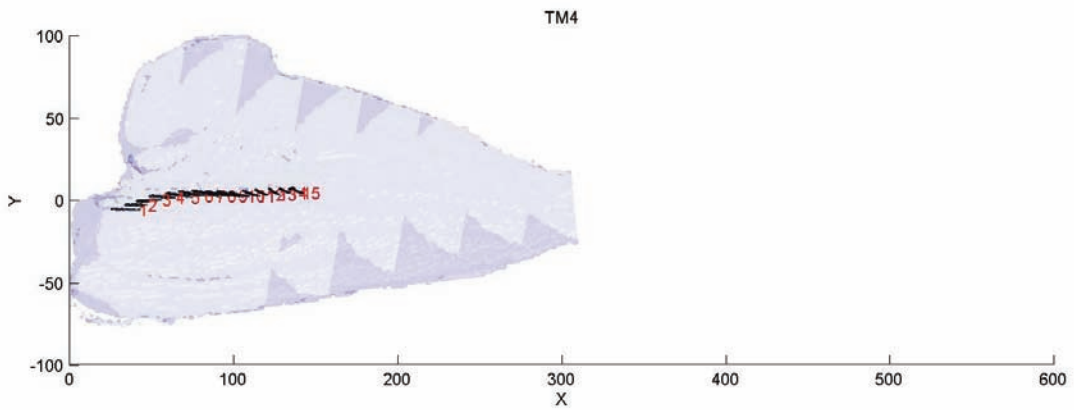
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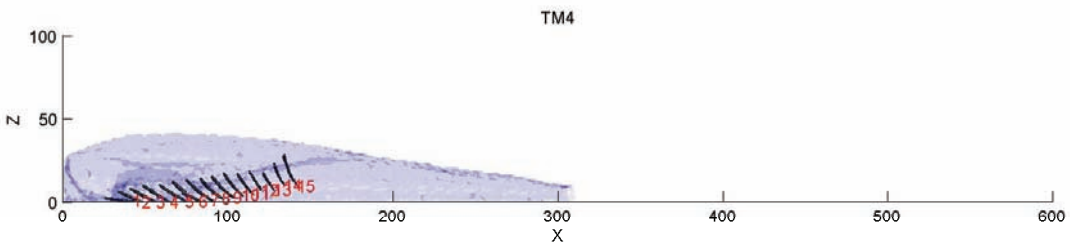
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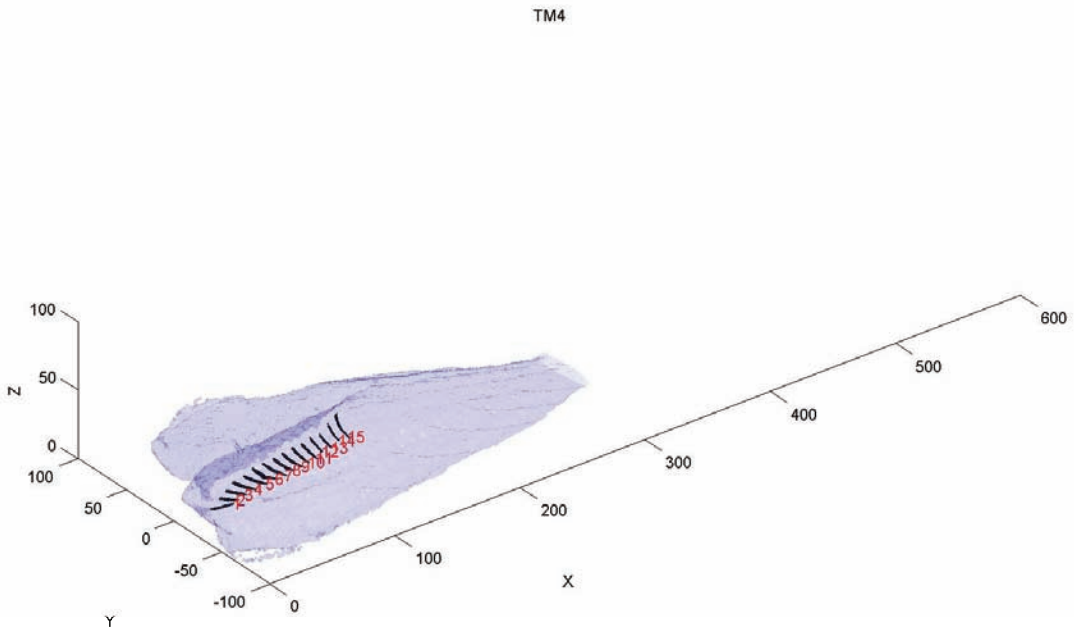
