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A New Technique of Bone Thickness Measurement for Pedicle Screw Insertion Safety Purpose

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***Abstract*— Pedicle Screw (PS) was originally accomplished for Spinal fixation but it has several limitations. If the pedicle screw passes though the cortex bone in surgery, it has a risk to damage the spinal cord and vertebral artery, which can be caused to a serious problem such as paralysis. Therefore, it should be avoided by all possible means. In current situation, it depends on a palpation of doctor to judge the boundary between the cortex and cancellous bone. Although many instrumentation has been described in several clinical studies, there are still lack of data in the literature concerning the measurement of bone thickness in real time mode. Most of the measurements of the bone thicknesses were based on CT Scan machine which is off-line technique. Therefore, the purpose of this prospective study was to develop a real time measurement of bone thickness for safety purpose of pedicle screw insertion. A total of 12 data was collected in each experiment. Ultrasound echo signal for each specimen was measured and used to measured bone thickness. Then, the results were compared with manual measurement of bone thickness which is by using a ruler. The percentage different of bone thickness was small for both methods which were 8.86 % for first method and 15.1 % for second method. This measurement values showed that the accuracy of bone thickness more than 84 % for both method. As a conclusion, both methods were suitable to use as a bone thickness measurement technique for pedicle screw insertion application.**

I. Introduction

Human having 24 vertebrae in the spine and each of the vertebrae has their own number and this number was given by the physicians. The lumbar area of the spine was the area which between thoracic regions and the sacrum. Fig. 1 shows the whole structure of the human vertebrae. Pedicles are the main and strongest part of the vertebra and the pedicles are two short rounded processes that extend posteriorly from the lateral margin of the dorsal surface of the vertebral body. There has pedicles for each side of vertebra.

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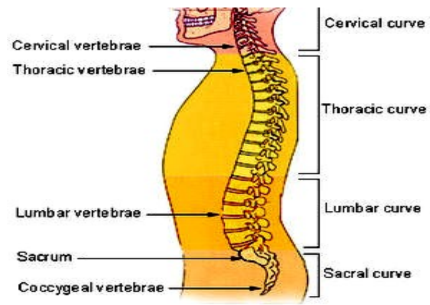


Figure 1. Structure of human vertebrae.

A. Pedicle Screw (PS)

Pedicle Screw fixation gives advantages for the people who have problem with their spinal. Usually pedicle screw provide greater rigidity with an improved fusion rate. A pedicle screw is a bone screw type and it was designed for implantation into a vertebral pedicle. Although pedicle screw was originally accomplished for spinal fixation, it has several limitations [1, 2]. For example PS placement is difficult for pediatric patient because they have limitation in the small size spine. Besides that, the use of PS fixation is limited by structural variation in pedical conformation [3-6]. The accurate placement of pedicle screws requires surgical skills and wide experience. Fig. 2 shows good placement of pedicle screw.

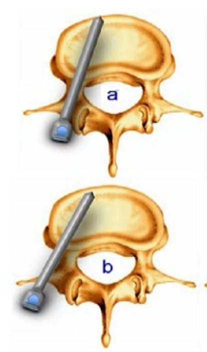


Figure 2. Placement of Pedicle screw.

B. Pedicle Screw (PS) placement

Currently, most of the pedicle screws are positioned using a free-hand technique or under fluoroscopic guidance. The error of screw misplacement and injury was range 10 % to 40 %, depending on the skill of the surgeon [7-10]. Then, image-guided navigation technique was introduced in clinical or hospital because its can reduce the screw placement errors and injury but not many surgeons was used due to high cost. Then, usually bone thickness was measured by using CT Scan

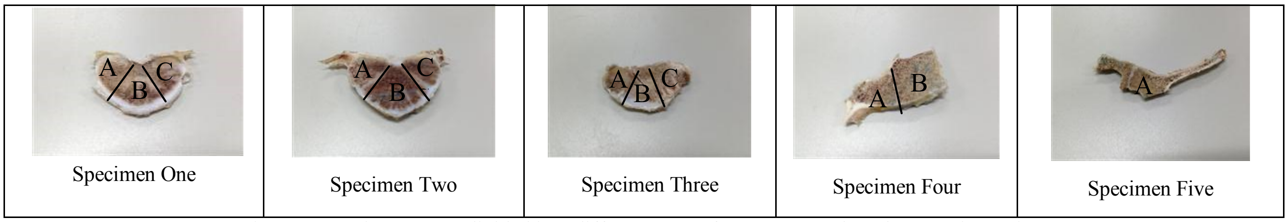


Figure 3. Specimens were divided into different parts of measurement based on specimen size.

in preoperative session for measurement of screw dimensions[7, 11-14, 17].

