CT Study to Correlate the Interpedicular Distance and Maximum Length Pedicle Screw: Intraoperative Guide to Ensure Safe Pedicle Screw Insertion

Laura Baxter

Student Number: 1802572

Tutors: Mr Stuart James, Mr Michael McCarthy, Mr Fabian Wong

Ethical Approval Not Required

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CT Study to Correlate the Interpedicular Distance and Maximum Length Pedicle Screw: Intraoperative Guide to Ensure Safe Pedicle Screw Insertion

Laura Baxter, Fabian Wong, Michael McCarthy, and Stuart James

Objective: To correlate the relationship between the interpedicular distance (IPD) and the maximum screw depth down the longest axis of the pedicle to the anterior vertebral body wall.
Design: Radiological Study
Setting: University Hospital of Wales
Method: Radiological software was used to take sets of measurements from CT scans of 20 young male adults, with no spinal deformity. Measurements were recorded, using mid-pedicle axial cuts, for all vertebrae between T1-L5. The recorded measurements were then analysed using Microsoft excel, SPSS, and JASP.
Population/Participants: 20 male patients aged between 20-30 years old, with no spinal deformity.
Findings: A statistically positive correlation ($p<0.001$) was found between IPD and PL. Alongside this a statistically significant difference ($p<0.001$) was established between PL and IPD in vertebrae T2-L4.
Conclusion: As PL increases in size the IPD also increases. Excluding T1 and L5, PL is found to be greater in size than IPD. Therefore, IPD can be used as an intraoperative safe template for safe pedicle screw insertion.

Introduction:

Pedicle screw fixation is commonly used to correct spinal deformities. It is widely recognised as the gold-standard approach in surgical spinal fusion (1). This technique involves inserting a pedicle screw down the length of the pedicle to the ventral surface of the cortex of the vertebral body. Screws are then connected to rods which together correct the deformity and stimulate fusion of adjacent vertebrae. Cummulatively, these instruments provide segmental immobilization of the spine by restricting range of motion and achieving stabilization (2, 3). The use of pedicle screws has evolved since 1970, when a French spinal surgeon, Roy-Camille, first pioneered their use for internal fixation (4). Compared to traditional techniques involving rod and hook mechanisms, pedicle screw apparatus has proven to be superior (5).

Despite the introduction of pedicle screw fixation carving a promising pathway for spinal surgery, it carries with it risks which need to be minimised with precaution. Pedicle screw malplacement is one of the main risks related to their use. Pedicle screws which exceed the maximum possible pedicle screw length for a certain vertebrae can result in breaching of the cortical layer. Screw malplacement could lead to sinister ‘neurological and vascular damage’ (6). For example, screws penetrating the vertebral column can result in spinal cord injury (SCI) which is a ‘life changing injury’ characterized by complete or partial loss of both sensory and motor functions (3). With these risks in mind, selecting the optimal length of pedicle screw to be inserted is a difficult task which surgeons are faced with. A study by Krag et al 2016, reviewing vertebrae T9 to L5, demonstrated that pedicle screws inserted with 80% penetration of the vertebral body rather than 50% penetration were 32.5% more secure (7). This suggests that the optimal pedicle screw should be of submaximal length.

Preoperative computer planning and intraoperative image guidance, using either fluoroscopy or computed tomography (CT), are used in combination to attain safe placement of pedicle screws (8, 9). However, other than the use of radiology to determine safe pedicle screw trajectory there is little literature offering a simple intraoperative guide to select optimal pedicle screw length for vertebrae of the thoracolumbar spine. One study by Copuroglu 2011, investigated the relationship between IPD and maximum pedicle screw length in the L1 vertebrae by assessing 72 CT scans and 39 cadaveric spines (10). Copuroglu 2011 found a ratio 'between the distance of the midline of the vertebrae and the screw entry point'(half IPD) and the pedicle length (PL) (10). From this a constant coefficient (CC) of 2.5 was found which could be multiplied by the distance measured between screw entry point and 'midline of the vertebrae' to give the 'maximum pedicular screw length' (10).

The question still arises as to whether there is a correlation between IPD and maximum pedicle screw length for the whole thoracolumbar spine, T1-L5.

Aim/Objectives:

The primary objective is to investigate whether there is a correlation between PL, maximum screw length, and IPD. The secondary aim of the study is to assess whether IPD could be used as a safe template for pedicle screw length for the corresponding vertebral level, to help guide surgery.