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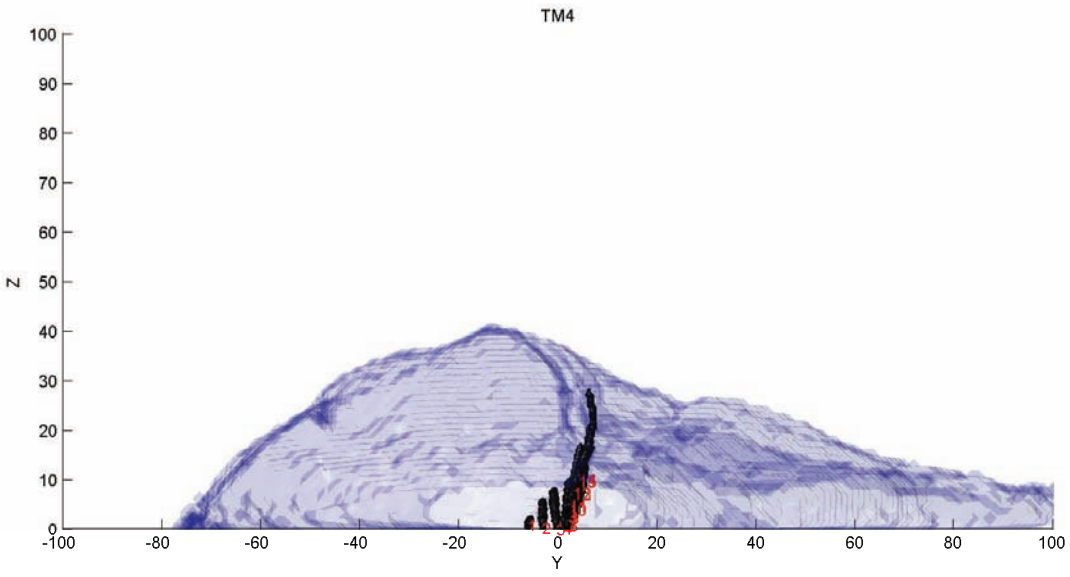
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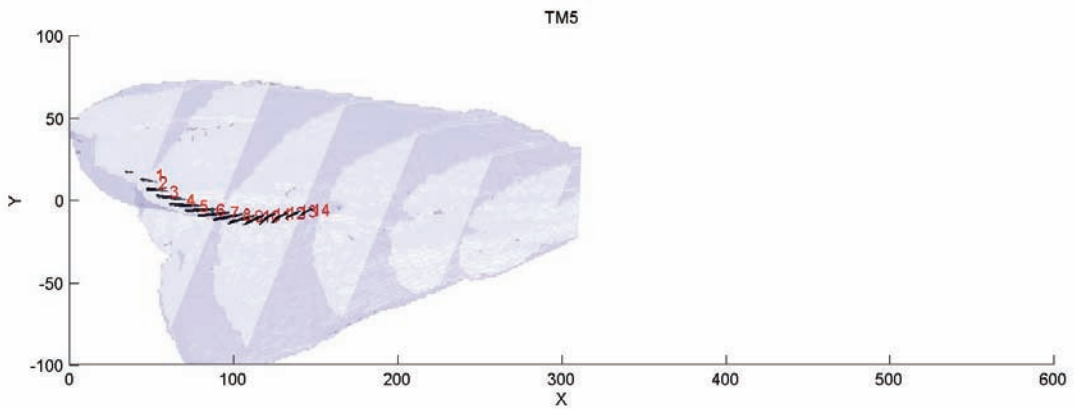
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