Automatic or robotic platform technique was a better way to use for placement of pedicle screw. It was significantly can reduces screw misplacement but it very expensive and use requires a learning curve which can be lengthy. This technique was almost not suitable for small hospital or clinics [7, 15, 16]. Although this technique was fully automated but placement of pedicle screw in the spine still using CT scan for monitoring process.

Although many instrumentation has been described in several clinical studies, there are still lack of data in the literature concerning their measure bone thickness in real time mode. Most of the measurement of the bone thicknesses were based on CT Scan machine which is off-line technique. Therefore, this study was important for safety of pedicle screw insertion by measuring bone thickness.

II. Methodology

This experiment was tested by two methods of bone thickness measurement which are by using ultrasound transducer attached with plastic (20 mm width) and attached with plastic (10 mm width). A total of 12 data was collected in each experiment. There was five specimens were used in this experiment. For each specimen, it was divided into different part for thickness measurement purposed. Each part was divided based on bone size and it's was showed in Fig. 3.

The PicoScope3205 and custom made frequency analyzer were used for ultrasound signal analysis. The signal that was produced by the ultrasound transducer was analysed for getting the time interval between the transducer and the bone t(u&b). Fig. 4 shows the analysis of ultrasound signal. Speed of the ultrasound wave was the important part that to know before running the experiment. This experiment used plastic (perspex) as a medium for measurement of t(u&b).

The speed of ultrasound wave in plastic has been used in this experiment was 2760 m/s [18]. The actual size of each specimen was measured by using a ruler before running the actual experiment. The measured data (initial bone thickness) was used to calculate the accuracy of the experimental result.

The equations were used to calculate bone thickness as follow:

$$d(u\&p) = v(p) * t(u+b) / 2 \quad (1)$$

$$d(p)=v(p) * t(p)/2 \quad (2)$$

$$d(b) = d(u\&p)-d(p) \quad (3)$$

Where;
d(u&p) was distance between ultrasound transducer and plastic with bone
t(u+b) was time taken between ultrasound transducer and plastic with bone
d(p) was distance between ultrasound transducer and plastic
d(b) was bone thickness.

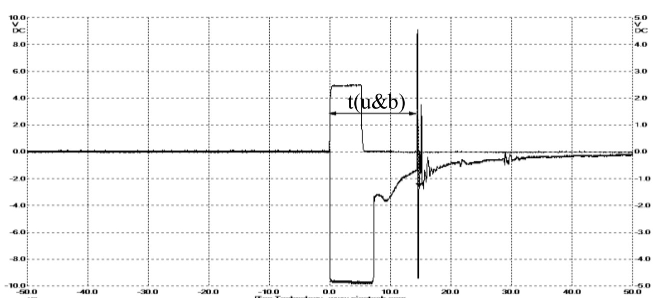


Figure 4. Analysis of ultrasound signal procedure.

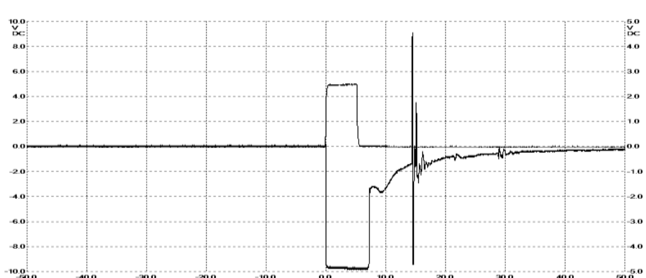
III. Results and Discussions

The results for all specimens were described. All specimens thicknesses were measured based on two different methods.