Method:

CT thorax, abdomen, and pelvis (CT TAP) scans, showing the whole spine, of 20 male adults between the ages of 20-30 were analysed using Synapse 5, radiological software. Only CT TAP scans with no spinal deformity were used to obtain measurements. All data was anonymised. Vertebrae T1 – L5 were analysed using mid-pedicle axial cuts. For each vertebrae 3 measurements in millimetres (mm) were taken as shown in Figure 1: left PL, right PL, and IPD. PL was measured from screw entry point to the ventral surface of the cortex of the vertebral body. Screw entry point was appointed throughout as lateral to the superior articular facet. From this point the measurement of PL was taken in the pedicle midline, parallel to the pedicular edges, to follow the trajectory of a pedicle screw. This attained a measurement which reflected the maximum pedicle screw length which could be inserted into each individual vertebrae. IPD was measured as the distance between the two entry points of the corresponding vertebrae.

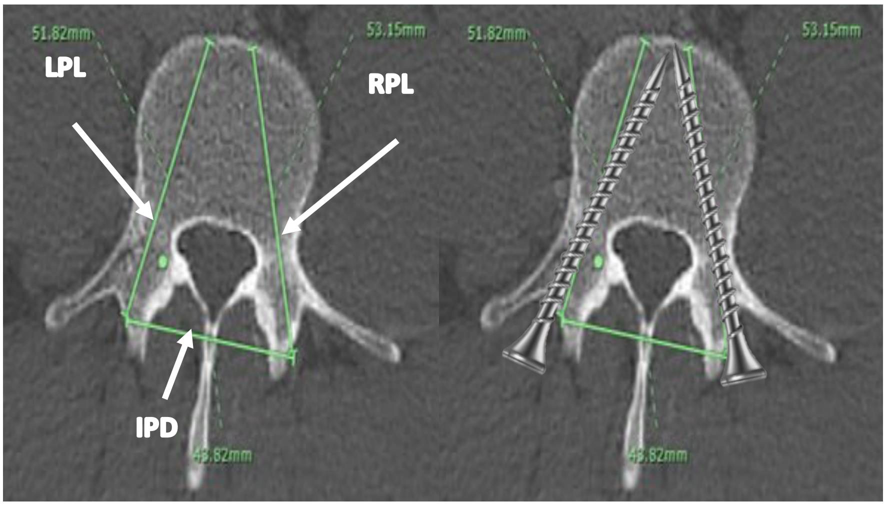

Figure 1: Three measurements in Synapse 5 were taken from each vertebrae (T1-L5).

Microsoft Excel was used to collect data in an anonymised manor. A total of 1,020 measurements were recorded following the first round of measurements. All measurements were repeated on a different week to assess intra-observer reliability.

A theory, previously formulated, hypothesised that there is a correlation between PL and IPD suggesting that as PL increases, IPD gets wider. To test this theory a null hypothesis was generated. **Null hypothesis:** There is no correlation between PL and IPD. The first data set was analysed using SPSS and JASP to establish whether a correlation existed. PL and IPD measurements were also analysed through paired-sampled t-tests to determine the difference between them.

Original measurements from Synapse were recorded to two decimal places. However, the data was transformed so that it could be analysed in more practical terms. PL values were rounded down to the nearest '0' or '5' (e.g. 34.03mm was rounded down to 30mm) as pedicle screw depth is in 5mm increments to ensure safe insertion. IPD was rounded to the nearest whole number. This transformed the data from continuous to discrete. The transformed data was also analysed using SPSS and JASP to establish the same correlation.

To assess intra-observer reliability, JASP was used to analyse intraclass correlation (ICC) for the first round of measurements verses the second round of measurements. ICC was determined for PL and IPD independently.

A p-value of < 0.001 was used to observe statistical significance.

No ethical approval was needed. No patient identifiable data is used within the report.

Results:

For each vertebrae both left and right maximum pedicle screw lengths, reflected by PL measurement, were recorded therefore a total of 680 PL measurements were collected. IPD was measured alongside PL's for each corresponding vertebrae level. A total of 340 IPD measurements were recorded. Figure 2 displays the mean length for PL and IPD at each corresponding vertebrae with standard deviation error bars incorporated. The x axis displays the vertebrae level (e.g. D01 = thoracic vertebrae level one, L1 = lumbar vertebrae level one) and the y axis displays the length in mm.

