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Support Spine Surgery by Information Technology

Z. T. Kocsis[1,*]

[1]Széchenyi István University, Department of Information Technology
Egyetem tér 1, 9026, Győr, Hungary
[*]E-mail: kocsis.zoltan@ga.sze.hu

Abstract: This paper presents a possible new method for supporting a specific spinal surgical procedure by artificial neural networks. The method should be based on the surgical demands and protocols used by surgeons in order to carry out successful operations. Considering these requirements, a plan for an algorithm that will be able to support surgeons in the preparation and the conduction of an operation is outlined. The aim is not to substitute the surgeon but to assist him. Furthermore, this paper demonstrates how the neural network to be designed can significantly reduce the possible surgical risks, thereby increasing surgery effectiveness.

Keywords: spine surgery; surgery; roentgen; medical diagnostic

1. Introduction

Medicine is a science that aims to preserve and restore human health. It deals with the functioning of the human body and the discovery of its diseases, and its healing. This science is not comparable to any other, such as physics, since it is not an exact science because it is the result of hundreds of years of experience and experimentation [1]. The human being cannot be said to be one specific thing, and so medicine has many fields. Neurosurgery is one of these disciplines. Neurosurgery [2] deals with operable diseases of various parts of the nervous system. This includes diseases of:

- the human brain,
- the skull surrounding the brain,
- the spine,
- the spinal cord,

- the nerves,
- the other less common diseases (e.g. developmental disorders).

Spinal surgery is most commonly performed due to the following diseases:

- spinal tumours,
- vertebral slip,
- herniated disc.

Vertebral slip is a surgical area where surgical errors can occur, which may require the patient to be re-operated. However, as we will show, this type of surgery can be supported by current IT technology. The aim of this research is to develop an algorithm that supports the surgical procedure where screws are placed in the patient's vertebrae during the operation. As described in [3], neural networks are used in many fields of medicine. We will demonstrate that, in addition to these fields, it is also possible to apply neural networks in spinal surgery procedures.

Neural networks are used in medicine both in order to predict diseases hidden from human eyes and to avoid the dangers that might come up during the treatment [4] [5] [6]. There are many sources of danger in spinal surgery that not only affect the patient undergoing surgery but also the staff caring for the patient. In this paper, we present a specific spinal surgical procedure with its dangers as well as a new Information Technology (IT) method to support this surgical procedure. It turns out that a neural network serves not only to improve surgical results but also to help the patient recover successfully.

2. Spine surgery problem

The problem to be solved during vertebra injury surgery is to place one or more screws in some vertebra to improve spinal stability and prevent deformation. Its preparation requires accurate and professional planning. This requires a great deal of the surgeon's knowledge and surgical practice. The main goal is to find identical, parallel points in the spine, where the screw is to be placed during surgery. Defining the points is not enough because the input angle along which the screw will be inserted also has to be identified.

Only X-rays, Computed Tomography (CT) and Magnetic Resonance Imaging (MR) images are available for surgeons in the preparatory phase. Diagnostic images of the patient can be used to determine surgical points. Medical robotics already has the tools to determine these points. These will be the main guidelines for the operation.