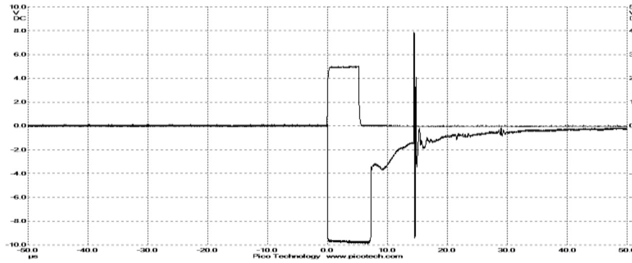
A. Method One : Measurement of bone thickness by using plastic width 20 mm.

Fig. 5 shows the result of specimen one for Part A and the time taken between ultrasound transducer and bone was 16.17 µs. For Part B and Part C were 15.45 µs and 15.81 µs, respectively. Then the value of bone thickness for Part A was 2.5 mm.

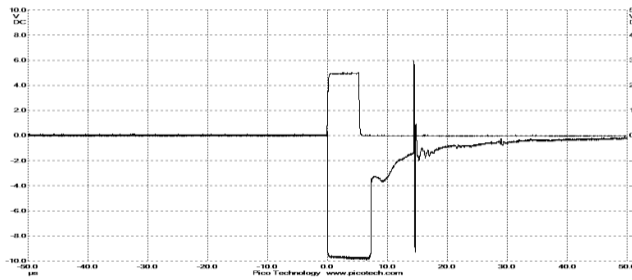
The value was 1.53 mm and 2.0 mm for Part B and Part C respectively. The value of bone thickness was almost same with initial value that were measured before running the experiment which were 2.0 mm for Part A, 1.7 mm for Part B and 2.0 mm for Part C.



(a) Ultrasound wave for Part A of specimen one.



(b) Ultrasound wave for Part B of specimen one.

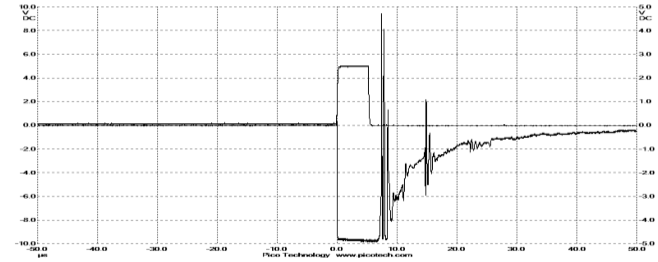


(c) Ultrasound wave for Part C of specimen one.
Figure 5. Result of ultrasound wave for specimen one.

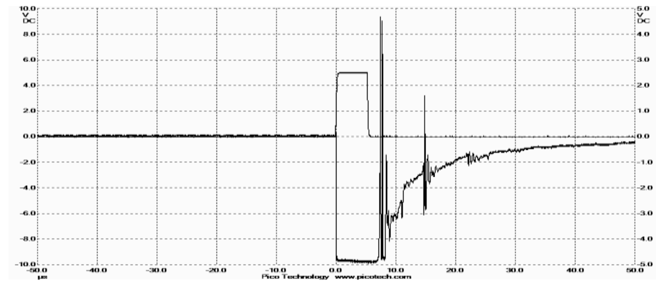
The detail of the result was shown in TABLE I. The percentage difference between initial and actual value of bone thickness for specimen one were 25.0 %, 10.0 % and 0 % for PART A, B and C, respectively. The highest percentage difference was 25.0 % for specimen one. Almost the percentage difference values was significantly small for other specimens. The average percentage different value of bone thickness was 8.86 %. It was showed that the accuracy of the bone thickness measurement almost 91.14 %.