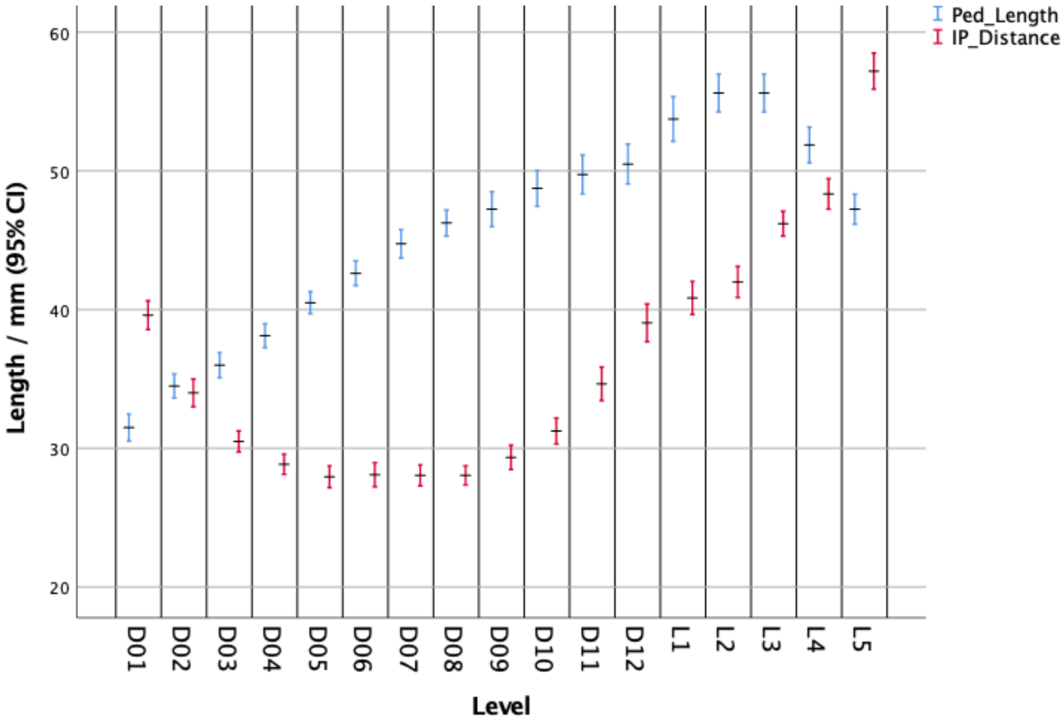

Figure 2: *Graph; Mean Length (mm) of PL and IPD for each individual vertebrae in the Thoracolumbar Spine with Standard Deviation Error Bars.*

To assess the correlation between PL and IPD, in the first set of untransformed data, a Pearson's correlation coefficient was calculated (**Table 1**). As shown in table 1, a Pearson's *r* value of 0.432 (p < 0.001) was found. Therefore, a positive correlation between PL and IPD was established: as PL increases, IPD gets wider. Relating to a study by Chan 2003, the correlation coefficient calculated through this Pearson's test describes the 'strength of linear relationship' between PL and IPD to be 'fair' - Chan YH (11).

Table 1: Pearson's Correlation Coefficient for the first round of measurements collected (untransformed).

Pearson's Correlations

			Pearson's r	p
Pedicle Length **(PL)**	-	Interpedicular Distance **(IPD)**	0.432	< .001

To test the null hypothesis that PL is less than IPD for each corresponding vertebrae in the thoracolumbar spine, a paired sample t-test was performed. The untransformed continuous data was used in this analysis thereby portraying a normal distribution and a correlation between PL and IPD, *r* = 0.432, p<0.001 (**Table 1**) had previously been established. This indicated that a paired sample t-test was appropriate, the results are recorded in Table 2. For T1 and L5 the null hypothesis that PL is less than IPD was accepted showing t(39) = -11.742, p > 0.001 and t(39) = -10.880, p > 0.001, retrospectively. Whereas vertebrae T2-L4 demonstrated PL to be statistically significantly greater than IPD (p < 0.001), thereby rejecting the null hypothesis.

Table 2: Paired Sample t-test. Testing the null hypothesis that PL is less than IPD (p<0.001) – untransformed, continuous dataset.