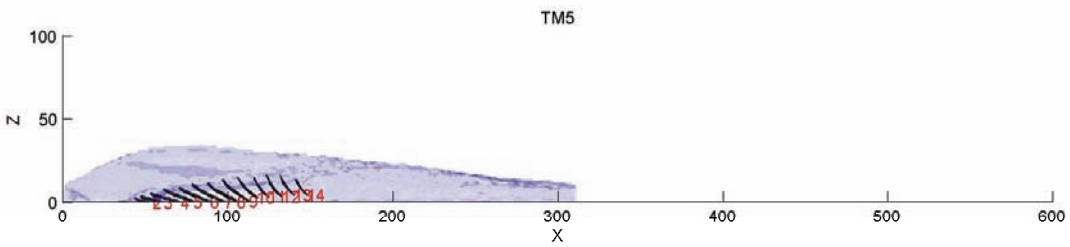
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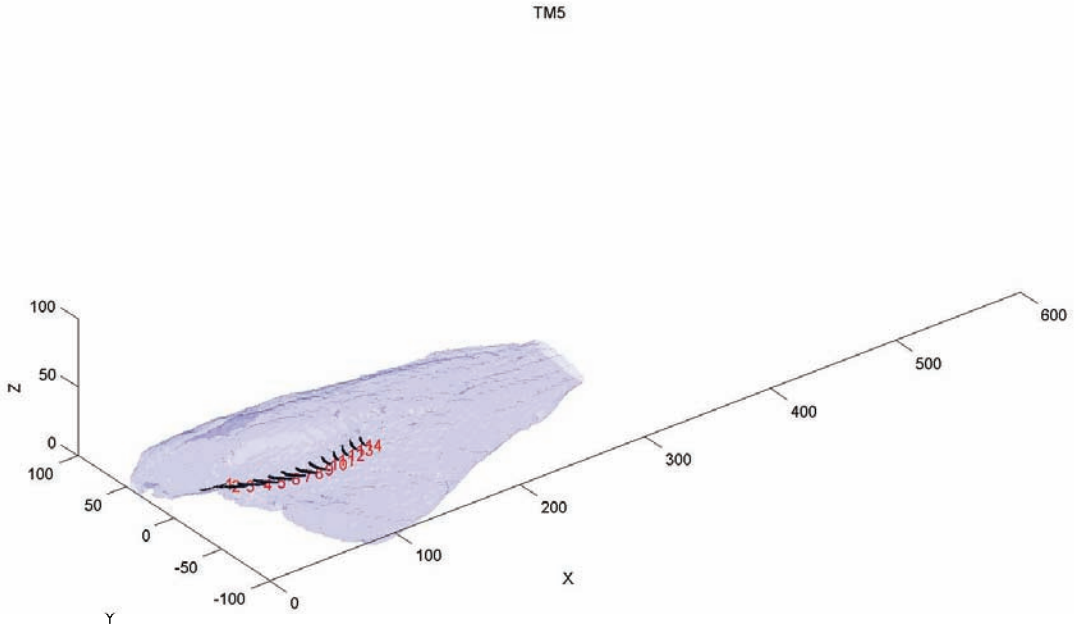
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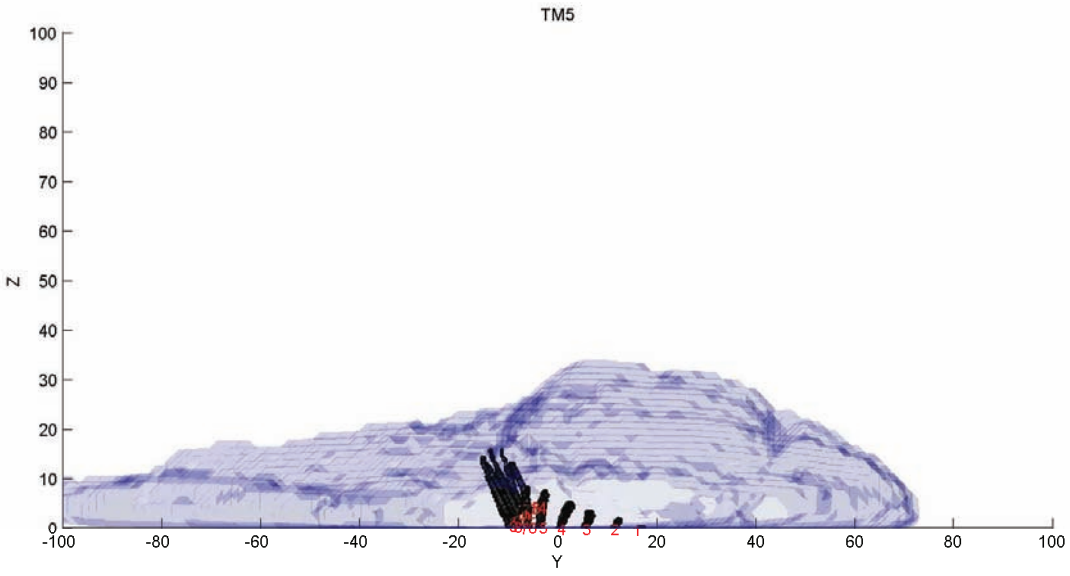