B. Method 2: Bone thickness measurement by using plastic width 10 mm.

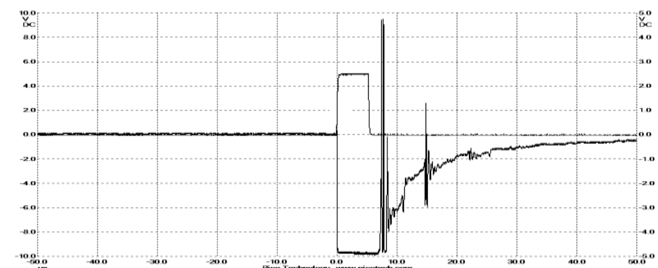
The experimental results of Part A for specimen one that was used plastic width 10 mm were shown in Fig. 6. The time taken between ultrasound transducer and bone was 8.50 µs. For Part B and PART C were 8.35 µs and 8.40 µs. The experimental results of bone thickness were 1.44 mm, for Part A, 1.3 mm for both Part B and Part C. The experimental result value of bone thickness has a bit different if compared with initial value which are 2.0 mm for PART A, 1.7 mm for PART B and 2.0 mm for PART C. The value of percentage different between experimental and initial value for specimen one were 30.0 % , 23.5 % and 35.0 % for Part A, B and C, respectively.



(a) Ultrasound wave for Part A of specimen one.



(b) Ultrasound wave for Part B of specimen one.



(c) Ultrasound wave for Part C of specimen one.
Figure 6. Result of ultrasound wave for specimen one.

The detail of the result was shown in TABLE II. The percentage difference for both experimental value and initial value was significantly small for all specimens except specimen one. Meanwhile, the highest percentage different value was 35.0 % for specimen one and the lowest was 5.0 % for specimen three. The average percentage different value of bone thickness was 15.1 %. This measurement method showed that the accuracy of bone thickness measurement almost 84.9 %.

TABLE I.
MEASUREMENT OF TIME TAKEN BETWEEN ULTRASOUND TRANSDUCER AND BONE WITH PLASTIC (20 MM), AND MEASUREMENT OF BONE THICKNESS.

	Specimen One			**Specimen Two**			**Specimen Three**			**Specimen Four**		**Specimen Five**
	Part A	***Part B***	***Part C***	***Part A***	***Part B***	***Part C***	***Part A***	***Part B***	***Part C***	***Part A***	***Part B***	***Part A***
Time taken(µs) (between ultrasound transducer and bone	16.17	15.45	15.81	16.05	16.29	16.41	15.46	15.68	15.98	16.49	16.63	16.42
Initial Bone thickness (mm)	2.00	1.70	2.00	2.75	3.00	3.00	1.80	1.80	2.00	3.00	3.00	3.25
Experimental value of bone thickness (mm)	2.50	1.53	2.00	2.40	2.69	2.86	1.55	1.85	2.20	2.97	3.16	2.87
Different (%)	25.00	10.00	0.00	12.70	10.30	4.70	13.90	2.80	10.00	1.00	5.30	11.70
Average(%)	8.86											

TABLE II.
MEASUREMENT OF TIME TAKEN BETWEEN ULTRASOUND TRANSDUCER AND BONE WITH PLASTIC (10 MM), AND MEASUREMENT OF BONE THICKNESS.

	Specimen One			**Specimen Two**			**Specimen Three**			**Specimen Four**		**Specimen Five**
	Part A	***Part B***	***Part C***	***Part A***	***Part B***	***Part C***	***Part A***	***Part B***	***Part C***	***Part A***	***Part B***	***Part A***
Time taken between ultrasound transducer and bone (µs)	8.50	8.35	8.40	9.80	9.50	9.50	8.57	9.00	8.86	9.80	9.75	9.45
Initial Bone thickness (mm)	2.00	1.70	2.00	2.75	3.00	3.00	1.80	1.80	2.00	3.00	3.00	3.25
Experimental value of bone thickness (mm)	1.40	1.30	1.30	3.20	2.82	2.83	1.54	2.10	1.90	3.23	3.16	2.75
Different (%)	30.00	23.50	35.00	16.40	6.00	5.70	14.40	16.70	5.00	7.70	5.30	15.40
Average (%)	15.10											

IV. CONCLUSION

Based on the result in TABLE I and II, the value of percentage different of bone thickness was small for both methods. This measurement values showed that the accuracy of bone thickness almost 91.14 % accurate for first method and almost 84.90 % accurate for second method. As a conclusion, both methods are suitable to use as a bone thickness measurement technique for pedical screw insertion application but it needs more research on that.

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