Paired Samples T-Test

Measure 1		Measure 2	t	df	p
PL-T1	-	IPD-T1	-11.742	39	1.000
PL-T2	-	IPD-T2	6.034	39	< .001
PL-T3	-	IPD-T3	21.357	39	< .001
PL-T4	-	IPD-T4	34.876	39	< .001
PL-T5	-	IPD-T5	38.995	39	< .001
PL-T6	-	IPD-T6	38.766	39	< .001
PL-T7	-	IPD-T7	44.634	39	< .001
PL-T8	-	IPD-T8	52.395	39	< .001
PL-T9	-	IPD-T9	41.219	39	< .001
PL-T10	-	IPD-T10	47.529	39	< .001
PL-T11	-	IPD-T11	34.443	39	< .001
PL-T12	-	IPD-T12	15.308	39	< .001
PL-L1	-	IPD-L1	20.113	39	< .001
PL-L2	-	IPD-L2	24.458	39	< .001
PL-L3	-	IPD-L3	16.521	39	< .001
PL-L4	-	IPD-L4	9.356	39	< .001
PL-L5	-	IPD-L5	-10.880	39	1.000

Note. For all tests, the alternative hypothesis specifies that Measure 1 is greater than Measure 2. For example, PL-T1 is greater than IPD-T1.
Note. Student's t-test.

As described in the method section, data from the first set of measurements was transformed to give a discrete data set. This data set portrayed measurements in practical terms. A Spearman's correlation test (**Table 3**) was run to analyse the relationship between PL and IPD. A moderate positive monotonic correlation was discovered between PL and IPD (Spearman's *rho* = 0.467, p < 0.001). Similar to the Pearson's test, the statistically significant correlation allows rejection of the null hypothesis and acceptance of the alternative hypothesis, that there is a tendency for IPD to increase as PL increases. Figure 3 displays a graph visualising the positive monotonic correlation found between PL and IPD

Table 3: Spearman's Correlation Test Results Table:

Spearman's Correlations

			Spearman's rho	p	Lower 95% CI	Upper 95% CI
Pedicle Length (PL)	-	Interpedicular Distance (IPD)	0.467	< .001	0.416	1.000

Note. All tests one-tailed, for positive correlation.

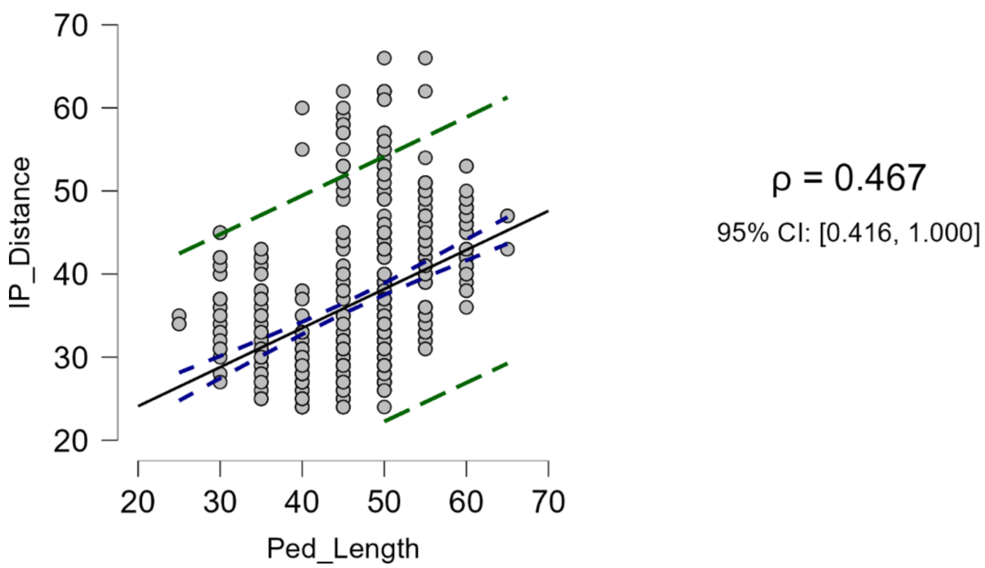

Figure 3: Graph showing Spearman's Positive Monotonic Correlation between PL (Ped_Length) and IPD (IP_Distance)

Similar to the paried-sample t-test carried out on the untransformed dataset, a Wilcoxon signed-rank test was run on the transformed, discrete dataset. A positive monotonic correlation had already been established through the Spearman's test (**Table 3**). However, this time the IPD was rounded down to the nearest '0' and '5' mm to assess its use as a pedicle screw template. The Wilcoxon test was performed to assess the difference between PL and IPD in more practical terms. The **null hypothesis** was set as: PL is less than IPD. Mirrioring the untransformed dataset, PL was found to be less than IPD in both T1 and L5. For these two levels the null was accepted, $t(39) = -4.610$, $p > 0.001$and $t(39) = -4.879$, $p>0.001$, retrospectively (**Table 4**). However, levels T2-L4 found a statistically significant difference ($p<0.001$) between PL and IPD, where PL was found greater than IPD. Therefore, between T2-L4 the null hypothesis was rejected.

