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Fundamental principle of Nuss procedure

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Abstract
Although Nuss procedure, the standard surgery of pectus excavatum, has been reported for more than 20 years, no surgeon in the world has explained the basic principle of it. We found the principle is actually the principle of lever. We deduced the principle and explain the significance of it.

Keywords: Nuss procedure, principle, lever, pectus excavatum

Introduction
Pectus excavatum is the most common thoracic deformity, and its surgical treatment has a history of more than 100 years [1, 2]. The early operation was open surgery. After Nuss procedure was reported in 1998, pectus excavatum treatment entered a minimally invasive era [1, 2]. Because of many advantages, Nuss procedure has gradually become a standard operation all over the world [2-4]. This procedure is considered to be a simple operation, which can be completed by placing an arc steel bar at the bottom of the depressed chest wall and supporting it (Fig. 1A, B) [1, 2]. Because of its simplicity, many doctors thought they knew the principle and easily tried to perform the operation. Such attempts often lead to disastrous consequences, and many operations will fail [5]. My department is the only independent chest wall surgery department in China, mainly completing five basic operations, namely chest wall defect, infection, trauma, tumor and deformity surgeries [3, 4]. In deformity surgery, pectus excavatum operation is the most common surgery. In the early stage, we also used the standard Nuss procedure. Later, when we realized some defects of it, we improved it and designed a new operation, i.e. Wung procedure [6, 7]. In the process of completing thousands of pectus excavatum operations, we have been studying the fundamental principle of Nuss procedure, and finally found that it is the principle of lever. This discovery enables us to have a clear understanding of this procedure, which provides very important guidance for our surgery. Our experience shows the importance of understanding the working principle of Nuss procedure, so it is necessary to introduce this principle.

Technical details of Nuss procedure
Before introducing the principle of Nuss procedure, it is necessary to briefly introduce the technical details of this procedure (Fig. 1A, B) [1, 2, 8]. Nuss procedure generally requires two incisions, which are located on both sides of chest wall. After the incisions are completed, a special guider is put into the thoracic cavity through the incision on one side of the chest wall, passing through the bottom of the chest wall depression and the opposite thoracic cavity, and then come out from the incision on the opposite side of the chest wall. An arc steel bar is connected with the guider and dragged into the thoracic cavity. The concave part of the steel bar is located at the bottom of the depressed chest wall, with its two ends are located outside the incisions on both sides. One end of the steel bar is connected with a special rotator. After the steel bar is rotated 180 degrees, the chest wall depression is supported and the deformity is eliminated. These technical details are the main contents of Nuss procedure.

Deduction of Nuss procedure principle
In Nuss procedure, since the main material is arc steel bar and the main operating instrument is rotator, the principle of this procedure is equivalent to the working principle of the steel bar and the rotator. However, from the perspective of physics, the working principle of these two things is quite complex. In order to describe this principle as authentically as possible, a common

method in physics can be used, that is, to build a physical model that can describe this working scenario.

It can be seen from the technical details of Nuss procedure that the motion tracks of the steel bar and the rotator are three-dimensional. In order to find a suitable physical model, the motion tracks must be simplified and simulated from a single dimension. After fully comparing the motion tracks of the three dimensions, we think that the horizontal plane track is easier to describe its working principle, so we choose this dimension to establish the physical model. On the horizontal plane, the starting position of the steel bar is shown in Fig 1A. As the steel bar is a symmetrical structure, we only analyze half of it for further simplification. Thus, the starting position of the steel bar becomes that in Fig 1C. Since the steel bar is arc structure, in order to establish an ideal model, we simplify it to a linear structure (Fig. 1D). In the process of the steel bar movement, the rotator is always connected to it. Therefore, they should be considered as an integrated structure. The actual shape of the rotator is a special irregular shape. In order to idealize the physical model, we also simplify it as a linear structure. After the above simplification and assumption, the integrated shape of the steel bar and the rotator on the horizontal plane becomes that in Fig. 1E. At this time, if the integrated structure is combined with the rib supporting the structure and the depressed chest wall, an ideal physical model will be formed, which is the same as the lever model in physics. In the standard lever model, there are three elements involved, namely, the lever itself, the fulcrum and the target object (Fig. 1F). Contrasting the above model, the integrated steel bar and rotator is the lever, the rib supporting the steel bar is the fulcrum, and the depressed chest wall is the target object (Fig. 1E). Finally, the physical model of Nuss procedure has been built. Since the working principle of lever is very simple, the basic principle of Nuss procedure becomes very clear. That is to say, the process of using the rotator to turn over the steel bar to support the depressed chest wall is actually equivalent to the process of raising the target object with a lever (Fig. 1G, H, I). Therefore, the working principle of lever is exactly the principle of Nuss procedure.