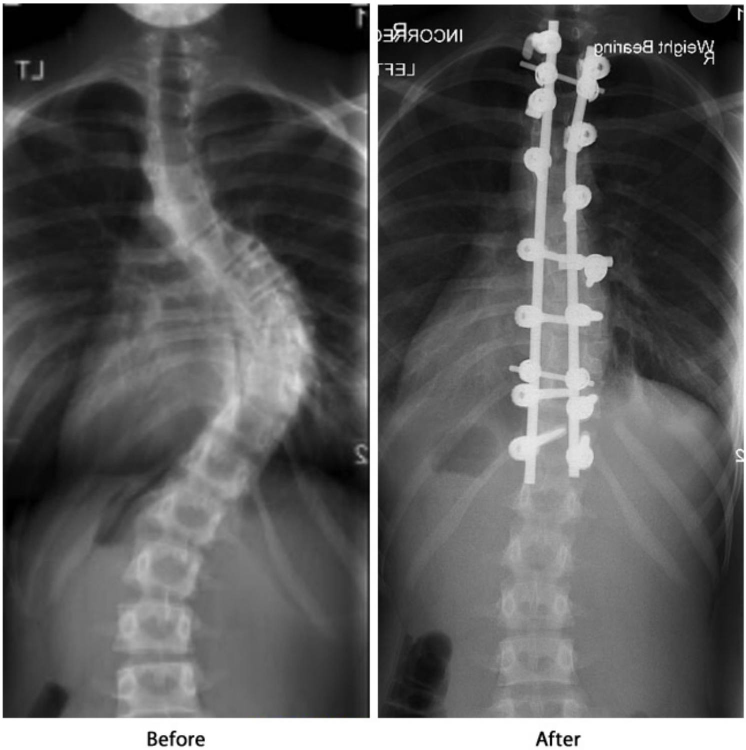

Figure 1. Patient before, and after surgery [7]

Fig. 1. shows a series of X-rays that show that the patient underwent spinal surgery because of a deformity of the spine. In this case, it was necessary to use a great number of screws because of the extreme deformation of the spine. The number of screws is determined by the surgeon performing the surgery.

2.1. Description of the surgery

To develop a properly automatized surgical procedure for surgeons, it was necessary to become familiar with the surgical procedure itself. Spinal surgery has been applied since 1967 [8]. Minimally invasive surgical techniques are used in many areas of surgery, such as lumbar, thoracic and cervical areas. Minimally invasive surgical procedures are those where surgeons perform surgical techniques without major cuts on the body. These techniques are also used during spinal surgery [9].

The algorithm to be developed should support a spinal surgery procedure that involves inserting a screw in the vertebra. These surgeries are performed because the spine becomes unstable for some reason. The screw to be inserted helps maintain stability [10]. Fig. 2. shows the spine stabilization after surgery.

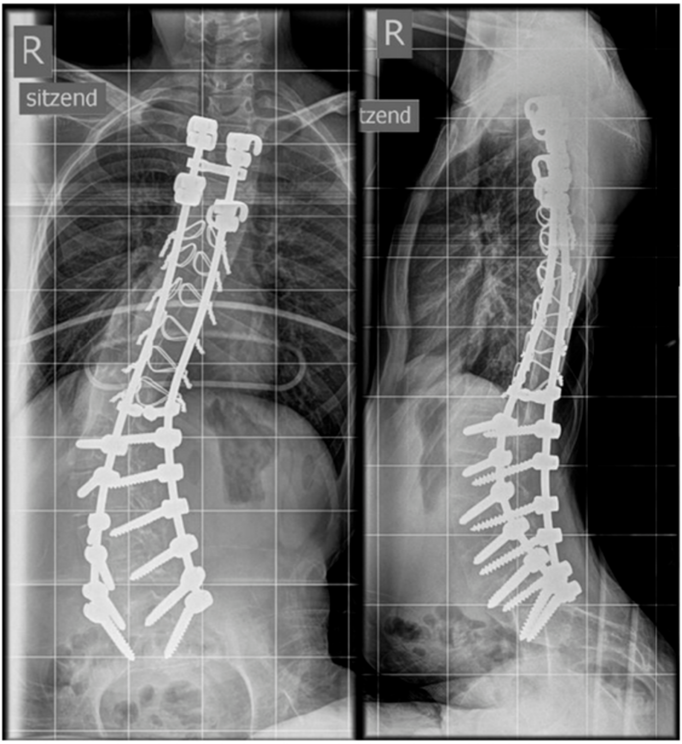

Figure 2. Spine stabilization [11]

3. Information technology in spinal surgery

Spinal surgery is an area of neurosurgery. Neural networks have long been used in neurosurgery. In recent decades, it has been used successfully in, among other things, the detection of brain tumours, analysis of cervical spinal cord, detection of neoplastic and non-tumorous brain disorders, and detection and prognosis of many other diseases of neurosurgery [12] [13] [14]. Several anatomical factors contribute to spinal stability. When a person performs heavy physical work, the spine is subjected to high levels of stress, which can lead to deformation of the spine and requires surgery. There are also cases in which the spine is deformed not as a result of a physical effect but as a result of an inherent factor. Spinal surgery is usually prepared by a surgeon. Because they cannot examine the patient's spine directly, they always have a medical imaging method to take a picture of the patient's spine. Based on the careful study of these images the surgeon plan his surgery.