Table 4: Wilcoxon Signed-Rank Test. To test how PL and IPD differ from eachother - transformed, discrete dataset.

Paired Samples T-Test

Measure 1 (PL)		Measure 2 (IPD)	W	z	df	p
PL-T1	-	IPD-T1	67.000	-4.610		1.000
PL-T2	-	IPD-T2	801.000	5.256		< .001

Paired Samples T-Test

Measure 1 (PL)		Measure 2 (IPD)	W	z	df	p
PL-T3	-	IPD-T3	820.000	5.511		< .001
PL-T4	-	IPD-T4	820.000	5.511		< .001
PL-T5	-	IPD-T5	820.000	5.511		< .001
PL-T6	-	IPD-T6	820.000	5.511		< .001
PL-T7	-	IPD-T7	820.000	5.511		< .001
PL-T8	-	IPD-T8	820.000	5.511		< .001
PL-T9	-	IPD-T9	820.000	5.511		< .001
PL-T10	-	IPD-T10	820.000	5.511		< .001
PL-T11	-	IPD-T11	820.000	5.511		< .001
PL-T12	-	IPD-T12	820.000	5.511		< .001
PL-L1	-	IPD-L1	820.000	5.511		< .001
PL-L2	-	IPD-L2	820.000	5.511		< .001
PL-L3	-	IPD-L3	820.000	5.511		< .001
PL-L4	-	IPD-L4	817.000	5.471		< .001
PL-L5	-	IPD-L5	47.000	-4.879		1.000

Note. For all tests, the alternative hypothesis specifies that Measure 1 is greater than Measure 2. For example, PL-T1 is greater than IPD-T1.
Note. Wilcoxon signed-rank test.

As initial measurements of all PL's and IPD's for each corresponding vertebrae in the thoracolumbar spine were repeated on a different week, the intraclass correlation coefficient (ICC) was calculated to assess the reliability and agreement between both the first and repeat data sets. ICC was calculated separately for both PL (**Table 5**) and IPD (**Table 6**) measurements. The ICC for PL and IPD equalled 0.983 and 0.985, respectively. From this it can be deduced that the first and repeat measurements for both PL and IPD are in considerable agreement. This demonstrates that the intra-observer variability was small, and therefore measurements were consistent and reliable.

Table 5: ICC assessing reliability and agreement between the first data set of PL's and the repeat (second) data set of PL's

Intraclass Correlation (PL)

Type	Point Estimate	Lower 95% CI	Upper 95% CI
ICC3,1	0.983	0.980	0.985

Note. 680 subjects and 2 raters/measurements. ICC type as referenced by Shrout & Fleiss (1979).

Table 6: ICC assessing reliability and agreement between the first data set of IPD's and the repeat (second) data set of IPD''s

Intraclass Correlation (IPD)

Type	Point Estimate	Lower 95% CI	Upper 95% CI
ICC3,1	0.985	0.982	0.987

Note. 680 subjects and 2 raters/measurements. ICC type as referenced by Shrout & Fleiss (1979).

Discussion:

Following statistical analysis, the results showed that in both the untransformed and transformed dataset there was a statistically significant positive correlation between PL and IPD. Demonstrating that as PL increases the distance between the two pedicle screw entry sites (IPD), of corresponding vertebrae, also increases. In addition to this, paired sample t-tests run on both the untransformed (student t-test) and transformed (Wilcoxon signed-rank test) dataset highlighted a statistically positive difference between PL and IPD between vertebrae T2-L4. Meaning that with the exception of T1 and L5, PL is greater than IPD.

In conjuction, the correlation and difference observed between PL and IPD in the thoracolumbar spine suggests that this technique could be used as an intraoperative guide to ensure long screws are not inserted. Between T2-L4, IPD can be intraoperatively measured and utilised as a safe template for pedicle screw length selection. A pedicle screw length of equal size to the IPD, for the vertebrae in question, will not breach the cortex of the vertebral body. This approach therefore ensures safe pedicle screw insertion.