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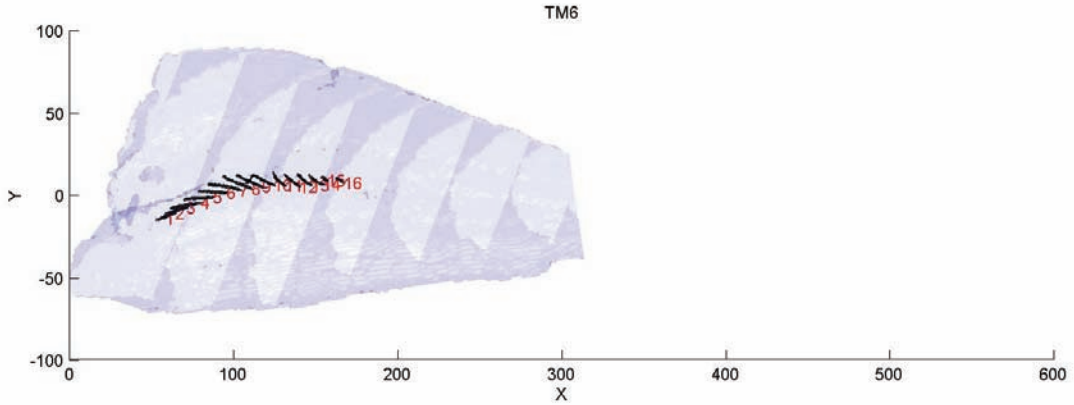
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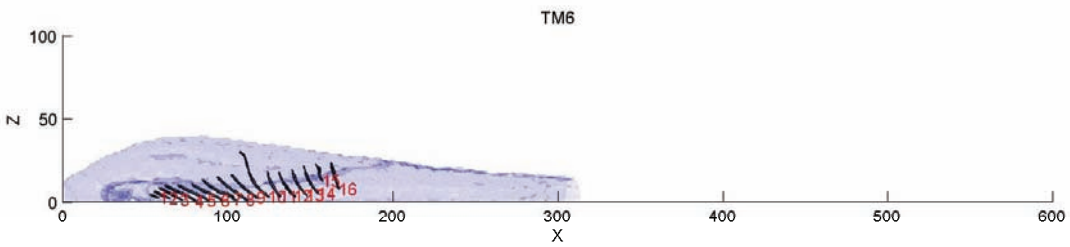
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