Significance of Nuss procedure principle

After the physical model of the steel bar and the rotator is built, the principle of Nuss procedure becomes easy to understand. This principle has strict requirements on the physical characteristics of the lever and fulcrum (Fig. 1F). The requirements for the lever mainly include two factors, namely sufficient mechanical strength and sufficient length. In Nuss procedure, the mechanical strength is mainly the requirement for steel bar, which is the basic condition to complete supporting work. The length is the requirement for the rotator. Sufficient length can reduce the force of rotating, which will make the operation very easy. The physical characteristics of the fulcrum are particularly important. Generally, the fulcrum must have three basic characteristics (Fig. 1F): (1) it must have sufficient rigidity. If the fulcrum is too soft, it is impossible to support the lever; (2) it must have enough height. If the fulcrum is too low, it is difficult to make the lever work normally; (3) it must have enough stability. If the lever is not stable enough, the normal work of the lever cannot be guaranteed. In Nuss procedure, the fulcrum is acted by a specific rib of the lateral chest wall. The fulcrum must be selected according to the above three basic characteristics. When the fulcrum is selected properly, the surgical effect can be basically guaranteed. On the contrary, if the fulcrum is too weak, too low, or not stable enough, the operation will inevitably fail. In the past work, we have received a large number of cases of Nuss procedure failure.[5] Their previous operations were performed by different surgeons, many of whom were even very famous thoracic surgeons. If the above principles are not understood, it would be difficult to make clear the causes of these surgical failures. In fact, all these failures have clear relationships with the steel bar and the fulcrum, which are the basic working elements of lever. If these elements are not properly designed and managed, the operation will be difficult to succeed.

Nuss procedure has been reported for more than 20 years, and a large number of pectus excavatum patients in the world receive this operation every year [1, 2, 8]. However, no one has ever explained the basic principle of this operation before, which has undoubtedly affected the safety and effect of surgery. After we explained the basic principle of Nuss procedure with the lever principle, the technical essentials related to the surgery became very clear. So far, we have completed thousands of pectus excavatum operations. It is precisely because we have fully understood the basic principle of Nuss procedure that we have achieved satisfactory results in our work.

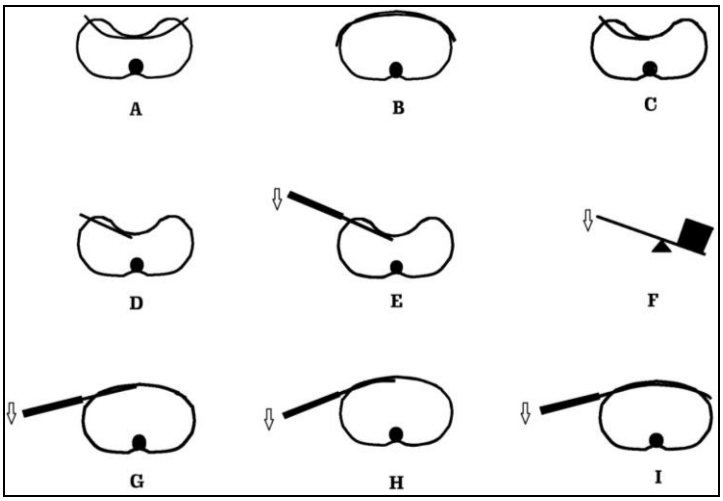

Fig 1: A, B, Schematic diagram of Nuss procedure. C, The shape and the position of the half of the steel bar. D, The steel bar is simplified into a linear structure. E, The rotator is simplified into a linear structure and combined with the steel bar into an integrated structure, and the ideal physical model is formed. F, Standard lever model in physics. G, The motion of the steel bar and the rotator in Nuss procedure model. H, The motion of the steel bar and rotator in the actual Nuss procedure (half of the steel bar is displayed). I, The motion of steel bar and the rotator in actual Nuss procedure

Conflict of Interest
Not available

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Not available

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