T1 and L5 not fitting the trend of difference obsereved between T2-L4, is likely to be explained by the fact that the trajectory of the pedicles in these two vertebrae often go over 30 degrees from lateral to medial and therefore the IPD is found to be much wider. A morphological anatomical study found that the the transverse angle of the pedicle followed a trend throughout the thoracolumbar spine (12). The study shows a decreasing transverse angle from T1-T12, and then increasing from L1-L5 (12)

Another morphometric analysis of 10 cadaveric spines, T1-L5, looked at the 'transverse interpedicular distance (TIPD)' measuring between 'the central axes of both pedicles of the same vertebrae at the site of insertion of the pedicle on the isthmus of the vertebra' (13). This analysis found variation in TIPD down the thoracolumbar spine, similar to what is shown in figure 2 (13). The study found a linear increase in TIPD between L1-L5, L5 having the widest TIPD (13). This finding was also observed in this study as displayed in figure 2. However, the morphometric analysis did not correlate TIPD to maximum pedicle screw length, therefore the correlation and difference we found between IPD and PL cannot be compared. The similar trends in IPD measurements along the thoracolumbar spine is promising.

Calculation of ICC for both PL and IPD, comparing first and second measurement sets, reflected little intra-observer variability (ICC= 0.983 and = 0.985 for PL and IPD retrospectively). Therefore, this showed that repeat measurements were consistent with the first round of measurements. Reliability between rounds of measurements was achieved.

Limitations:

This study is limited by the fact that exact measurement points for IPD and PL were not likely to have been consistent throughout the data collection process. Therefore, measurement errors are likely to exist in the datasets.This is a result of the data collectors little experience with Synapse 5 software. The sample size is of a small scale therefore limiting the study further as the results may not be a realistic reflection of the whole population. To remove this limitation, the sample size should be expanded, incorporating deformed spines and spines of females to allow comparison between genders.

Data was collected by one data collecter, including repeat measurements, therefore only intra-observer reliability could be assessed. To enhance the results, a second data collector should be involved in taking all measurements separately to the first data collector. This will allow inter-observer relaiblity to be analysed, assessing the extent of agreement between the two individuals. Inter-observer reliability will provided a higher level of reliability which is crucial when evaluating the 'quality of surgical care' (14).

Conclusions:

This study set out to investigate two main aims: firstly whether there was a correlation between IPD and PL in vertebrae T1-L5 and secondly whether IPD could be used intraoperatively as a safe template for pedicle screw length selection in the thoracolumbar spine. Conclusions drawn from this radiological study show that there is a positive correlation between IPD and PL, showing as that as PL increases so does IPD. Findings relating to the secondary aim show that between T2-L4, PL is always greater than IPD. Therefore, excluding T1 and L5, IPD can be safely utilised as a measurement template for pedicle screw length of the corresponding vertebrae. This is a quick and uncomplicated, intraoperative method to select a safe pedicle screw length which will not penetrate the cortex of the vertebral body.

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Reflection:

Educational objectives include:

- Determine the correlation between interpedicular distance and maximum screw length
- Develop skills to carry out a full literature review
- Correctly use radiological software to take measurements of interpedicular distances and the distance between the pedicle and the anterior vertebral body wall
- Understand importance of confidentiality
- Develop skills in data handling and analysis
- Gain a better understanding of the risks and benefits surrounding spinal surgery
- Learn about pedicle screw insertion

Reflecting upon this SSC I recognise that I have gained a new set of skills which I believe will be of benefit to the rest of my time at university and beyond graduation when I am training as a Doctor. Of which include:

- Learning how to use and take measurements from the radiological software Synapse 5
- Using excel to handle data and perform functions on datasets to aid statistical analysis
- Exploring the use of JASP and SPSS to carry out statistical analysis
- Understanding types of statistical tests and how each differ from each other to cater different data types
- Respecting and abiding to patient confidentiality, anomynising data to protect the patients
- I have a deeper understanding of the morphology of the thoracolumbar vertebrae and have learned about pedicle screw fixation

This coursework has given me an insight into the realm of research of which I am excited to explore. I would like to thank all of my supervisors and a special thank you to Fabian Wong for helping to statistically analyse my results.