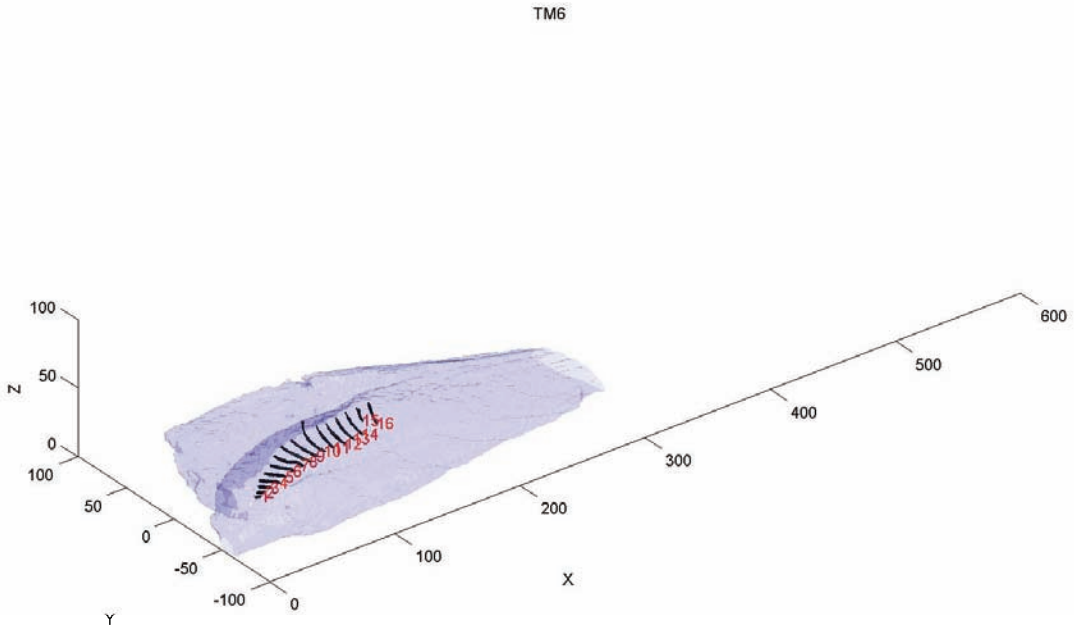
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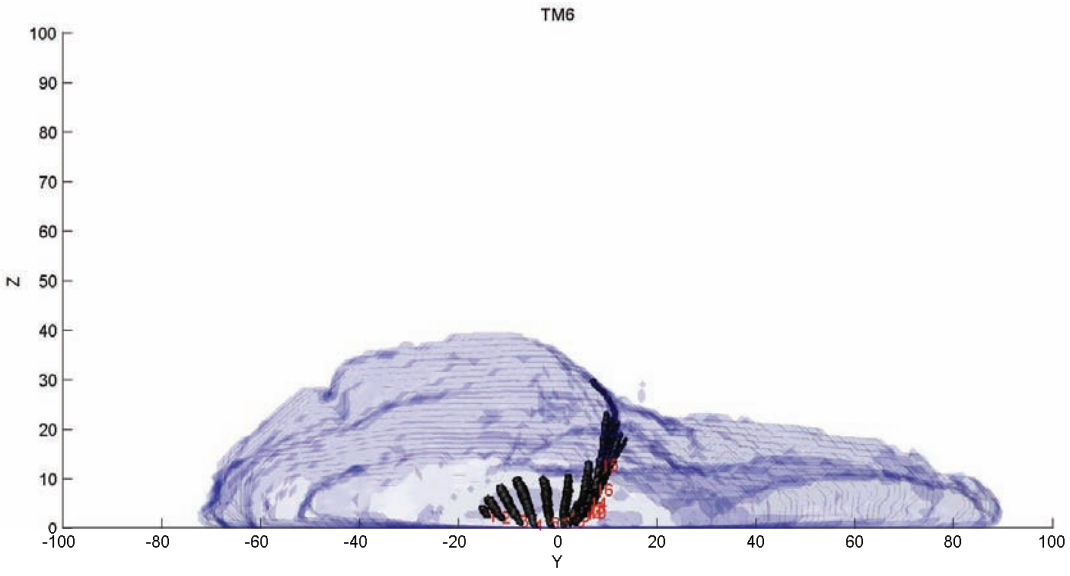
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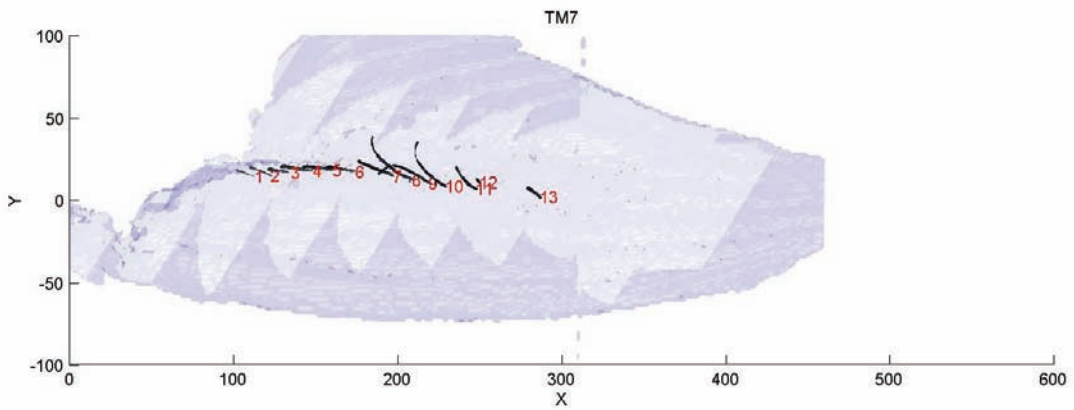