Thanks to technological and IT advances, neural networks are already in place to help perform biomechanical examinations in the preparatory phase for spinal surgery. Biomechanics are provided by “mechanical factors” of the spine. Fig. 3. shows the biomechanical coordinate system of which some actors should be considered before surgery.

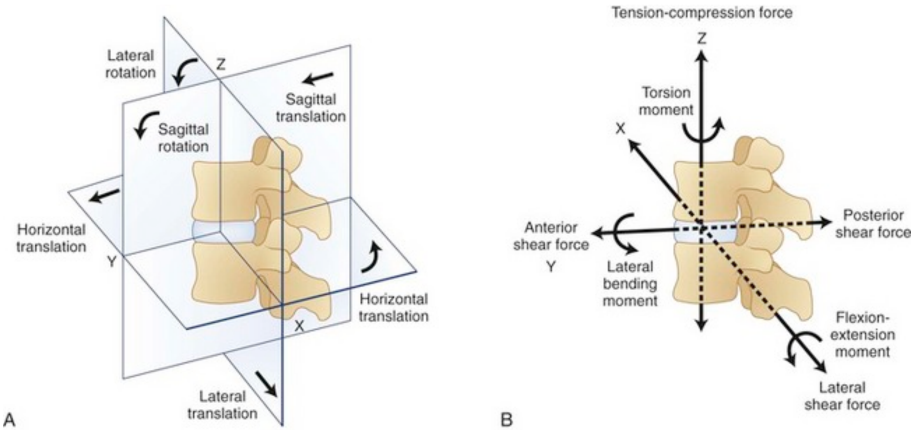

Figure 3. Spinal motion segment planes and directions of motion [15]

3.1. Requirements for spinal surgery

The basic requirements for preparation and surgery are set by the surgeon. Preparation requires medical diagnostic images. Based on the pictures taken, surgeons can make surgical plans. These images can be CT, MR or X-ray. It is not always sufficient to make a single image of a patient, as the surgical part cannot often be identified from a single image.

During surgery, the patient receives only an X-ray, which has the disadvantage that X-rays affect both surgeon and patient. The patient may move during the operation, and the success of the operation will depend to a large extent on the surgeon's response to the movement. Depending on the shift, new images may also need to be taken. There is a medical need to reduce the number of X-rays during surgery, which increases the length of surgery. What is more, there is a government decree stipulating how much radiation the patient and surgeon can receive each year.

Once the X-ray has been processed by the surgeon, the point where the screw is to be inserted should be sought. Thereafter, the other steps of the insertion must be planned in theory and then perform surgery. Fig. 4. shows the screws used during surgery. They range in size is from 4.5 to 8.5 millimetres, which is also decided by the surgeon [16].

Figure 4. Bolts for use in spinal surgery [16]

The steps presented here are all supported by IT. There are many benefits of using IT-assisted surgery:

- Radiation is reduced for both the patient and the surgeon.
- Surgery preparation facilitates the work of the surgeon and improves surgical results
- Surgical time would be reduced to its half, so this way more patients could be dealt with in a day
- Bad screws can be avoided, which also prevents patient re-surgery.

However, there are some disadvantages as well.

- It requires a long time for the algorithm to be reliable.
- Surgeons would need to be trained so that they can efficiently use the IT supported tools.
- Preparatory time would also be longer.

3.2. A task to accomplish

A deep learning neural network can be used to support the presented tasks. The neural network must be able to help the surgeon prepare for surgery, which requires finding the exact position of the screw. CT and MR images are suitable for this. Since there are many of these images taken during an examination, it is necessary to select those taken from the surgical area and the area through which the screw must pass. Taken these decisions, the algorithm needs to be prepared to learn so that it can get better with every surgery. One of the benefits of this, apart from helping the surgeon, is that there is no need to take too many pre- and post-operative images of the patient, resulting in less radiation.

Initially, medical diagnostic images of the spine should be studied. Medical diagnostic image not only shows the spinal cord slice, but also soft tissue and other bones are visible. Fig. 5. shows a view of a vertebral column.