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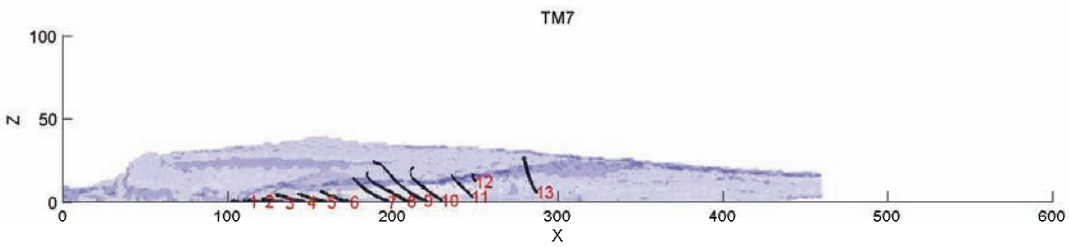
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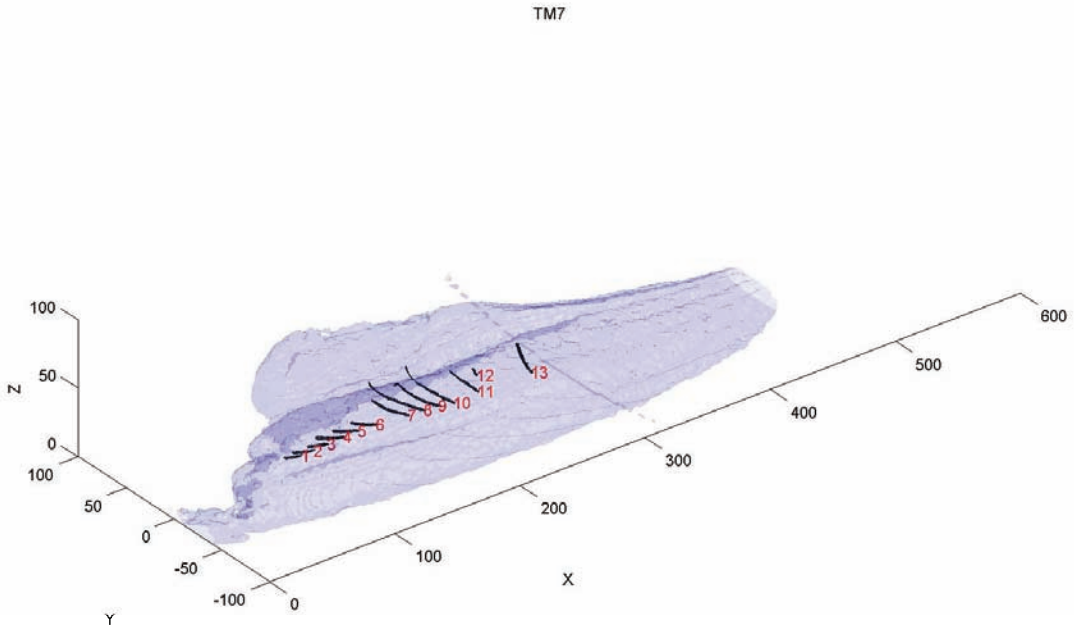
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