Figure 5. CT scan of vertebra

Surgeons usually use these diagnostic software's to view these images. These software's allow to change the properties of the image. This property is the window / level value, which is best compared to the brightness and contrast values of images. By changing these properties, only the bone is visible in the image. Hundreds of medical images will require experimentation with the above values so that only the bone is visible in the image being processed. Soft tissue is not needed for surgery. Fig. 6. shows an image that can be processed by setting the values.

Figure 6. Modified CT scan of vertebra

On the CT scan of Fig. 7. the screw insertion point can now be found. We have talked to surgeons about where to place the screw in the vertebra. They refer to this as the pedicle.

Figure 7. Red circles shows pediculus

In medical practice, during surgery, the screw is placed in this area by surgeons (Fig. 7.). This is necessary because the most common surgical failure occurs when the hole is moved away, which makes the screw unable to perform its stabilizing role. This point alone is not enough, as the drill must be started not here but before the vertebra. Consequently, it should be possible to determine the vertebral outline.

From the line drawn from the centre to the outline, you can calculate the distance at which the drill bit should be started.

Besides, the algorithm must be able to determine the screw insertion depth. The most common complication is that the screw overstretches and hits a part of the body or a vessel, which endangers the patient's life. Part B in Fig. 8. illustrates the point at which the screw may penetrate the vertebra. This can also be said of the algorithm from the above outline. How deep it can be drilled into the vertebrae can be told by surgeons. This can be used to set the optimum drilling depth for the vertebrae in question.

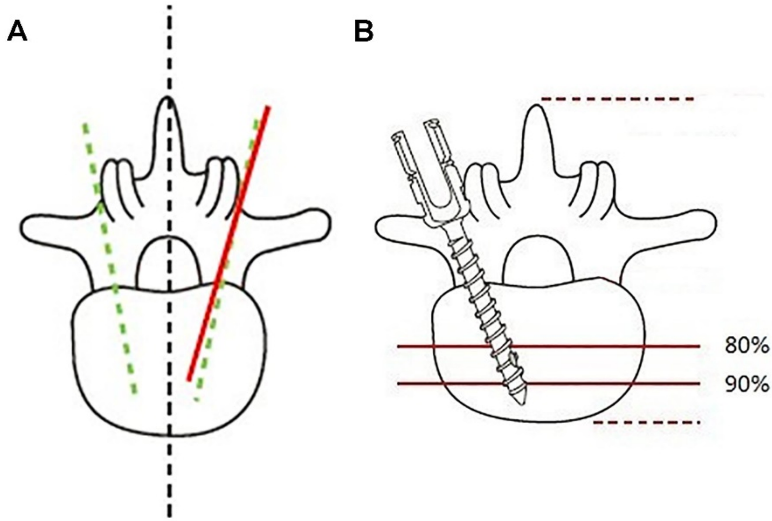

Figure 8. Pedicle screw position [17]

As shown in Fig. 9. in addition to determining the depth, the algorithm must also be able to determine the input angle. Not all human spines are fully similar to each other, so a fixed value cannot be set. Currently this is also determined by the surgeon. The surgeon does not see through the vertebrae, so it is also up to his experience to determine the angle of the input, so if the screw is not exactly flush with the vertebrae there may be a danger.

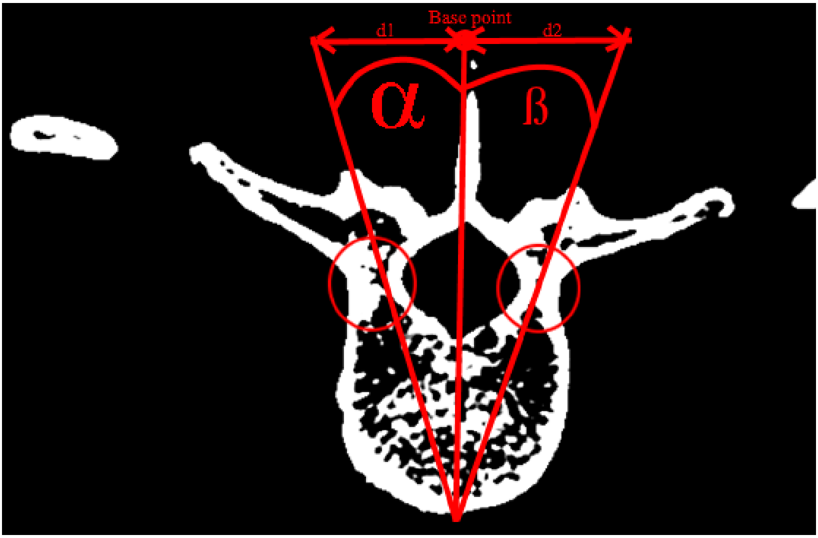

Figure 9. Surgery points

To determine the input angle and the other surgical points, you will need a reference point, which in this case will represent the absolute zero point of the drill. From this point you have to draw a perpendicular line that will represent the centre of your vertebra. A line drawn from the centre of the pedicle intersects this centreline so that the angle of the two lines relative to each other becomes the inlet angle of the screw. The reference point can also be the point at which movement to the left and right can be determined, where the drill has to be set to the correct input angle. The data to be searched is illustrated in Fig. 10.

The algorithm will be able to execute these steps in two-dimension. CT MR and X-rays provide only two-dimensional images, but this is not sufficient to perform the surgery. From the CT and MR images, the algorithm should be able to determine the input point in a third dimension and the entire surgical area.

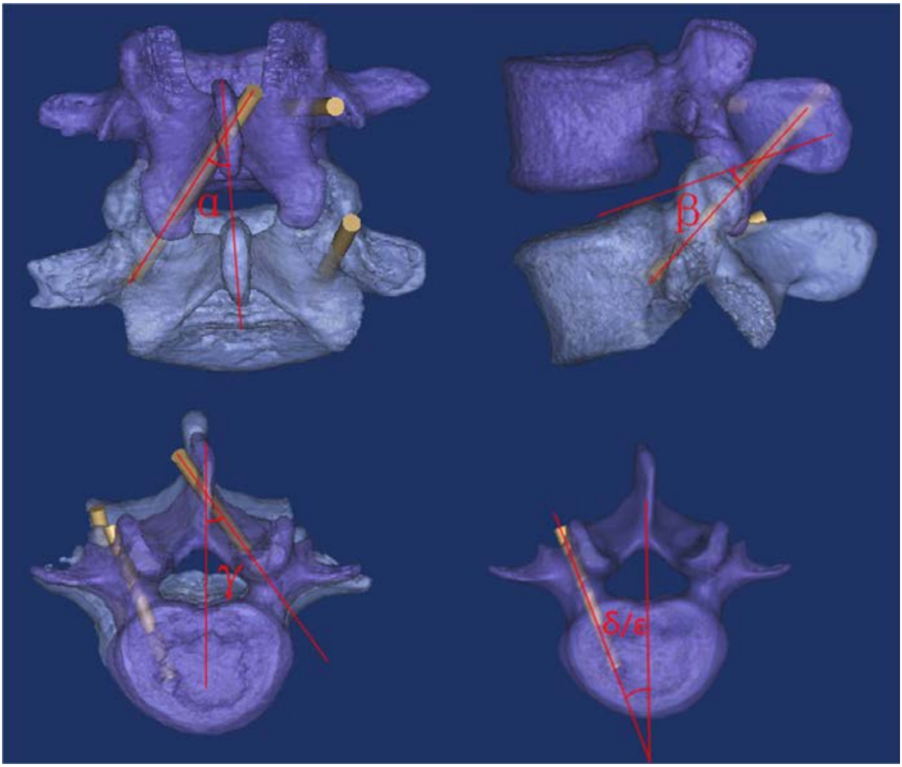

Figure 10. Pedicle screw 3d model [18]

Fig. 10. shows a three-dimensional model of CT images. It is visible that there is a horizontal view of two vertebrae on the upper left, a lateral view on the upper right and a front and rear view of the lower vertebra. The image shows well that all angles to be determined are visible. From the two-dimensional image, you can tell the centre of the pedicles, the input angles to the centres, and the depth of placement. In the three-dimensional image, the top view entry point must be found.