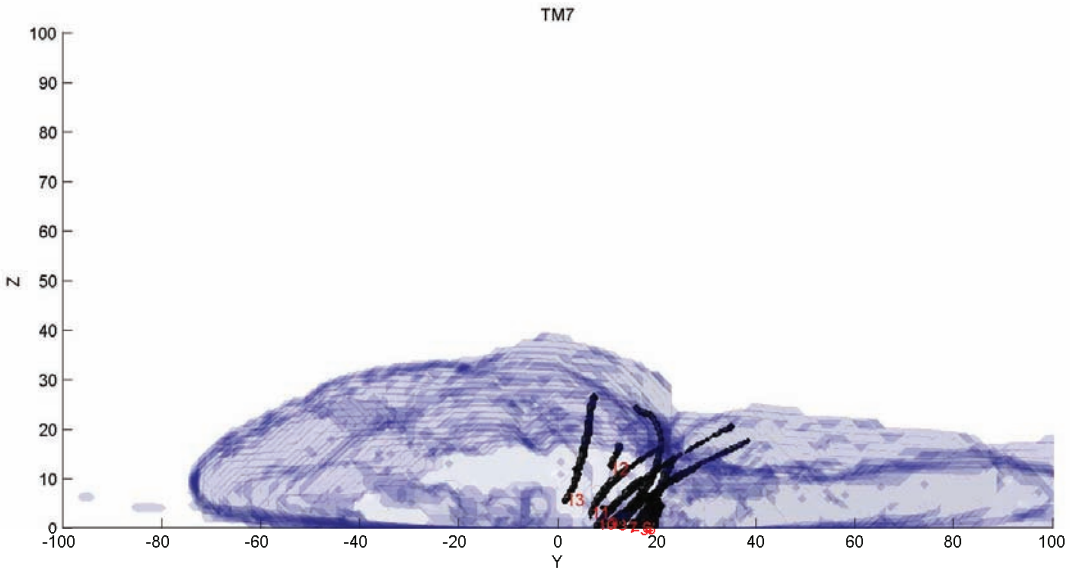
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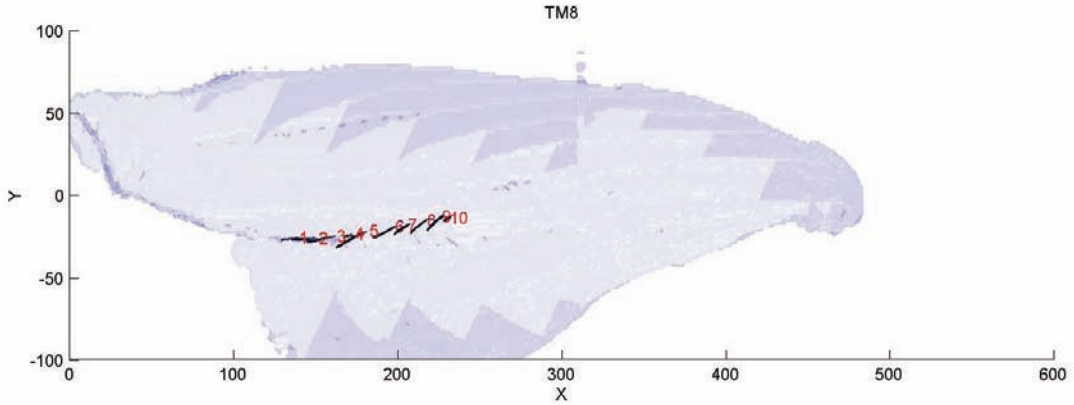
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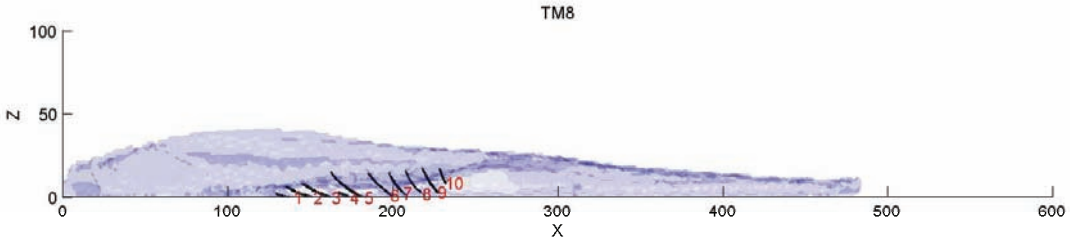