The images shown are only a horizontal slice of the vertebra. In medical diagnostic images, the data of the distance of the given slice from the head is stored in millimetres, but this is only 2D data. By aligning these images, you can obtain the operative vertebra. An image created from these images may already be suitable for defining third-dimensional data. Fig. 11. illustrates the angle ß to be searched, which represents the angle of the third dimension. Because this image is made up of two-dimensional images, the rest of the data is suitable for third-dimensional use.

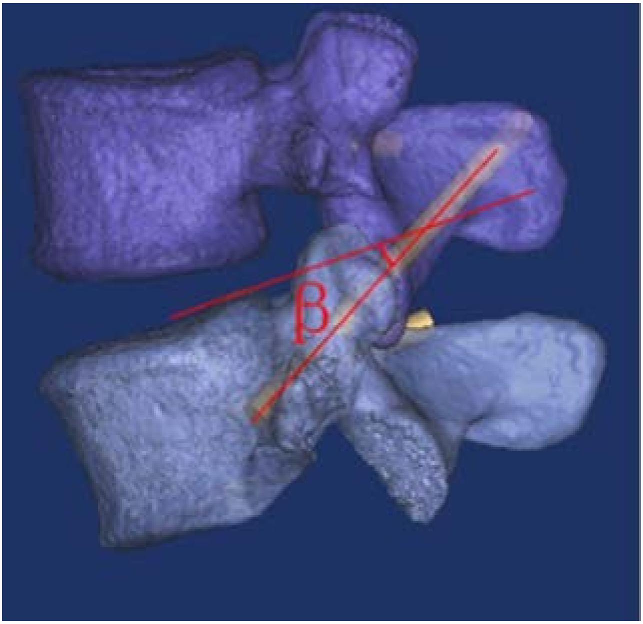

Figure 11. 3-dimensional angle [18]

All in all, the algorithm to be implemented has to find data that the surgeon would not be able to determine with sufficient precision with the help of his eyes and practice. The success of current surgeries depends on the surgeon's preparedness and experience. The algorithm to be developed would contribute to further success and reduce surgical risks.

3.3. Preparations for the research

Before starting the implementation of a particular neural network, several cases need to be looked at.

- It is to be examined to what extent the screw placement is successful in the current operations.
- Radiation exposure measurements should be made to determine the extent to which the patient, surgeon, nurse, and surgical staff are exposed to radiation. This should be done to determine the minimum imaging procedures.
- Assess the medical needs that are expected before surgery and during preparation and surgery.

- The neural network should be developed according to the needs of the surgeon to prepare for surgery and then to facilitate surgery.
- Medical diagnostic images of the human spine need to be obtained, which can be CT, MR, or X-ray. These can be used to create a student dataset.

The items listed here should be grouped in order of importance, then the algorithm should be developed in consultation with surgeons, first to two-dimensional images and then to three-dimensional images.

The algorithm to be designed must implement the following.

- Be able to scan a series of medical diagnostic images.
- Have the surgeon select the image for the surgical area from the selection, the algorithm learns which image contains the surgical area.
- From the selected image, the algorithm determines the centre of the vertebra, the pedicle, and then the size of the screws to be used and the angle of placement concerning the centreline.
- Be able to determine the top of the vertebra and the point where the drill should be started.
- Be able to define a third-dimensional input angle.
- Give the surgeon a suggestion to perform the surgery, but the surgeon may change it if he needs to.

4. Summary

Based on various consultations with surgeons I have come to the following conclusion. According to the surgeons it is necessary to provide IT support for operations. This task requires the combined application of medicine and informatics. I need to analyse the medical needs for surgery in detail. These needs are different, both in the preparation and the performance of the surgery. The main purpose of the surgery is to find parallel identical points that can be compared to each other to determine the location, parameter and placement depth of the screw.

The most important task in preparation for surgery is that the algorithm should be able to recognize specific points. For example, working with a sufficient amount of student data, take the vertebra arch as a workspace on an extracted CT image. The algorithm should be prepared to minimize radiation to the patient and the surgeon or treatment staff. It is also necessary to be able to meet medical needs during surgery. One of the biggest problems is that there may be movements during surgery. Because only X-rays are taken during the operation, it is necessary to be able to determine the work area based on the previous radiograph and so perform the surgery. This also ensures less radiation exposure.

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