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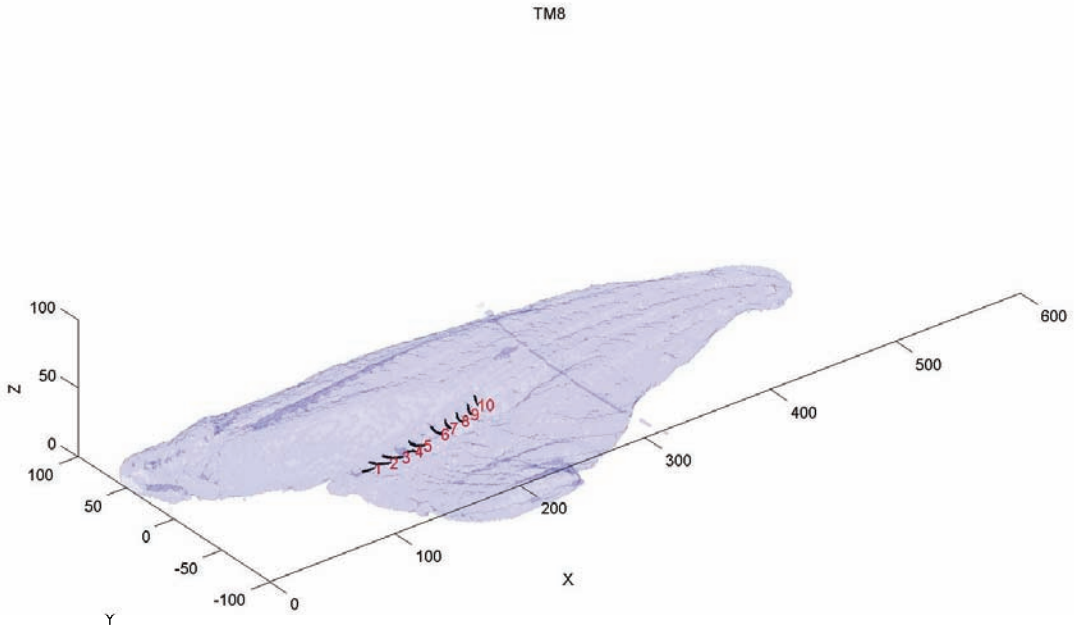
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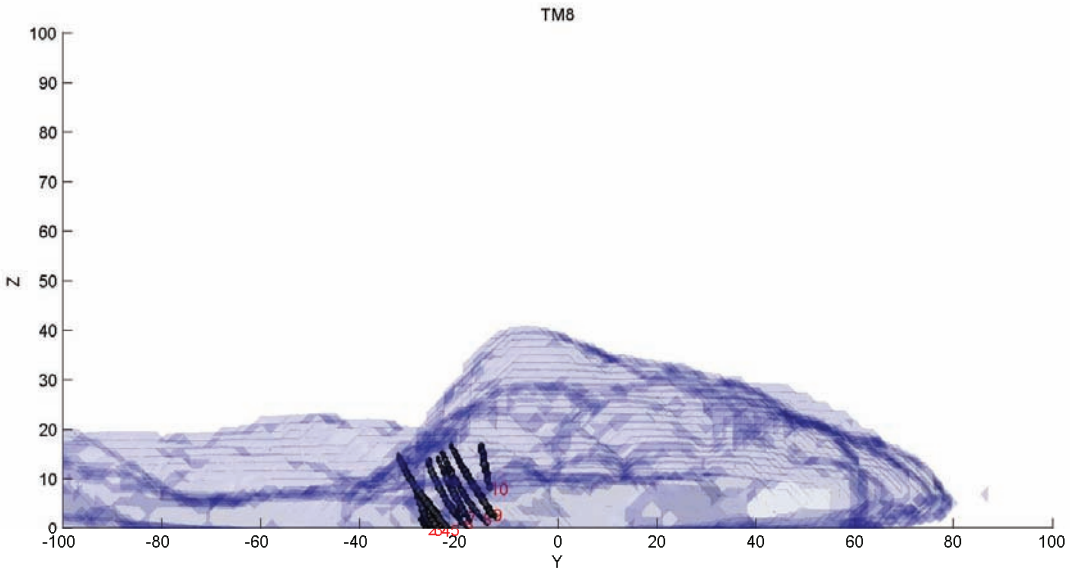
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